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DISSERTATION

Circular Plastic Packaging for Food Applications

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I confirm that going to press this thesis needs the confirmation of the examination committee.

Affidavit

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume. If text passages from sources are used literally, they are marked as such. I confirm that this work is original and has not been submitted elsewhere for any examination, nor is it currently under consideration for a thesis elsewhere.

City and Date

Signature

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Abstract

Food packaging is in a phase of extensive redesign, based on demands to improve its ecological performance. To this end, technical and non-technical design aspects, such as packaging functions and criteria related to sustainability are widely reevaluated. Throughout the packaging branch, continuous improvement of designs was a steady goal and as such, visible in developments like lightweight solutions. However, the requirements for design have reached higher complexity: The criteria for sustainable packaging (circularity, effectivity, efficiency, safety) gained importance, coming along with potential trade-offs between these criteria and / or basic packaging functions (protection, containment, communication, convenience). Next to that, circularity is given the spotlight in the branch, often referring to designs that are considered recyclable.

Existing packaging solutions are differently hit by these circumstances. Some fit the current understanding of what is important for future designs, while others receive pressure towards change. A multitude of global actions took up the topic of future proof designs of products and processes (e.g. UN Sustainable Development Goals, European Union's Green Deal etc.) and research engages in multiple prevailing challenges in this regard.

In this work, one finds different subtopics regarding packaging redesign, considered important in the scientific community, *i.a.* the innovation of multilayer flexibles, the evaluation of design aspects in underrepresented food groups such as cereal and confectionery, the analysis of related life cycle assessments and the development of improvement strategies, as well as the inclusion and empowerment of consumers for better packaging design. To draw a picture on how far sustainable design is already implemented in food packaging solutions, we undertook literature and market analyses, evaluated products in comparison to longtime given as well as future design goals and identified possible improvements that did not reach products and processes yet. Main outcomes include the identification of a vast potential to improve material efficiencies in marketed products, visible in broad ranges of product-to-packaging ratios within comparable food products, the compilation of the technical consensus on material selections for recyclable design in barrier flexibles, the development of improvement strategies in packaging design for cereals and confectionery, strategies for improved integration of packaging into related life cycle assessments as well as the development of strategies and tools to include consumer perspectives into technical and non-technical design aspects. Up to now, different small-scale solutions are visible in marketed products. The interdisciplinary nature of the field and a top-down goal, circularity, seem to lead to a variety of bottom-up strategies. Design changes overall seem insufficient considering other known possibilities that could already be implemented in packaging solutions. A recently presented proposal (November 2022) to substantially change the packaging and packaging waste directive reinforces this impression but inherits long sought chances to overcome persistent obstacles.

Kurzzusammenfassung

Lebensmittelverpackungen befinden sich in einer Phase umfassender Neugestaltung, basierend auf Forderungen, ihre ökologische Performance zu verbessern. Technische und nicht-technische Designaspekte von Verpackungsfunktionen und Nachhaltigkeitskriterien werden zu diesem Zweck weitgehend reevaluiert. In der gesamten Verpackungsbranche war die kontinuierliche Verbesserung von Designs ein stetiges Ziel und als solches in Entwicklungen wie etwa effizienten, leichten Verpackungen sichtbar. Die Anforderungen an das Design sind aber komplexer geworden: Kriterien für nachhaltige Verpackungen (Zirkularität, Effektivität, Effizienz, Sicherheit) haben an Bedeutung gewonnen, sind von potenziellen Zielkonflikten zwischen den Kriterien selbst und / oder grundlegenden Verpackungsfunktionen (Schutz, Behältnis, Kommunikation, Convenience) begleitet. Zusätzlich wird der Zirkularität ein Platz im Rampenlicht eingeräumt, vor allem in Bezug auf Designs, die als recycelbar gelten.

Bestehende Verpackungslösungen sind unterschiedlich von diesen Umständen betroffen. Einige entsprechen dem aktuellen Verständnis dessen, was für zukünftige Designs als wichtig erachtet wird, während anderen Druck in Richtung Veränderung entgegengebracht wird. Eine Vielzahl internationaler Handlungsempfehlungen hat das Thema des zukunftstauglichen Designs von Produkten und Prozessen aufgegriffen (z. B. UN Sustainable Development Goals, Green Deal der Europäischen Union etc.). Die wissenschaftliche und industrielle Forschung widmet sich in diesem Zusammenhang zahlreichen aktuellen Herausforderungen.

Diese Arbeit umfasst mehrere, weithin als wichtig erachtete Unterthemen bezüglich der Neugestaltung von Verpackungen, u.a. die Innovation mehrschichtiger flexibler Verpackungen, die Bewertung von Verpackungsdesigns in Lebensmittelgruppen wie Cerealien und Süßwaren, die Analyse entsprechender Ökobilanzen und die Entwicklung von Verbesserungsstrategien sowie die Integration und Stärkung der Verbraucher*Innen. Um zu eruieren, inwiefern Neudesign bereits in Lebensmittelverpackungen umgesetzt ist, wurden Literatur- und Marktanalysen durchgeführt, Produkte im Vergleich zu bestehenden sowie zukünftigen Designzielen bewertet und Möglichkeiten zur Verbesserung identifiziert, die sich noch nicht in Produkten und Prozessen widerspiegeln. Zu den Ergebnissen gehören die Identifikation von Ineffizienzen in vermarkteten Produkten, unter anderem sichtbar im breiten Spektrum von *product-to-packaging ratios*, die Ausarbeitung des technischen Konsenses zur Materialauswahl für recyclingfähiges Design flexibler Barriereverpackungen, die Entwicklung von Verbesserungsstrategien für Cerealien- und Süßwarenverpackungen, Strategien zur verbesserten Integration von Verpackungen in Ökobilanzen sowie die Entwicklung und Anwendung von Strategien und Werkzeugen zur verbesserten Einbeziehung der Verbraucher*Innen-Perspektive in technisches und nicht-technisches Verpackungsdesign. In vermarkteten Produkten sind kleinteilige Lösungsansätze erkennbar. Die Interdisziplinarität des Fachs und ein *top-down* Ziel, Zirkularität, tragen zur Vielzahl an *bottom-up* Strategien bei. Bisher sichtbare Designänderungen erscheinen angesichts weiterer bekannter Möglichkeiten, die bereits umgesetzt werden könnten, oft unzureichend. Eine erst kürzlich (November 2022) vorgestellte, vorgeschlagene weitreichende Veränderung der Gesetzgebung rund um die Verpackungs- und Verpackungsabfallrichtlinie untermauert diesen Eindruck. Dieser Vorschlag bringt langersehnte Chancen, hartnäckige Hürden in der Gestaltung nachhaltiger Verpackungen zu überwinden.

Article Contributions

This cumulative doctoral thesis consists of the following articles, published in peer-reviewed journals:

First Paper

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- Visualization

Fifth Paper – Submitted Manuscript

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I have provided the following contributions to this paper:

- Conceptualization
- Original draft preparation
- Review and editing

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Foreword to Background and Funding

The problem set in this thesis starts on one hand with an updated, time-bound regulatory requirement for food packaging, which is its recyclability [1, 2], and, on the other hand, applied research, trying to rethink and resolve environmental challenges posed by packaging [3]. The applied research, in this specific case, is related to packaging design, finding a future ideal in environmentally sustainable products, where circular/cyclic, particularly recyclable packaging is one main goal in food supply chains with currently predominant single-use plastic packaging [4].

The thematic focus of this work is packaging redesign, particularly concerning the status quo of food environments, in which products are made available for consumers [5]. Three main connected topics were chosen as a base for this thesis, which arose from project-related challenges:

- Flexible barrier packaging,
- cereal and confectionary packaging,
- and consumer integration.

Most publications regarding this thesis were developed in the context of the COST Action 19124, “RETHINKING PACKAGING FOR CIRCULAR AND SUSTAINABLE FOOD SUPPLY CHAINS OF THE FUTURE (CIRCUL-A-BILITY)”. This pan-European network project, most of all, the participation in the working group “Cereal and confectionary”, initiated questions about packaging redesign, based on intentions “... to share data on the consequences of specific food product – package interactions and to keep the behavior of consumers as a critical focus.” [Description, 3]. Furthermore, the predominant perspective taken, in which the packaging design issues were addressed, and publications derived, was to address both, “... the major technical and non technical hurdles for implementation of sustainable food packaging ...” [Description, 3].

The following pages bring together related subtopics, which follow the above-mentioned intentions, looked at, through the lens of packaging redesign.

Section 4 is based on previously published or submitted work, where content is partly reproduced and/ or modified for this cumulative thesis. The publications as such can be found in the annex B.

1. Introduction

1.1 Food and Food Packaging

Human nutrition consists of various food products with unique compositions. Most of the foods show different quality and safety related characteristics, amongst others, determined by intrinsic factors such as macro- and micronutrients, water activity (a_w), pH, redox potential (E_h) and more, but also through the applied production- and processing methods. Based on these compositions of foods, related characteristics and applied production- and processing methods, the optimal storage conditions for foods vary [6, 7]. Products that show similar characteristics in certain aspects, might be taken together in categories or groups [7, 8]. Different extrinsic factors, such as a food's contact with light, gasses (e.g. oxygen), the exposure to different temperatures or humidities too influence its composition and affect its quality and safety. The application of packaging allows a certain level of control over these intrinsic and extrinsic factors. It offers a barrier towards hardly controllable surrounding environments, allowing to set up specific conditions within a package and facilitating a shelf-life extension (protection function) [6, 7, 9]. Packaging can therefore be described as a “*mediator or separator*” [9, p.16]. Packaging can also be considered as a possible key in a hurdle concept [7, 10]. Combined with, for example, modern shelf-life extension strategies, such as modified atmosphere packaging (MAP) or active and intelligent packaging, it even allows to modify the use of preservatives (e.g. of interest for “clean labels” [11]) or (nutritionally) unfavorable heat applications (e.g. enzymatic activity) [7]. Questions of shelf-life can be linked to topics such as food losses or waste, food security and in general, resource use [6, 7, 12]. To this end, the understanding of a product's requirements is an important prerequisite to adequately design or choose packaging [7], given the perspective that packaging is a service to a (food) product [13].

Next to the above-mentioned protection, reference literature (such as [6]) describes containment, communication and convenience as being the main other (primary) packaging functions. While containment, accordingly allows to move products, convenience should make consumption easier and stands for example, for an “*apportionment-*” and “*unitizing function*” [6, p.3]. Further, communication is described as providing information *i.a.* to consumers and other stakeholders along the supply chain [6].

In packaging, these main functions should be met to design a successful packaging solution. Vice versa, they also allow the evaluation of an existing packaging's performance, e.g. “*Functions/Environments Grid*” [7, p.5] referring to “*environment matrix*” [14, p. 241]. As a note aside, multiple levels must be considered (*i.e.* primary, secondary, tertiary packaging [15]).

Practical examples regarding the fulfillment of basic functions can include, for example packaging that has to meet high barrier needs towards oxygen, water vapor or light (protection) and in parallel must be accepted by consumers (communication, convenience). In various scenarios it means that a balance has to be found, between sometimes contradictory goals, such as providing product visibility versus protecting from light transmission [6, 7, 16]. Undoubtedly however, a long-term successful package also needs a strong product [17].

From a scientific view, a few products do not necessarily need packaging. At least some packaging levels can become unessential in distribution scenarios describing e.g. seasonal, regional products [18]. In general though, packaging can be seen as an important part of a food system, which includes “... *all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food ...*” [19, p.29]. It is described as “... *essential and pervasive ...*” [6, p.1].

1.2 Sustainable Food Packaging

Besides the basic functions, there are also attributes which are important in packaging design, such as its (environmental) sustainability [6]. Depending on sources considered and respecting that sustainable packaging might be understood differently along the supply chain [20], several subcriteria to this attribute can be named [16]. One can find for example packaging safety, effectivity, efficiency and circularity told to determine its sustainability [16]. In the therein referenced and refined “*packaging sustainability framework*” [21], safety is *inter alia* associated with “... *ecological and health impacts ...*” [16, p.56]. Effectivity is related to the basic packaging functions (such as provided in [6]) and efficiency described as “... *to minimise resource consumption ...*” [16, p.51], mentioned in relation to evaluation methods such as life cycle assessments (LCA) [16]. Circularity - a “*cyclic*” packaging - is characterized via the “... *use of renewable materials and recoverability at end-of-life ...*” [16, p.47]). The attribute of sustainability and its criteria can be used to derive design goals and evaluate a packaging's performance and are generally important looking at design considerations [16, 22]. Available studies take up multiple aspects regarding these criteria, such as specific product comparisons via LCAs [23], the circularity of plastic packaging [24] or a secondary materials quality and safety [25].

1.2.1 Focus Circularity

Out of the above mentioned subcriteria to sustainable packaging design [16], circularity became a real buzzword, not necessarily determined to a single branch: one can find various publications and related initiatives, speaking about changing predominant, linear patterns of production and consumption, such as for products like packaging, to circular/cyclic ones [22, 26, 27]. Although the concept of a circular economy being nothing new [28], it is overall trending in science [27]. Regarding packaging design, perspectives were taken up and (re)published, such as the one that waste can/should be designed out [28,29]. Ellen MacArthur as one representative pursuing a circular economy, picked up many ideas in regard to packaging design, *inter alia* referring to Braungart & McDonoughs “*cradle to cradle*” approach [22]. Visualized through the butterfly diagram, one therein finds recoverable (technological) and renewable (biological) cycles [30] applicable to packaging, similarly addressed in [16]. Accompanying the diagram, different more or less environmentally preferable options and how to achieve circularity of materials and products (all being “*nutrients*” [22]) are described [30].

Some parallels to these options can also be found in cascade-like approaches for material use, such as the waste hierarchy (e.g. reuse or recycling) [31]. Next to that, the “*cradle to cradle*” approach [22] is even reflected in life cycle assessment in such a way that an LCA can be partial (referring to life cycle stages), semi complete (cradle to grave) or complete (cradle to cradle) [32].

Looking particularly at the technological cycle and reflecting that a vast majority of food packaging is based on materials that can be linked to this cycle (rather than linked to the biological one) and related to necessities or intentions of single-use [33], the last and least valuable option to reach circularity of

a material or product from this angle, is recycling [30] (while in the waste hierarchy, it is disposal [31]). Recycling is described as a goal for materials or products which cannot be matched with previous, more favorable options (sharing, reusing, remanufacturing etc.) [33] and discussed as not substantially altering associated production or consumption, but degrading *e.g.* a product's marketed value [34 referring to 35]. This perspective (degradation) is also reflected in safety concerns regarding secondary material [25] and reflects that circularity is only one criterion that must be considered in design [16]. Next to that, recyclability is neither necessarily more sustainable [36], nor does it automatically allow closed cycles without further resource inputs [35]. An even more profound change is found to be necessary to reach a circular economy [34 referring to 37], also considering *i.a.* growing resource demands and production, such as for plastics [1, 4].

Hence, for a fuller picture of sustainable packaging besides a focus on circularity and recyclability, the addressed LCAs, within their limitations, are approaches noting growing interest over years [38]. They can give numeric information about the environmental impacts of a product, allowing a certain comparison of different packaging design options such as recyclable versus non-recyclable [23, 36]. Through this, they make information visible and understandable within the context of the broader network of food systems (*e.g.* [19]), even to a point where one can state that packaging accounts for 5% of the worldwide CO₂ emissions, with variations referring to different food groups [39].

Besides above exemplary critics concerning recycling [34, 35], the known more holistic, life-cycle considerations such as through LCA [16, 38] and, although recycling being the least favorable option within the understanding of technological cycles [33], it overall became a dominant goal for packaging design optimizations. It is represented in various publications, in combination with the top-down goal of circularity, for example in European political perspectives (First circular economy action plan [40] with the European Plastic Strategy [1], the Green Deal [41], a new circular economy action plan [42] etc.) or in the United Nations Sustainable Development Goals, such as in goal n.12: “By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse” [43, goal 12 targets]).

It even comes that the branch is at a point where trend analyses show that non-recyclable packaging will no longer be tolerated [44]. This hits existing packaging designs differently. While, for example, hollow bodies such as food grade polyethylene terephthalate (PET) bottles already are recyclable and can reach a certain level of circularity [25], (small, multilayer) flexibles (and other packaging solutions) must be innovated [4]. In the current infrastructure, they do not match sorting and recycling processes due to various technical and systemic reasons [4].

1.2.2 Effectivity, Efficiency, Safety

Staying within the example of flexible multilayers, it becomes clear that efficiency, effectivity and safety can heavily influence the overall result of a packaging's sustainability: These solutions are for example efficient considering used material amounts, visible in LCAs [36, 45]. They are thin, lightweight and also effective in offering barriers based on material combined in layers [45, 46], profiting from combinations of different materials characteristics, such as crystallinity, branching, tacticity or polarity [47, 48]. However, the thermal incompatibility of their layers (mainly laminated or co-extruded [49]) *inter alia* hinders recycling [50]. Furthermore, small flexibles such as confectionary wrappers or sachets are problematic regarding littering potential (safety issue [16]) [4].

Reflecting the goals addressed at the beginning [1, 2], this indicates the need for design changes. Looking at the available infrastructure, the step to turn back to theoretically already recyclable solutions got into focus: Suggestions to reduce material variability to so-called mono-material (at least 90% in the case of polyolefins) have been published [51]. However, reducing material complexity could lead to thicker films due to inferior barrier properties [45, 46], undermining their efficiency (product-to-packaging ratios are said to be 5 to 10-times lower in branch publications compared to alternatives [52]). In comparable marketed products even 60-times higher material efficiencies between packaging formats (flexible versus rigid) could be found [53]. Still, design recommendations moved towards (mono-)polyolefins providing the substrate material for prospective flexibles [51, 54], with economies of scale in their favor [55]. Industry based recommendations e.g. [51, 54] include different maxima of ethylene vinyl alcohol (EVOH), aluminum oxide (AlOx), silicon oxide (SiOx) and metallized content, such as laid out in detail in *table 1*.

This example shows that it is not a simple task to decide which criteria to prioritize in design under the umbrella of ecological sustainability, given that trade-offs between related subcriteria and even between basic functions might occur [6, 16]. Such dilemmas are in practice dealt within interdisciplinary (“*cross functional*” [16, p. 304]) packaging design / development teams, touching “... *multiple business units involved in packaging-related decisions ...*” [16, p. 304].

1.2.3 Holistic Solutions

Regarding the above-mentioned possible trade-offs between packaging functions, sustainability related design criteria and the linked overall environmental performance of packaged (food) products, the measurement, and the reduction of negative effects, such as greenhouse gas emissions or specifically food waste, became a central topic [39, 56]. In this regard, LCAs are a tool helping to decide about possible environmental effects of different product-packaging designs [23], also in the exemplary dilemma about non-recyclable (multilayer) flexibles [36]. Multiple studies can be found in scientific literature, which can put up with false beliefs about packaged food products and allow a differentiated picture, comparing environmental impact categories (e.g. climate change, ozone depletion, eutrophication, toxicity etc. [57]), also regarding food losses and waste [12, 23]. Such considerations furthermore meet the need for future product evaluations and developments being holistic (life cycle thinking approach) and collaborative [16]. This is of high importance, also touching upon the development of an interdisciplinary understanding regarding packaging, such as the sought harmonization of design recommendations (e.g. in guidelines like the development of the product environmental footprint (PEF) [57]) or the aspired harmonization of the waste collection and separation [42]).

Holistic and collaborative development also holds the inclusion of stakeholders, and consumers are necessarily under these stakeholders, not only, but also to avoid failures like non-acceptance [16]. Given that continuous/continual improvement is another goal in developments of processes and products (e.g. discussed in certification schemes such as ISO standards [58]), these failures are, however, a great opportunity to reflect on design improvements. However, referring to “*cradle to cradle*” one can note that it should not be a goal to improve “bad designs to versions that are “less bad”, but to potentially start over development processes [22].

This need for inclusion of stakeholders to reach sustainable solutions [16] brings back attention to the communication, as an important basic packaging function [6]. Publications suggest that communication about sustainability is ubiquitously used [59] but so far, analysis of what exactly is communicated to consumers via packaging, was found to be scarce, as addressed in [53]. Communication might be one cause hindering “... *the uptake of better strategies* ...” [16, p. 8] for design, *e.g.* through “... *mixed messages* ...” [16, p. 8]. Consumers have a hard time to differentiate between sustainable products and such that only claim to be [59]. They are confronted with various messages through cues that promise certain attributes and rely on routines and heuristics such as color, material or known recycling options [60, 61]. This can open paths to potentially feeling misled and subsequently is a potential base for objections considering food packaging [62]. The perceived value of packaging is partly low in society and the negative perception is even said to be getting worse [16 referring to 63, 62]. It is associated with the way people experience packaging (*e.g.* “... *waste in their garbage* ...” [7, p. 645 referring to 64]. In this context, one can also address other end-of-life behavior, such as littering, due to *e.g.* unconcern or lack of environmental awareness [65 referring to 66]. The worth of the resources, which ran into (packaged) products, is hardly visible with the naked eye [12] and most functions of packaging are fulfilled by the time of consumption [7]. However, to allow participation in a circular economy, it is critical that greater attention is sought for clear communication when redesigning products, such as packaging [42].

1.3 Perspectives from Legislation Touching Upon Food Packaging Design

Staying with circularity and coming back to legislative requirements for packaging, one finds that the concept of a circular economy literally made it to the level of the European Union. In 2015, the European Commission adopted a Circular Economy Package [67] and being part thereof, the first Circular Economy Action Plan was released [68], including “A European Strategy for Plastics in a Circular Economy” [1]. New requirements for packaging (such as (increased) recyclability or changes considering single-use plastics) were set and related directives adopted [2, 68]. Later, the European Green Deal [41] was published with one building block presented by the New Circular Economy Action Plan (2020) [26, 42], introducing for example the intention to scale up circularity to mainstream and speaking about challenges in “*key product value chains*”, such as packaging [42, chapter 3.3] or plastics [42, chapter 3.4]. It was discussed that there is a lack of comprehensive requirements “... *to ensure ... products placed on the EU market become increasingly sustainable* ...” [42, chapter 2.1]. A legislative initiative regarding sustainable products is therefore in preparation [69].

However, already before these publications, prerequisites existed that touch(ed) upon the key principles of sustainable packaging, also representing concepts favored in ideas of circularity. One can name longtime existing requirements from, *e.g.* the packaging and packaging waste directive (94/62/EC) [2], but also regulation (EU) No. 1169/2011 [70], which could already be visible in today's product designs. One can also name interactions with consumers here again within these prerequisites, as their empowerment was already longtime central in previous older perspectives (*e.g.* in 1169/2011 [70] but got again lifted via the Green Deal in 2020 and the associated action plan [42].

Looking at long established packaging design perspectives, the following can be exemplarily named:

- the minimization of the environmental impact of packaging [2],
- the limitation of packaging weight and volume to minimum adequate amounts to maintain safety, hygiene, and consumer acceptance [2],
- accurate, clear and easy information to consumers, including “... *the presentation of foods, in particular their shape, appearance or packaging, the packaging materials used, the way in which they are arranged and the setting in which they are displayed.*” [70, article 7].

Next to the above given design criteria, non-goals such as overpackaging and related discussions [71], as well as worries about misleading (packaging) practices have been present for years [7 referring to 64, 62]. Still, these perceptions about disadvantages of (food) packaging design still seem not to have ended in redesign, as one still finds objections against, also in new products, as laid out in [72]. Addressing furthermore changing markets and prices in 2022, negative feedback about packaging (e.g. “shrinkflation”) came to public interest, represented by consumer protection agencies [73]. Referring once more to continuous / continual improvement (e.g. ISO [58]) packaging design that is frequently objected to was therefore found to be an opportunity, worth taking up into redesign considerations [72].

1.4 Influencing Factors for Sustainable Packaging Design and the Supply Side

Given the broad set of requirements and challenges in packaging design, one gets a glimpse of the complexity that comes along. Every decision can be critical, even in such a way, that changing one design aspect can have far reaching effects on a packaging's (environmental) performance. Even seemingly small decision, like the selection of pigments, can affect a packaging's end-of-life [4]. An incomplete selection of important design aspects could include:

- (i) food characteristics [6, 7],
- (ii) material characteristics such as for polymers with barrier functions [47],
- (iii) material amounts used and needed [2],
- (iv) material origins (e.g. primary, secondary material, fossil based, bio based etc.) [4],
- (v) material combinations or mono-material, separable or (thermally) compatible materials [47, 50],
- (vi) interactions with the filling goods (e.g. food residues influencing recycling [74], safety concerning migration and toxicity etc. [25]),
- (vii) options for reuse or single use and relations to available infrastructure, such packaging return systems (e.g. with deposit) [4],
- (viii) (separate) collection options [42],
- (ix) compatibility of sorting machinery with marketed formats (and *vice versa*) [4, 74],
- (x) compatibility of recycling processes with marketed solutions (and *vice versa*) [4, 74],
- (xi) consumer information and behavior influencing a products success, *inter alia* through purchase decisions on the supply side [16] or the recoverability of materials via use- (e.g. food residues [74], as well as emptiability [75]) and disposal behavior [65].

Looking at products and analyzing the status quo on the supply side against these multiple requirements to identify potential for change, one discovers many gaps towards design goals in initiatives (e.g. A European Strategy for Plastics in a Circular Economy [1]) or even long in force

legislation (e.g. packaging and packaging waste directive [2], regulation (EU) No. 1169/2011 [70]). The available packaging solutions in surrounding food environments [5] brought up the perspective of widely known and discussed, but in practice underrepresented evident design improvements, which stands in contrast to someplace demanded profound design innovations [22].

2. Aims

This thesis combines a broad range of topics that touch upon packaging design under the umbrella of ecological sustainability. It deals with potential design solutions considering primary packaging functions and sustainability related design criteria, as well as improvement potential in life cycle assessments. The main question followed throughout all publications is *which technical and non-technical design aspects, in context to aspired ecologically sustainable packaging design, with a special focus on circularity, are yet underrepresented in marketed packaging solutions and in their evaluation?*

The aim behind this question and of the derived publications is to capture the status quo of marketed packaging designs and their evaluation, to share this information in scientific networks and to give guidance to improve designs based on the findings. Stakeholders widely strive for improvements in packaging design but implementations in products lack application and evaluations are inconsistent considering packaging (e.g. LCA). The goals of European initiatives or legislation touching upon packaging design are present, but the products and processes show action gaps. This implies the need to clarify how far designs have come until now and which beneficially reported design potential is not realized and might need more attention. Therefore, different marketed food packaging designs were collected, analyzed and discussed, considering prospectively tolerated technical and non-technical design. The perspectives from the level of consumption were included for the sake of holistic, collaborative improvements.

All publications taken into this cumulative thesis followed more specific aims on their own. The first publication aimed at identifying the current consensus on how flexible multilayers should prospectively be designed and at collecting which obstacles must be overcome. The second publication aimed at building a comprehensive base for sustainable packaging development in the found underrepresented food groups of cereals and confectionery. Within the third publication, an extension of the second one, the environmental burden of packaging in the very same food group was comparatively evaluated. Its aim was to discuss, to which extent cereal and confectionary packaging is represented in LCA studies, and which improvements can be prospectively implemented in considering packaging. The next and last two publications aimed at developing and providing design tools and guidance for packaging developers, to analyze and consequently improve packaging solutions, based on what matters to consumers.

All five articles, reviews and research papers, aim at adding to continuously improving food packaging for sustainability, which is herein considered as an approach to design future proof, successful products and processes.

3. Project Related Methodologies

The selection of methodologies behind the publications depended on the project settings in which the research needs were formulated. In the published papers, one finds literature- and field research via predominantly qualitative but also quantitative analyses, considering marketed packaging solutions, stated design optima and assessments. Both approaches, qualitative and quantitative analyses, were used to derive technical and non-technical redesign recommendations. Only a share of the works conducted over the last years was published. This share is the main focus of the next lines, providing an overview of the steps taken behind the published papers.

First, **non-systematic literature reviews** were conducted to develop a deepened understanding of problem fields and state-of-the-art knowledge about packaging formats, specific product group requirements, as well as their targeted design states from industrial, political, and academic perspectives. These multiple literature reviews were essential, as condensed information about food packaging redesign was found to be missing for specific topics (first paper) at the beginning of the studies and later, specific, highly important food groups were found to be somewhat underrepresented in sustainability / packaging debates (second and third paper).

Three long-term projects running in the Packaging and Resource Management section at FH Campus Wien, which were dealing with the innovation of multilayer barrier flexibles to recyclable solutions based on legislative requirements [1, 2], initiated the need to first gain an overview of the supply chain's consensus on recyclable flexibles with barrier functions (first paper). This included a comprehensive literature research including gray literature, such as industrial reports as main sources to find such evidence, respecting that the origins of information concerning waste management have to align with infrastructure. In pre-steps taken for specific projects, such as the collection and evaluation of packaging material specifications, various marketed packaging solutions within the project's product ranges, were already identified as technically non-recyclable, based on a multitude of used material combinations [50]. Different food groups, categorized in barrier ranges [76] were in focus, referring to requirements towards tolerable oxygen- and water vapor transmission (snacks such as nuts and seeds, convenience products such as fresh cut salads, sandwiches, spreads and confectionery). To derive recommendations on which design steps to take and develop recyclable alternatives for these product groups, the research about the supply-chains consensus about recyclability was an important first step. In practice, one of the three projects consequently followed approaches of prototyped film productions (coated, mono-polyolefin barrier films [77]), while changes in material combinations for theoretical thermal compatibility [50] and/or modified atmosphere packaging (MAP), paired with tests at particular production lines and shelf-life analyses allowed design improvements in many other problem sets given (unpublished data).

Parallel to these projects regarding recyclability improvements for flexibles and already touching upon confectionary packaging design, a European network project started [3], which placed an even stronger focus on product groups that already were part of previous projects (cereal and confectionery), similarly known for needing (multilayer) barrier applications [7] and therefore recyclability conflicts [4]. Two further reviews were worked out and published, focusing on one hand, product requirements as well as traditional and modern packaging concepts in these food groups

(second paper) and, on the other hand, conducting an analysis of their packaging environmental footprints throughout published LCAs (e.g. [78, 79, 80]). Measures for design and LCA improvements were in focus (third paper). For the first review, that was particularly dealing with cereal and confectionary packaging, reference literature was screened for related packaging functions and packaging properties, a characterization of the product group, its decay mechanisms and applied packaging solutions. A collection of modern, experimentally tested shelf-life extension strategies regarding packaging, such as active and intelligent packaging for cereal and confectionery products was compiled (e.g. [81, 82]). Packaging relevant information was presented to build a common base for further packaging development in this food group. It enabled the preparation of the next review for these food groups, regarding the environmental impacts in relation to its packaging and applied evaluation. We derived how and to which extent the packaging of these products is considered in life cycle assessments, which is, regarding comparability, an aspect of known limitations leading to actions (e.g. [57]).

For the review regarding this second goal, similarly like above, approaches started with a comprehensive literature research, following key word combinations of given food group categorizations [8]. A multitude of product data was collected through the review of published LCAs, which were consequently compared. Numeric and graphic data was extracted directly and indirectly if necessary (“Webplotdigitizer” for analyses of figures [83]). In a multi-step approach, the four phases of LCA, according to ISO standards 14040 [84] and 14044 [85] were compared over all the collected publications. Ranges of published greenhouse gas emissions were derived for cereal and confectionery in relation to the applied packaging solutions. Based on this, improvement strategies for packaging design could be phrased, depending on the formerly addressed sustainability criteria [16]. According to the phases of LCA [84, 85] and the found data, also improvement strategies for the LCAs were worked out specifically, reflecting found issues and differences in approaches. Next to that, given management related activities from the studies were collected (e.g. [56, 86]) and compiled as a supporting framework to promote sustainable packaging for cereals and confectionery.

Market analyses (fourth and fifth paper) were in a further step initiated to compare the status-quo of marketed packaging solutions against targeted technical and non-technical designs. Such as in global reports dealing with sustainable and healthy diets and touching upon packaging in aspects, it was considered important to “*Analyze existing food systems to identify potential changes needed ...*” [87, p. 12,] and “*Identify, in any given context, which foods are available ...*” [87, p. 12,]. As the projects and the reviews revealed that multiple, different packaging formats existed for cereal and confectionaries, *inter alia* due to very specific requirements, a food product was searched up with availability and comparability over the European market, having a multitude of different applied packaging solutions. To this end, an international product collection of confectioneries over Europe was initiated within the network of COST [3]. A structured guidance for sample collection was set up and shared in an international group of researchers. The collected packages were sent to Vienna. The sample was analyzed for technical and non-technical design criteria from the perspective of consumption (forth paper), leaning against the cue-utilization theory [88]. The analysis was built up as an “... *examination of cues and attributes...*” [53, p. 7]. It included the visual examination, material and packaging type examinations and the physical examination of packaging, such as opening and emptying [89, 90, 91]. The data in those steps was gathered and coded, relying on formerly published cues and attributes as well as newly considered ones, such as described in [53]. The data was visually processed in a matrix,

showing on one hand qualitative information about packaging design and, on the other hand, quantitative information about the frequency of use of such designs in the sample (heatmap, such as in [12]).

Based on a subsample of these products, an international exchange was arranged, where further **structural analyses** of the packages were carried out, such as cross section microscopy (polarization microscopy and attenuated total reflection (infrared spectroscopy) [92], LCAs based on the material composition identified in cross cuts, as well as accelerated shelf-life tests and sensory analysis). The results of these analyses remain unpublished until now, besides project based technical reports. The first steps in cross section cuts were further developed and used for the analysis of a single retailer's assortment of cereal and confectionary products, in combination with preparation methods based on microtome cuts, leaning against approaches discussed in [92].

To meet the goal of consumer empowerment [42] and their desired integration as an intention of the European network project [3], another feedback loop to marketed packaging designs (supply-side status quo [87]) was initiated (fifth paper), reflecting options for design improvement. In a direct but unobtrusive manner, consumer feedback to packaged products was collected through a **netnographic approach**, leaning against Kozinets [93]. This approach includes the formulation of research questions, the identification of online fora/communities focused on research question relevant topics and the learning about its participants. It involves data collection based on identified detailed and descriptively rich data/communication, as well as its interpretation [93]. Based on these perspectives, a comprehensive online search with colloquially used keywords was initiated, which led to the collection of a dataset about dissatisfying, technical and non-technical packaging designs. Publicly shared pictures of food products were used as the sought primary, descriptively rich data, often accompanied by explanations and discussions about the dissatisfactory packaging characteristics. The gathered data was categorized into food groups [8] and analyzed for the packaging design reasons behind the public complaints. All collected complaints were broken down into twelve redesign categories that consumers had objected to, considering feedback as a source for optimization potential. Within the derived categories, information to legislative guidance (such as perspectives from the packaging and packaging waste directive [2], or 1169/2011 [70]) was condensed as support for future avoidance and sensitization for product developers in reconsidering designs. Comparable steps were taken in a European Briefing Paper on Misleading Packaging Practices in 2012 [62], analyzing if implemented legislation can sufficiently prevent misleading packaging, analyzing data from European consumer protection agencies.

4. Summary of Publications

4.1 Recyclability and Redesign Challenges in Multilayer Flexible Food Packaging - A Review

4.1.1 Thematic Background

Recycling rates for plastic packaging are low throughout Europe [94] and increases of the same are asked from multiple sides [1, 2, 4]. Different packaging designs are differently related to these low rates and while some, such as PET bottles, reach inclusions of great shares of recycled secondary material [25], other packaging types can't deliver to such expectations [4]. Flexible food packaging is one that struggles with these aspirations and therefore must be redesigned to enhance recyclability [4]. About 40% of packaged food comes in flexible solutions [52]. Overall multi-material flexibles account for 10 weight percent of the plastic packaging market (26% of flexibles are multi material) [95]. Up to now, in multilayer flexibles, different materials were combined to access beneficial characteristics of single materials (polarity, branching, tacticity etc.) to offer barrier properties towards water vapor or oxygen transmission [47]. With the packaging branch now putting a certain focus on resolving the recyclability issues [1, 2, 4], these packaging solutions are no longer supported [44]. They are considered as non-recyclable in the context of mechanical recycling in existing waste management infrastructure [96, 97]. Therefore, new packaging designs are needed to further meet the existing product requirements while changing to recyclable materials [4]. Next to material-wise design requirements for recyclability, various structural issues complicate the steps towards sustainable and circular packaging solutions (e.g. [4, 96, 97]).

4.1.2 Key Findings

Given a comprehensive review of scientific and gray literature, solutions brought up for the packaging branch to straighten out the above-described situation, mainly rely on choosing mono-polyolefins as substrate materials, with tolerable combinations of barrier material layers such as depicted in table 1. Within recommendations, small differences can be found [51, 98]. Certain coatings, such as AlOx and SiOx seem to be the industry's consensus of design for prospective, recyclable barrier flexibles in combination with unpigmented, transparent substrate films made from polyolefins. A certain EVOH-content is tolerated as well, next to (more) discussed metallization [51, 54, 98, 99, 100].

Table 1. Tolerated materials in multilayer barrier flexible packaging, taken from [101, table 3, p. 10].

	EVOH	Metallization	SiOx	AlOx	Acrylic coatings	PVOH	PVDC	References
PP-film	Conditional-limited	Conditional-limited	Fully compatible	Fully compatible	"any other barrier" no-low compatibility		No-low compatibility	[98, 100]
	<5%	Compatible with PE or PP mechanical recycling	<5%	<5%	<5%	<5%	Further investigation	[51]
PE-film	<5%	Conditional-limited	Fully compatible	Fully compatible	"any other barrier" no-low compatibility		No-low compatibility	[54, 99]
	<5%	Compatible with PE or PP mechanical recycling	<5%	<5%	<5%	<5%	Further investigation	[51]

Abbreviations: PP (polypropylene), PE (polyethylene), EVOH (ethylene vinyl alcohol), SiOx (silicon oxide), AlOx (aluminum oxide), PVOH (poly vinyl alcohol), PVDC (polyvinylidene dichloride).

Packaging solutions as before, combining for example more than 20 layers of materials, found in market analysis, [102] must be replaced. Satisfactory substitutions for now widely found combinations of polyolefins with PET and PA, favored for reasons of sealability or puncture-resistance must be found [96, 103]. Next to that, tendencies are visible that EVOH contents could further be diminished considering tolerable amounts, such as it happened in the case of rigid polypropylene packaging [104, 105, 106].

Besides these recommendations, various structural problems are still limiting the introduction of flexible film that actually gets recycled, as depicted in [101, figure 1, p. 3] Nevertheless, economies of scale are in favor of the proposed pathway to go with barrier flexibles in favor of polyolefins [55]. One of the most critical hurdles after all, is to overcome safety concerns and reaching positive EFSA opinions on secondary polyolefins, now limited to very few examples (*e.g.* HDPE bottles) [107].

4.2 Cereal and Confectionary Packaging: Background, Application and Shelf-Life Extension

4.2.1 Thematic Background

Cereal and confectionery products are reported to receive less attention in discussions about ecological sustainability (*e.g.* [78, 108, 109]). However, for packaging redesign, cereal and confectionery are similarly of importance, regarding their economic relevance [110, 111]. In industrialized countries, even 50% of carbohydrates are consumed through bread [112]. To broaden the consideration of these product groups in sustainability related discussions such as packaging redesign, cereal and confectionery was given the spotlight in this work. The packaging functions, packaging properties, a characterization of the product group and its decay mechanisms, as well as applied modern shelf-life extension strategies (modified atmosphere, active and intelligent packaging) were collected, based on a comprehensive literature research and categorization according to the *Guidance document describing the food categories in Part E of Annex II to Regulation (EC) No 1333/2008 on Food Additives* [8].

4.2.2 Key Findings

A multitude of packaging solutions is available and marketed for cereal and confectionary products, including applications of all widely used packaging materials (various plastics, glass, metal, paper, and

cardboard). Overall, a broad range of water activities and moisture contents can be identified over various product types, next to many different material combinations and applications of shelf-life extension strategies [7]. Lots of the food products categorized, exhibit a low water activity (a_w below 0,75) [7, 113, 114]. Moisture changes like water uptakes are therefore considered as important decay mechanisms for many products in these food groups (ranges of 0.35 to 0.5 a_w) [7, 9, 115, 116], next to possible oxidation mechanisms, based on varying fat content, aroma loss and uptake, or the loss of structural integrity [9]. Regarding the considered literature, cereals and confectionaries are often described as stable products, with feasible storage under dry and ambient conditions (e.g. cereals, dry pasta, pulled sugar etc.) [113, 117, 118]. The different applied marketed and experimental packaging concepts found for cereal and confectioneries show that their shelf-life heavily depends on the packaging used (table 2). This can be linked to effects on food waste potential and a high relevance regarding current efforts in packaging redesign [56].

However, the great diversity of product characteristics, packaging solutions and associated shelf-lives such as depicted in [119, table 3, p. 13] induced the need to evaluate the packaging's environmental effects in detail before formulating redesign recommendations for the products. As data about their environmental impact in comparison to the filling goods could not be found anywhere condensed, an analysis comparing the environmental impact ratio between cereals and confectioneries against their applied packaging solutions was found to be a necessary further step.

4.3 Cereal and Confectionary Packaging: Assessment of Sustainability and Environmental Impact with a Special Focus on Greenhouse Gas Emissions

4.3.1 Thematic Background

Building upon the research needs formulated in the previous review, *Cereal and Confectionary Packaging: Background, Application and Shelf-Life Extension* [119] and the aim to provide a knowledge base for practitioners confronted with packaging redesign for these products, work to gather data about the impact ratio / burden share between the associated emissions for food products and their applied packaging solutions was initiated. In general, this share between a packaging solution and its product depends on various factors and can vary significantly between product groups [120, 121]. On average, packaging is considered as accounting for about 5% of the CO₂ emissions in the food system [39]. Looking at households, influences of consumption patterns in diets are however visible [120]. Knowing about the possible differences between product groups, consumption patterns [120] and the 5% being an average value for the packaging burden in the food system [39], greater attention was found to be necessary for cereal and confectionary packaging, when destined to result in redesign recommendations. For this purpose, life cycle assessments of products within this group were collected, analyzed, and compared in detail, according to the four phases of LCA [84, 85].

4.3.2 Key Findings

The collection, analysis, and comparison of the LCAs resulted in a broad range of impact ratios in this product group. 28 studies including more than 100 cereal and confectionary products were found and compared regarding therein differently applied approaches on how to consider packaging in the LCAs and the outcomes regarding greenhouse gas emissions. Looking at the goals of the studies, it was found that the food products mostly were in focus, more than the packaging solutions applied. Only a small

share of the studies included the importance of packaging and explicitly mentioned packaging in the study's aim (e.g. [86]). Most studies applied cradle-to-grave approaches (e.g. [78]). Packaging was overall found to be underrepresented in the functional units applied, with exceptions in some studies, such as [80]. Referring to end-of-life scenarios in cradle-to-grave approaches, national recycling rates were considered by the study's authors (e.g. [86]). The actual recycling of the specific packaging solutions was seemingly not considered, although being of high importance for small format packaging solutions, such as found in confectionery [4]. Food waste was the most noticed indirect packaging effect mentioned in the studies (e.g. [78, 108, 86]) and in all LCAs mutually, the CO₂ emissions / global warming potential / carbon footprint, was assessed (table 2), whilst combinations with various impact categories were found, depending *i.a.* on the studies foci (e.g. [78, 108, 109]). Different assessment methods could be identified (PAS 2050 [122], ISO 14044 [85] etc.), limiting the comparability of the studies. Secondary data was in most LCAs the dominating source of calculations such as in [78, 108]. Despite the limitation in comparability, an estimated range as an average percentage of 9,18% greenhouse gas emissions connected to packaging in this food group was found over all analyzed LCAs.

Table 2. Reviewed cereal and confectionary life cycle assessment (LCA) studies (n = 28), taken from [123, table 1, p. 7].

Category	Sub-category	LCAs* n = 28		Products n = 108		Greenhouse gas emissions		
		n	%	n	%	Food-packaging system [kg CO _{2eq}]	Packaging [kg CO _{2eq}]	Packaging (%)
Confectionary	Cocoa and chocolate products	9	32	41	38	3.28	0.25	9.86
	Other confectionary including breath freshening micro-sweets	2	7	4	4	2.80	0.16	4.68
Cereals and cereal products	Whole, broken or flaked grain	2	7	9	8	12.53	0.14	1.25
	Flours and other milled products and starches	2	7	3	3	0.65	0.04	5.30
	Breakfast cereals	2	7	4	4	0.87	0.15	19.68
	Pasta	4	14	10	9	1.33	0.10	7.24
Bakery wares	Bread and rolls	5	18	20	19	1.03	0.04	4.37
	Fine bakery wares	3	11	12	11	1.93	0.04	11.22
Ready-to-eat savorys and snacks	Potato-, cereal-, flour- or starch-based snacks	1	4	1	1	0.43	0.04	8.14
	Processed nuts	1	4	4	4	1.87	0.33	20.10
Overall (average)						2.67	0.13	9.18

*Some LCA studies covered more than one (sub)category. Therefore, given numbers do not sum up to n = 28 or 100%.

Overall, it was found that packaging was insufficiently and/or non-consistently included in the LCAs. Recommendations on how to change this were formulated on [123, table 4], next to packaging redesign recommendations and options to management related activities, supporting the transition to sustainable packaging on [123, table 5].

4.4 (Not) Communicating the Environmental Friendliness of Food Packaging to Consumers - An Attribute- and Cue-Based Concept and Its Application

4.4.1 Thematic Background

The empowerment [42] and inclusion of consumers [3] is regarded as a necessary change in different actions or initiatives regarding future sustainable product design, such as for food packaging. Consumers have a right to informed choices [70] and explicit and implicit communication via packaging design in various food products about “environmental friendliness” can be named in this relation, with increasing importance [59]. While consumer behavior, such as the understanding and preferences for environmentally friendly packaging is well investigated [60, 124, 125, 126, 127], the supply-side, meaning the communication towards consumers and the range of comparable, competitive products, which they can choose between, is found rather underrepresented, besides exceptions (*e.g.* [90]). Regarding published research, the link between the packaging design that implies sustainability and the cues that might deliver such messages, are found to be partly missing. To understand which packaging design aspects (technical and non-technical such as material selections, packaging formats, product-to-packaging ratios, packaging levels, disposal information, textures, colors, graphics etc.) imply “environmental friendliness” for consumers and to prospectively improve the related communication in these design aspects, a pan-European sample of packaged confectionery was collected and analyzed. The theoretical background leans against the cue utilization theory, addressing for example situations, where product characteristics cannot be objectively evaluated by observation [88]. As consumers might have a simplified understanding of sustainability, rely on heuristics and routines [60, 128] and might harbor false beliefs about packaging [124, 126], an analysis of given cues and attributes in relation to packaging sustainability was found to hold chances for design improvements.

4.4.2 Key Findings

To conduct such an analysis over a multitude of packaging solutions, comparable competitive products were in a first step identified. One product type of confectioneries, namely wafers, were chosen. The marketed packaging solutions were found to be designed in many ways over Europe, regarding sizes, packaging types, material selections and amounts as well as non-technical designs. Although the quality related product characteristics (*e.g.* shelf-stable, nonperishable, high sugar, high fat, crispy/brittle) and degradation mechanisms, such as requirements against moisture uptake or oxidation [7] must be quite similar between different types of this product, the packaging designs are of great diversity as addressed in [53]. The dependance of sweets on packaging at the point-of-sale might be one cause behind, reflecting motives such as confectionery being treats, offering gift functions and similarly profiting from seasonal influences in designs via special editions, like other products [7, 89, 129].

However, in analyzing more than 160 product samples of packaged wafers, communication was found to be very limited. The examination of the products in combination with packaging design cues, proven to matter to consumers as indicated by literature (*e.g.* [130, 131]), as well as associated attributes standing for “environmental friendliness” (*e.g.* [124, 125]), depicted that very little communication regarding sustainability can currently be found. From 49 applicable attribute and cue combinations, less than a fourth was used by companies (figure 1). Next to that, very broad ranges of product-to-

packaging ratios were found, implicating serious inefficiencies in material use, when reaching from 2:1 to more than 100:1 between comparable products, addressed in [53]. Regarding packaging formats and material selections, inconsistently applied design criteria reflecting food requirements were identified, such as different sealing techniques, concepts on mechanical protection, recloseability, light protection and others. The findings regarding communication are depicted with frequencies in an attribute-cue matrix (figure 1). This provides a tool to identify applied cues with connected attributes in products. For packaging designs, it should enable improvements in the effectivity of packaging, meeting targeted communication as a basic function [6] and the sought empowerment of consumers [42].

Figure 1. Heatmap of environmentally friendly cues that were utilized. Abbreviation: P2P ratio (product-to-packaging ratio), taken from [53, figure 2, p.9].

		CUES									
		CONSUMER JOURNEY									
		View Visual Cues			Touch Sensory Cues		Read Informational Cues	Consume Structural Cues			
		Color	Label	Image / picture	Haptics / texture	Tightly packed	Text	P2P ratio	Packaging levels	Waste pieces	
ATTRIBUTES	LIFE CYCLE STAGES PACKAGING	No stage	-	30 %		11 %	17 %		12 %		
		Material production	Reused								
			Recycled								
	Packaging production		Renewable								
			Less packaging				79 %	48 %	85 %	73 %	
			Local production								
	Transport and use		Environmentally friendly production								
			Light-weight					48 %			
			Space-saving				79 %				
	Post-use		Recyclable	76 %							
			Reuseable								
			Bio-degradeable								

4.5 Consumer Complaints about Food Packaging – Submitted Manuscript

4.5.1 Thematic background

The redesign of packaging is in the middle of realization based on time bound legislative goals for recyclability in the European Union [1, 2]. Not only do legislative directions require changing packaging design [1, 2], also consumers are often dissatisfied with packaging solutions, object against their design and implicate the need for improvements [7 referring to 64, 62]. Consumer protection agencies [62, 73] and European security systems such as the Rapid Alert System for Food and Feed [132] are supportive in certain cases of dissatisfactory or unsafe packaging. However, objections might not reach such supporting infrastructure as discussed in [62] and information about dissatisfying packaging solutions can also be found elsewhere. Consumers, for example, share various information about their experiences online and therefore often publicly available [93]. For the goal of improving products like packaging (e.g. [58]), feedback such as online shared experiences or even complaints, are a valuable source of data. The consumer's empowerment [42] and the integration of their perspectives [3] into technical and non-technical design changes, was seen as a chance starting from their own feedback.

4.5.2 Key Findings

Following an established data collection approach, leaning against Kozinets Netnography [93], more than 250 consumer complaints about packaging were collected online from various webpages and consequently analyzed for redesign options. The found complaints were on one hand broken down into food groups according to the *Guidance document describing the food categories in Part E of Annex II to Regulation (EC) No 1333/2008 on Food Additives* [8] and on the other hand, categorized (“recontextualized” [93, p. 64]) into twelve groups of possible (re)design areas, which consumers had objected to with their shared experiences (*table 3*).

Table 3. Complaint categories in food categories, taken from [72, table 2, p. 8].

		Complaint Categories											
		Unclear, hard-to-read or incorrect text-based information about ingredients, manufacturing processes or origins	Unclear, hard-to-read or incorrect text-based information about product size or pieces	Relabelling	Too much information	Unesthetic, uncommon design	Graphics implying certain ingredients or (ingredient) amounts or manufacturing processes	Unclear or beautifying colours and colour schemes	Hiding or showing specific parts through e.g. windows or sleeves	Closures and sealing	Expensive packaging solutions	Packaging size, format or waste amount versus product size	Unnecessary use of packaging or a certain selected packaging material
Product category	0. Compound foodstuff		X				X		X	X		X	X
	1. Dairy products and analogues	X					X		X	X		X	
	2. Fats and oils and fat and oil emulsions	X						X				X	
	3. Edible ices									X		X	
	4. Fruits & vegetables	X	X					X				X	X
	5. Confectionery		X				X		X	X	X	X	
	6. Cereal and cereal products	X	X					X	X			X	X
	7. Bakery wares	X		X		X	X		X			X	
	8. Meat	X					X		X			X	
	9. Fish and fishery products								X			X	
	10. Eggs and egg products											X	X
	11. Sugars, syrups, honey and table-top sweeteners	X											
	12. Salts, spices, soups, sauces, salads and protein products		X			X		X	X	X		X	
	13. Foods intended for particular nutritional uses	X			X	X							
	14. Beverages	X	X		X		X		X	X		X	X
	15. Ready-to-eat savouries and snacks		X			X			X			X	

The collected issues shared by consumers were analyzed in detail. The qualitative perspective dominates the analysis. It was found that complaints in particular product groups, such as fruit and vegetables, dominated the sample and complaints related to sustainability concerns were omnipresent over all groups. This goes along with literature, indicating that design changes are a persistent wish or concern in some specific product groups [7 referring to 64, 16]. Some objections also were related to technical aspects, such as closures or sealing, addressed in the publication. Objections against communication via texts, graphics or wrong impressions about a product's size were found in various complaints (table 3).

For the guidance of practitioners confronted with packaging design, a snapshot of possible related legislative perspectives, such as from the packaging and packaging waste directive [2] or the regulation (EU) No. 1169/2011 [70], touching upon the mentioned (dissatisfying) designs, was discussed. The non-existent, misleading, deceptive, inconsistent communication allowed a new perspective on the partly low perceived value of packaging in society [7]. Referring to the regulation (EU) No. 1169/2011 [70], as well as a Briefing Paper on Misleading packaging [62], some packaging designs can even belittle the right to informed choices. Redesign is pressing in such cases. Overall, consumer acceptance is of high importance for current and future designs to be successful, even more when collaboration is necessary to reach design goals such as circularity (*e.g.* collection behavior) [16, 17].

5. Scientific Relevance and Discussion

5.1 Recyclable Barrier Flexibles and the Harmonization of Design Recommendations

That flexible packaging is a relevant topic in packaging redesign, especially small formats and / or multilayer, was discussed widely, such as by the Ellen MacArthur Foundation [4]. The reason for investigating multilayer flexibles here, was at first related to a time-bound substitution-need for barrier flexibles in Austrian food products, we were confronted with. In relation to prospectively tolerated (recyclable) packaging design, the highly important question was, which design to recommend. In a broader sense than project related, one could follow quickly changing design recommendations in the branch, mirrored in constantly updated compilations like design guidelines [133] and could consequently see insecurity about where to go with this packaging solution's design to meet future the expectations. One could find published inconsistencies regarding material selections, like shown in *table 1*, and complex barrier requirements of the related filling goods (*e.g.* [7]). To find consensus in the recommendations on this certain packaging type, comprehend the circumstances that led there and share this information with stakeholders, we condensed available information to this very first review.

The outcome that mono-polyolefins with barriers such as EVOH, AlOx and SiOx are considered as the best design options for recyclable multilayer flexibles in combination with transparent / unpigmented polypropylene or polyethylene film, answered the pressing question in which direction to change designs (*table 1*). Next to that, many more obstacles for the redesign of (multilayer) flexibles, besides the technical recyclability, could be identified, such as laid out [101]. This is of high relevance, as the message that material selections for flexibles directly change their end-of-life or automatically improve their ecological sustainability is currently likely to be wrong, related to manifold other challenges and trade-offs [101, figure 1, p. 3].

Still, lots of effort is put in this redesign, but it is now visible that the harmonization of design requirements for single packaging formats does not suffice. Referring to very recent developments (proposal for legislative changes), one can more and more see that even with redesign of packaging solutions “...many Member States are struggling to meet the recycling targets established in Article 6 of Directive 94/62/EC.” [134, p.1]. Non-recyclable packaging even grows in its share [134].

The design recommendations are technically an understandable direction to go but practically, and provocatively said, currently running into nothing. To understand and share that the technical design for circular packaging solutions is not THE one important criterion approaching sustainable production and consumption, is found to be very important in moving forward. Whilst one can respect that a common understanding of designs that better match the given infrastructure is an option (with limitations) to start bottom-up, one also must acknowledge that the literature already suggested fragmented / uncoordinated efforts being part of the struggle improving packaging designs [4]. The solutions for multilayers (reduction of recommended material selection) partly continues feeding into this struggle, as the possible recycling / secondary material outcome is (still) downcycling, when unapproved for similar applications as before [107].

For the sake of discussion, one could however pretend that all barrier flexibles change to these material combinations, stay similarly efficient in needed material amounts and the needed shelf-lives of products are not impaired by altered materials. For collection, one would have to make sure keeping this packaging type out of undifferentiated wastes [24, 135], address the littering potential of (small) flexibles [4] and set up a separate or easily sortable collection to improve the profitability of reprocessing and the quality of secondary material [1, 4, 42]. One would have to eliminate safety concerns of polyolefins being used as secondary materials in food contact [107] and make sure that overall, sustainability is achieved while (mechanical) recyclability, as being only one option within circularity, not overrated as a mitigation measure, next more favorable options [30, 36].

These considerations are highly important for design that is meant to be holistic (life-cycle-thinking) [16], but redesigns of specific packaging solutions can, as visible in the proposal to change legislation [134], not start this off. This proposal would allow a change from fragmented national interpretations to pan-European rules [134] and seems like a more promising way of harmonization, addressing sustainability issues with packaging, besides bottom-up solutions in specific designs.

5.2 Giving Holistic Redesign Recommendations in Specific Food Groups

Besides proposed legislative changes [134] and the chances that might come along, consensus currently is (and seems to stay) that holistic considerations for design are highly important (life-cycle-thinking) [16, 134]. It also means that the whole product-packaging system should be considered [16]. To this end, the broad range of food products, which differently profit from packaging via shelf-life extensions (and related food waste), are of high interest for packaging redesign [12, 56].

For some food groups, discussions regarding sustainability seem rather present (*e.g.* animal-based products), while staples such as cereals, or more hedonistic food groups, such as confectionery, are mentioned to be partly underrepresented (for example in literature referring to LCAs [78, 108]). This was found to be interesting and of high scientific relevance regarding redesign, as they show a high economic potential and high amounts are consumed and/or wasted [12, 110, 111, 112]. Next to that, they show various decay mechanisms with possible shelf-life extensions, heavily depending on packaging [7, 136].

To give cereals and confectionery spotlight in redesigning product-packaging systems and consequently get the chance to add to the sum of scientific knowledge in this regard, we developed a comprehensive literature base for practitioners (second review) [119]. Going into detail about the impact ratio / environmental burden shared between food product and packaging, the given data was found to also be dispersed. To address this gap and get evidence where one could communicate an average share of emissions for these product categories, we undertook a third comprehensive review. Accessible scientific and industry data regarding available life cycle assessments was collected and evaluated to form the sought profound base before giving recommendations for redesign.

At this point though, it was found that packaging was not even sufficiently included in many LCAs of these products, and secondly, considered very differently in the LCAs [123]. Both these outcomes are highly relevant, regarding that missing benchmarks complicate efforts for targeted changes like redesign, such as mentioned in reports related to sustainable (and healthy) diets, recommending analyzing existing food systems [87]. To understand the ranges of LCAs results in these food-packaging

systems, in relation to the elsewhere environmental burden of packaging overall [39], the greenhouse gas emissions of available LCAs were taken together for this benchmarking.

Going into a discussion about this, one has to note that the comparability of such outcomes is limited, and the fair question is, how to improve this aspect and allow better benchmarking also. We used the data to identify aspects that might improve the considered LCAs. Differences and similarities between the evaluated LCAs were made visible and perspectives from packaging technology, on how the researchers had included and could differently include packaging, were worked out. This is a highly relevant outcome providing practical steps for improvement [123]. Because as mentioned above, the success of efforts to harmonize products and processes regarding packaging, so far seems limited [134] and the diversity of environmental assessments might play into this, or is at least an acknowledged problem, with high relevance concerning targeted mitigation measures, taken up in actions, such as the establishment of PEF [57].

5.3 Empowering the Consumer and Integrating Consumption into Redesign

Going further with the addressed life-cycle-thinking, important for packaging design [16], one can go into detail about stakeholders that so far received less attention in above considerations. Designing sustainable packaging and bringing it to the markets, needs at the point-of-sale, consumers who can identify and choose such products. This is currently given high importance in perspectives from the European Union (empowerment) [42] and in connected research projects [3]. Between competitive products, all design efforts might run into nothing, if technical and non-technical design does not allow informed choices (*e.g.* [70]).

Now it comes that we found cues in relation to sustainability attributes very little applied [53]. Although the discussion about (too) extensive labelling is valid as well (*e.g.* green claims [59]), a market check in confectionaries, regarding explicit and implicit design, enabling consumers to choose more sustainable packaging, painted a different picture with similar outcome though [53]. Examining more than 160 packaged products and finding 49 applicable cue-attribute combinations based on literature and the sample itself, less than a fourth was used in the packaging designs (figure 1). This is highly relevant in analyzing the communication strategies unintentionally and intentionally applied by the producing industry, but also reflecting design recommendations from a different perspective. It is very important to consider aspects in design, which are proven to matter to consumers in decision making (*e.g.* [53, table 1, p. 4]). Next to that, it was found that design should but does not easily allow choosing more sustainable packaging, but also lead to wrong impressions about products. The topic is currently highly relevant because of redesign actions demanded. This kicked off a second analysis regarding dissatisfying packaging designs [72]. Provocatively speaking, people are not only held in the dark when wanting to choose specific packaging [53], but also being partly misled by its design [72]. This perspective even gains more relevance besides demanded redesign, as prices of products rise [137] and packaging designs seemingly make use of consumers' expectations, not constantly checking product characteristics [62]. These two market analysis, regarding the status-quo of marketed food products and their packaging's characteristics, add new insights to this topic. They add to the sum of scientific knowledge in closing a gap towards the consumers perception in offered packaging designs and analyze the potential design drawbacks in now given purchase options.

6. Conclusion and Outlook

All these circumstances are highly relevant in technical and non-technical packaging design and lead to questions about how serious the redesign is actually taken, given the found status quo of marketed products [53, 72], evaluation processes [123] and the current analysis of limited visible success of redesign [134]. Concluding the last years works in this relation and addressing the throughout leading research question from the aim, *“Which technical and non-technical design aspects, in context to aspired ecologically sustainable packaging design, with a special focus on circularity, are yet underrepresented in marketed packaging solutions and in their evaluation?”*, one has to state that omissions can be found in all design aspects considered important for successful packaging (basic packaging functions [6] and criteria related to sustainability [16]). Although this seems like an easy and obvious thing to say, it was very recently (November 2022) reported at the European level as well: A lot of effort is put in redesigning packaging to be more efficient, effective, cyclic and safe [16], but its success is still fairly limited in the European Union [134]. Current *“... discrepancies create legal uncertainty for businesses, leading to lower investment in innovative and environment-friendly packaging and new circular business models.”* [134, p. 2], which is visible throughout the publications taken into this thesis.

Hope for improvement lies in these very new efforts to drastically change and improve the legislative framework [134] (top-down) and move ahead the fragmented actions [4]. In line with the Green Deal, the aspirations to move towards a circular economy and to become a climate neutral continent [41], packaging design measures must reflect the waste hierarchy, such as the reduction of overpackaging, the reduction of material complexities, as well as harmonized and understandable labelling. These issues are addressed in various perspectives this work, as well as now, listed in the proposal to change the legislation [134, p.19, 20]. Improvement in these areas would meet many of the so far persistent obstacles.

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Appendix

A. Conference Abstracts and Posters

Montanuniversität Leoben: Recy & DepoTech Konferenz, 2020

Abstract

Collective research projects: Reviewing gaps in the recycling of multilayer flexible food packaging

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ABSTRACT: *Recyclability and sustainability are conflicts in multilayer flexible food packaging, where material combinations (polymers, paper, aluminium) intend functionality. To increase the sustainability of multilayer flexible packaging through recyclable solutions, systemic and technical obstacles need to be considered. A holistic redesign approach, addressing food protection and the packaging's end of life (collection, sorting, recycling) is essential to improve these already sustainable packaging solutions. To this, current collective research projects at the University of Applied Sciences, aim to closely link science and industry, promote research in the field of sustainable packaging and provide solutions to recycling goals of the European Union.*

1 SUSTAINABILITY THROUGH RECYCLABILITY? Sustainability of food and packaging are issues in the global discussion on how to reduce unintended climate and environmental changes (UN 2015). For many consumers, packaging seems to be an unnecessary companion of food, harming ecosystems. Without any doubt, littered items from mismanaged waste pose a threat to the environment. However, it is often neglected that packaging plays an important role in the protection of food and allows reducing food loss and waste and herewith-associated environmental impacts. Still, one prerequisite is that adequate waste management is given (PlasticsEurope 2018). An optimal point of packaging, as depicted in the so called Soras Curve or Innventia AB Model illustrates this issue: In the case of insufficient packaging, food deteriorates and indirectly induces environmental harm, as resources, which ran into its production, are lost. In the case of too much packaging, waste at end of life is increased (EC 2011). Until now, multilayer packaging is offering protection at this optimized point - lightweight solutions and tailored protection (Barlow & Morgan 2013). Against the background of a circular economy, the requirement of protection and sustainability, especially in the context of reduced material use, does not suffice, and recyclability is focussed recently (EC 2018). The main issue with multilayer flexibles is that they are, due to incompatibilities of the used materials, in most cases chemically, but not mechanically recyclable (McKinlay & Morrish 2016). Science and industry mostly agree on how to redesign for favoured mechanical recyclability, based on available infrastructure. However, for food products with complex requirements, already recyclable solutions cannot be widely adopted. Browsing recommendations for the redesign of flexibles, a focus on polyolefines is found (Ceflex 2020). This is comprehensible for recyclability reasons, but as far as the molecular constitution allows, barrier properties are not comparable to, for example, aluminium layers (Dixon 2011). Hence, conflicts between sustainability and recyclability arise, as it is not self-evident, that recyclability enhances sustainability. This potential trade-off is shown in publications, discussing that changing from recyclable but rigid mono material packaging, to non-recyclable flexible multilayer solutions, would still

be the environmentally preferable option, i.a. accounting for lightweightness (Flexible Packaging Europe 2018). Nevertheless, recyclable solutions are a top goal of political agendas, reaching for sustainability through circularity (EC 2018). Particularly, the balance between recyclability and sustainability induces need for research. Industry alone is hardly able to develop and evaluate new packaging solutions striving for recyclability and sustainability in replacing multilayer flexibles, as connected improvements and assessments affect various stakeholders (Ellen MacArthur Foundation 2017, EC 2014).

2 NEED FOR COLLECTIVE RESEARCH The University of Applied Sciences initiated collective research projects, addressing this balance. One of the largest projects, "REFLEX – Collective research for recyclable food packaging film", involving more than a dozen partners from industry, focuses on the development of recyclable coatings to substitute the need for material combinations to generate protective barrier properties for packaging. Redesign recommendations from industry, prioritizing polyolefin films, are taken into account, as infrastructure (collection, sorting) exists, and mechanical recycling is possible (Ceflex 2020). In the substitution of multilayers, coatings (commonly SiO_x, AlO_x) are considered as a promising approach to optimise barrier properties of polyolefins (Dixon 2011, Morris 2017). The aim of the project is to increase the technical readiness of specific coatings. One main obstacle in substituting multilayer flexible packaging through coated mono polyolefins, is processability since coatings show mechanical instability in steps of converting, processing and filling. As the chosen base material shows flexibility, the coating too must possess some degree of "flexibility" or must be applied self-protective (for example between polymer layers). If coatings are rigid and unprotected, occurring cracks make applications needless, as barrier properties are thus diminished (Morris 2017). Reflecting issues accompanying the substitution of multilayer flexible packaging to recyclable solutions, several questions still remain to be answered. Considerably more work will need to be done, to determine how specific coatings can be improved to generate widely applicable solutions. With collective research projects, aiming for enhanced technical readiness of coatings, holistic packaging improvement is facilitated. Joint action, including all stakeholders, is key to develop circular products.

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Collective Research Projects: Reviewing Gaps in the Recycling of Multilayer Flexible Food Packaging

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Framework

I. Pressure to innovate plastic packaging for recycling and sustainability

- 2015: European Circular Economy Package¹ & Closing the Loop - An EU Action Plan for the Circular Economy²
- 2018: European Strategy for Plastics in a Circular Economy³
- 2020: New Circular Economy Action Plan⁴

II. Complexity referring to flexible (multilayer) packaging in food applications⁵

- Sustainable and recyclable solutions
- Combinations of polymers, paper, aluminum

Gaps

III. Technical and systemic gaps on multiple stakeholder levels⁵

- Design, collection, sorting, recycling
- Coordination, sustainability

IV. Addressing one gap: Coordination of actions in collective research

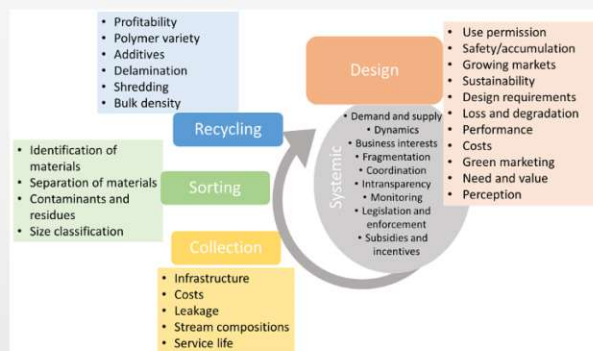
- Collective implementation, evaluation and validation of developments and goals
- Scientific theory and stakeholder's practical enforcement
- Development of new plastic packaging solutions for recyclability in existing infrastructure
→ Coated mono material polyolefin solutions to overcome deficient barrier properties

Approach

V. Implement and test innovative approaches in practical applications

- Coordinated actions of research projects to design sustainable as well as recyclable flexible multilayer packaging

for example FFG funded
"Branchenprojekt recyclinggerechte
Lebensmittelverpackungsfolien",
project number 881293,
Collective Research;
together with the partners
OFI and Packforce Austria



Further steps

VI. More aspects induce obstacles, for example:

- Potential trade offs
→ recyclability and sustainability
- Recycling and circularity
→ Use permission for secondary material

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Università Di Foggia: First Circul-a-bility Conference, 2021

Abstract

Analysis of sustainable packaging attributes in the confectionary sector

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Every year more and more packaging waste is generated in Europe, with consequent negative direct impact on the environment. On the other hand, packaging also plays an important role in safely and conveniently distributing products throughout the supply chain. While research on sustainable packaging as an option to significantly reduce this environmental impact is growing, it failed to examine real packaging choices available to consumers in the market. The purpose of this paper is to evaluate packaging solutions in the market by examining their sustainability-related attributes and the cues they provide to consumers for judging the sustainability of each packaging. It provides a comprehensive market analysis (field study) of packages in one product category. The confectionery and bakery goods segment is an excellent example of the important impact packaging can have on consumer decisions at the point of sale. Especially for wafers, that come in different types, shapes, sizes also fulfill a gift function. In this paper, we first reviewed the consumer research on packaging and sustainability on which we build an empirical-based conceptualization of sustainability attributes and cues of packaging solution. Based on an attribute-cue-matrix we show which attributes and cues that producers use in their communication with customers. Our results can help to better understand the gaps between the attributes consumers find important and the cues they use on one side and the attributes and cues the providers use on the other side.

Taken from:

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Aarhus University - CiFOOD Conference, 2022

Poster



Redesign and recyclability challenges in flexible food packaging Spotlight on cereal and confectionary packaging

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1 INTRODUCTION Gaps - Material composition - Infrastructure - Economic, environmental cut-off-points Need for action - Limitations regarding material choice - Fill the gap respecting infrastructure - Design recommendations → mono-polyolefins	3 CURRENT RESEARCH – LITERATURE & FIELD STUDIES <table border="1"> <tr> <td>LIT.</td> <td> - Review on redesign recommendations https://doi.org/10.3390/foods10112702 - Review on packaging and shelf-life extension in the product group - Review on CO₂-eq burden share between packaging and product </td> </tr> <tr> <td>FIELD</td> <td> - Case study European wafer packaging - Subsample: Microscopy, FTIR, life cycle assessment - Student work on film build-up and recyclability of retailer assortment - Microscopy, FTIR, recyclability, life cycle assessment </td> </tr> </table>	LIT.	- Review on redesign recommendations https://doi.org/10.3390/foods10112702 - Review on packaging and shelf-life extension in the product group - Review on CO₂-eq burden share between packaging and product	FIELD	- Case study European wafer packaging - Subsample: Microscopy, FTIR, life cycle assessment - Student work on film build-up and recyclability of retailer assortment - Microscopy, FTIR, recyclability, life cycle assessment
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FIELD	- Case study European wafer packaging - Subsample: Microscopy, FTIR, life cycle assessment - Student work on film build-up and recyclability of retailer assortment - Microscopy, FTIR, recyclability, life cycle assessment				
2 GOAL Identify & promote sustainable packaging solutions for cereals, baked goods, snacks and confectionary	4 OUTLOOK Verify outcomes - Sustainability assessment - Food quality & safety - Consumer acceptance 				

Work in WG4 of COST Action 19124 - RETHINKING PACKAGING FOR CIRCULAR AND SUSTAINABLE FOOD SUPPLY CHAINS OF THE FUTURE; www.cost.eu  Funded by the European Union 

No conference booklet available. Conference details available online: <https://conferences.au.dk/cifoodconference2022> (accessed on 14 December 2022).

Pulp and Paper Institute Ljubljana - 2nd Circul-a-bility Conference, 2022

Abstract

Why do people complain about packaging? - A netnographic case study of consumer complaints deriving needs for packaging redesign

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Packaging heats tempers so that stakeholders along the value-chain ask for optimization. Current patterns of resource use, mostly addressing end-of-life scenarios, led to politics putting this issue on its agenda (e.g., A European Strategy for Plastics in a Circular Economy). Packaging producers and science work on design for and from recycling, brand owners and retail try to reduce plastic amounts and waste management focuses collection, sorting and recycling improvements (e.g., Design Guidelines, The Global Commitment). While a lot of movement is going on and people dedicate work to improve packaging solutions, consumers still feel unheard and seem to perceive packaging as being e.g., unsustainable, unnecessary or misleading. This dissatisfaction has a certain power to support or undermine actions improving packaging sustainability and induces necessary discussions reflecting the stage of consumption. Overall, dissatisfaction might lead to hardly visible exit scenarios (i.e., don't buy product again), but it also results in publicly available discussions online, that consumers use to make their voices heard. People share pictures, thoughts, and feelings. The uploaded content is available for a long time, sometimes for years and continues to promote the bad reputation of products, producers or packaging. Taking a closer look at this user generated content via netnography as research method and understand what exactly bothers people, is a chance to optimize packaging beyond conventional perspectives. It is, for example, a starting point to introduce consumers needs more into redesign, if necessary, through legislative changes that protect better from misleading packaging. This could improve how people perceive the packaging's value, how they handle it and engage in the needed steps to improve the overall sustainability of products (e.g., recycling behavior). To understand dissatisfaction with packaging at consumption, over 200 virtual cases of complaints shared online by consumers were collected. During an analytical phase, the cases were coded by a group of researchers to define complaint contents, as well as categorized and integrated into a framework, based on the stimulus-organism-response model (packaging specifics, consumer motives, complaint outcomes). The qualitative analysis to source reasons of dissatisfaction, as well as the question on how to prevent such outcomes, were the focus areas of the study. The findings indicate that the basic packaging function of communication is in most cases the origin of dissatisfaction, whether if it stems from implicit design like sizes or explicit elements like text-based information. Multiple complaints are about showing or hiding specific product parts. The concern of packaging being unsustainable is also present in the sample, e.g., reflecting unpacking and repacking of products with natural protective peels or shells. In the current data, some product groups lead the looked-up discussions more than others do (e.g., confectionery, fruits & vegetables). Summing up first results, a need to improve implicit and explicit communication is visible and packaging redesign could make a change. If the communication function of packaging is not met, consumers can't be part of an economy, where their perceptions and interactions also determine sustainability – they will continue to ask for skipping packaging and science will ask why, as it is thought to be already optimized to its best.

Taken from:

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B. Full Articles

- Bauer, A.-S.; Tacker, M.; Uysal-Unalan, I.; Cruz, R.M.S.; Varzakas, T.; Krauter, V. Recyclability and Redesign Challenges in Multilayer Flexible Food Packaging—A Review. *Foods* 2021, 10, 2702. <https://doi.org/10.3390/foods10112702>
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Review

Recyclability and Redesign Challenges in Multilayer Flexible Food Packaging—A Review

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Abstract: Multilayer flexible food packaging is under pressure to redesign for recyclability. Most multilayer films are not sorted and recycled with the currently available infrastructure, which is based on mechanical recycling in most countries. Up to now, multilayer flexible food packaging was highly customizable. Diverse polymers and non-polymeric layers allowed a long product shelf-life and an optimized material efficiency. The need for more recyclable solutions asks for a reduction in the choice of material. Prospectively, there is a strong tendency that multilayer flexible barrier packaging should be based on polyolefins and a few recyclable barrier layers, such as aluminium oxide (AlOx) and silicon oxide (SiOx). The use of ethylene vinyl alcohol (EVOH) and metallization could be more restricted in the future, as popular Design for Recycling Guidelines have recently reduced the maximum tolerable content of barrier materials in polyolefin packaging. The substitution of non-recyclable flexible barrier packaging is challenging because only a limited number of barriers are available. In the worst case, the restriction on material choice could result in a higher environmental burden through a shortened food shelf-life and increased packaging weights.

Keywords: multilayer packaging; flexible packaging; polyolefin; recyclability; redesign; mono-material; shelf-life of foods

1. Introduction

Packaging is essential for maintaining the quality, safety, and security of many food products [1,2]. Robertson [1,3] described its basic functions as protection, containment, convenience, and communication. In addition to these functions, packaging should be recyclable but often faces end-of-life challenges. Recycling rates, particularly for plastic packaging, are low (42% on average throughout the European Union in 2018) [4]. Politics at the European level demand a stepwise increase in recycling rates for packaging [5]. This induces pressure on certain packaging solutions. Trend analysis shows that non-recyclable plastic packaging will no longer be tolerated by brand owners and retail chains [6]. Until 2030, all plastic packaging must be reusable or recyclable [5]. To reach this goal in the EU, most countries need investments to upgrade the collection, sorting, and recycling infrastructure, and principles of design for recycling must be comprehensively applied [7–9].

Guidelines from industry and academia support this transformation. They give guidance on material choice and design for packaging, packaging aid, and decoration, mostly in relation to established collection, sorting, and recycling infrastructure of specific regions or countries [10–12].

Multilayer food packaging is especially under pressure since it combines various materials such as polymers, paper, aluminium, and organic or inorganic coatings [13–15]. Considering environmental effects measured by Life Cycle Assessments, these packaging solutions are highly efficient [16,17]. The main problem, however, is that they are hardly recycled in the existing waste management infrastructure, as Europe widely relies on traditional approaches of mechanical recycling in regranulation processes, which generally means combined processing of materials [4,13,18,19]. The thermal incompatibility of the diverse combined materials is one major obstacle in reprocessing [20]. New technologies such as chemical recycling show promising results, but they need further and deep investigation and up-scaling [21,22]. Currently, a great deal of effort is put on the redesign of multilayer flexible packaging to improve the recyclability in the existing collection, sorting, and recycling infrastructure [21]. Recyclable film solutions based on polyolefins (polyethylene (PE) and polypropylene (PP)) have already been achieved, as packaging waste material streams exist for these films, at least for mixed polyolefin streams [23–25]. As polyolefins already dominate flexible food packaging, the restriction of the use of certain polymers such as polyethylene terephthalate (PET) or polyamide (PA), which are not compatible with polyolefin recycling, is tangible [11,26–29].

A challenge is posed by the fact that enhancing the recyclability of multilayer films often goes hand in hand with a reduction of packaging efficiency. Current solutions on the market have been optimized over the last decades for resource efficiency and product protection. Reducing the complexity of these films would likely lead to thicker films and therefore heavier packaging solutions would be required [30,31]. This goes against the goals of a circular economy to reduce resource consumption and environmental impacts [7].

Multilayer flexibles by weight account for 10% of all packaging solutions [21]. The relative amount may not seem huge, but at least 40% of food products are packed in flexible solutions [32]. This induces the need to review redesign suggestions. Their comparison should allow the implementation of redesign approaches throughout and be supported by the European packaging branch.

A brief overview of the characteristics of multilayer flexibles, their contribution to sustainability, and their incompatibility in widely applied recycling technology make it possible to discuss the future design of this type of packaging. Research is necessary to bring recyclability and overall sustainability together in barrier packaging. Material combinations and recycling options with a clear benefit for the environment have to be developed.

The main objective of this review is to gather information on the benefits of multilayer flexible food packaging and show the negative recyclability trade-offs, especially for food technologists. The whole food-producing industry is under pressure to apply recyclable, at best circular packaging solutions throughout. To get there, we have to raise consciousness about what is considered as recyclable, and which negative effects might come along with redesign if we strive for circularity to enhance the packaging sustainability of specific products. This work mainly focuses on literature back to 2009, as the very first collection of hurdles (Figure 1) started in 2019, collecting evidence on a topic that gained momentum in the last decade.

2. Multilayer Flexible Food Packaging

Multilayer food packaging is a tailored packaging application. Beneficial properties of diverse materials are combined into one packaging solution. Flexible packaging like pouches, bags, lidding as well as rigid packaging like trays, cups, and bottles consist of variable material, sometimes combined in layers. Through the approach to combine

materials, these products offer technical and systemic strengths but also weaknesses along the life cycle stages, from production to use phase and end-of-life scenarios [13,19,33,34].

Figure 1 shows a collection of hurdles in relation to circular packaging, with a focus on multilayer flexible packaging, but not solely limited to it, encompassing literature research via Science Direct, Google Scholar, and Scopus, following the keywords “circular multilayer packaging”, “recycling flexible packaging”, “circular economy multilayer”, “multilayer recycling”, “polymer film food”, as well as secondary sources therein. Most mentioned hurdles, for example, the coordination along the supply chain, costs, and profitability, or the separation of materials, were collected and assigned to life cycle stages.



Figure 1. Hurdles to circularity of packaging focused on, but not limited to multilayer flexible packaging [7–9,13,14,19,21,26,30,33,35–76].

The improvement of barrier properties of packaging to control the food quality and safety is one main intention of combining materials. The permeability against relevant gases (oxygen (O₂), carbon dioxide (CO₂), nitrogen (N₂), water vapor (WV)), the transmittance of light, the barrier against grease or oil, as well as odors/aromas are important elements controlled by packaging. Depending on mainly fat, carbohydrates, and protein contents of food commodities, diverse permeability, and light transmission is acceptable to reduce negative changes in food quality or safety [77].

2.1. Production, Characteristics, and Application

The characteristics of multilayer flexible packaging are related to the molecular properties of the used materials. The polymer type, its crystallinity, branching, tacticity, and polarity influence the gas permeability and light transmission of the film. In order to reach the required packaging specifications, a combination of polymers or the introduction of other non-polymeric layers like paper or aluminium is frequently applied. This could be taken as a point for differentiation. Some multilayer flexible packaging solutions solely include polymeric layers. In other cases, also stiffer material like paper is included [77,78]. There is hardly any limit to imaginable combinations. Even 24 layers of material combined into one film are marketed, found in a cheese packaging solution through polarization microscopy [79].

The production of multilayer packaging film mainly relies on extrusion or lamination processes. While extrusion (coextrusion) is reported to dominate the production of multilayers for inter alia practicability and economic reasons, lamination is necessary to combine material that cannot be coextruded (for example the combination of polymers with non-polymers) [80]. Next to these two basic production methods, coatings allow the integration of even more beneficial properties to one packaging film, e.g., more functional layers. Whereas Selke and Hernandez [34] discussed metallization through vacuum deposition or SiO_x (silicon oxide) as examples for coating, Farris [80] refers to the application of melts and liquids. Recent developments in this area include the development of nanocoatings applied at levels below a critical concentration. Coatings can form a thin layer of material that can be deposited directly on a surface, applied in liquid form (film-forming solution/dispersion), by immersion, homogeneous spreading, or spraying [81,82]. In either

way, customization to enhance barrier properties is possible. As an example, polyolefins as non-polar polymers, show low water vapor but high oxygen permeability. To reduce the oxygen permeability, barrier layers are introduced [77].

Based on the quantity, polyolefins, PET, PS, and polyvinylidene chloride (PVC) are in general the leading polymeric materials in packaging applications in Europe [4]. Hässänen [79] stated in a case study, that in samples of purely polymeric multilayer flexible packaging, polyolefins, polyamides, and PET, followed by ethylene vinyl acetate (EVA) and ethylene vinyl alcohol (EVOH) dominate this type of packaging.

Polyethylene in general is used as a moisture barrier and for its toughness. low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE) are used as sealants, bonding layers, tie resins, adhesives, or structural layers. LDPE and LLDPE are found in several applications of flexible food packaging. Exemplary for bakery products, mono- or multilayer solutions including LDPE or LLDPE are widely marketed. With increasing barriers needs against moisture, high-density polyethylene (HDPE) is of higher interest in flexible packaging. The crystallinity of HDPE induces strength and stiffness, which allows its use as a structural layer. One prominent example of the use of HDPE in multilayer flexibles is cereal packaging, possibly in a combination with EVOH for the enhancement of the oxygen barrier [15,34,78,83,84].

Polypropylene in packaging is referred to as a moisture barrier, connected to benefits through its crystallinity. Reflected in the high melting point, it offers strength and is stable against exposures to higher temperatures. It shows clarity and stiffness and is also used as a sealant. Specifically in multilayer flexible packaging, it is frequently combined with PE. Metallization of PP is common for dry food products, requiring high oxygen barriers [13,15,34,78].

Polyamide is used for its mechanical properties, as an oxygen as well as oil, grease, and aroma barrier. Beneficial optical and thermal properties also lead to its use in multilayer food packaging. PA is also used in vacuum packaging or applications with modified atmospheres, for example in the food group of meat. Addressing possible polymer combinations with PA for meat, PE is common [15,34,77,83].

Oil and grease resistance is also known to be a beneficial property of PET, not only for PA. Its printability, thermal, mechanical as well as optical properties are the reasons for its use in multilayer packaging solutions, similarly for example in meat packaging [15,34,77,84].

In addition to the commonly used polymers in packaging (PE, PP, PET), EVOH and EVA can broaden the attributes of the bulk plastics [4]. EVOH finds use predominantly as a barrier material against oxygen, oil, and grease. In multilayer flexible packaging, it is widely used for food products, which in contact with oxygen, would face quality degradation. This includes a variety of possible applications, for example, snacks products. Contrary to metallization, it offers transparency [15,34,77,78]. EVA is used as a sealant and adhesive in multilayer food packaging. Furthermore, also its optical properties are said to promote its use. Applications in multilayer flexibles include inter alia combinations with polyolefins, for example in fresh convenience products like pre-cut salads [15,34,78]. Another adhesive used in packaging is Polyurethane (PU) [78].

Polyvinylidene dichloride (PVDC) is used for its barrier properties against oxygen and moisture, its optical properties, as well as a layer resistant to oil and grease. Its stiffness or softness is highly customizable. Food products in multilayers with PVDC are for example snacks. Its use in shrink films or stretch wraps, mono- or multilayer variations, can also be found [15,34,77,78].

Next to the above-specified polymers, aluminium is used to protect the food from moisture, oxygen, and light. Optical properties too account for its use in multilayer flexible packaging. One multilayer example with aluminium foil is packaging of food with sterilization steps in production, for example, ready-to-eat meals [15,34,77].

Coatings such as aluminium oxide (AlOx) and silicon oxide both facilitate highly enhanced barrier properties against oxygen and moisture while offering transparency at thicknesses in the nanometer range, compared to several micrometers for polymer-

based barrier layers. In multilayer flexibles, one can find for example combinations with PET. However, these coatings are discussed as being prone to cracks affecting the barrier properties, inter alia when used on flexible substrate materials. In general, the coatings can be used between layers to enhance the durability [13,51,77,78,80].

Furthermore, paper is a material commonly used in multilayer flexible food packaging, including non-polymeric layers. Depending on the paper, it can increase the rigidity/stiffness of multilayer packaging. Marketed solutions include combinations with PE, also EVOH or foil. Paper is beneficial in the context of printability and shows different possible haptics and optics compared to polymer packaging. It is also used as a light barrier [34,51,78,80].

Within this multitude of possible materials to combine, Kaiser et al. [13] gave an overview of widely used polymers in multilayer flexible packaging and their associated application purpose. A modified version is shown in Table 1. It points up that single multilayer structures are hard to exemplify as “typical”.

Table 1. Properties and materials in multilayer flexible food packaging. Modified after the work in [13] based on the works in [51,85,86].

Mechanical Stability	Oxygen Barrier	Moisture Barrier	Light Barrier	Tie Layer	Sealant
PO	EVOH	PO	Aluminium	PU	PO
PET	PVDC	EVA	Paper	PO	EVA
PS	PA	PVDC			PA
Paper	PET	Aluminium			PET
	SiOx				
	AlOx				
	PVOH				
	Aluminium				

Abbreviations: PO (polyolefins: polyethylene, polypropylene), PET (polyethylene terephthalate), PS (polystyrene), EVOH (ethylene vinyl alcohol), PVDC (polyvinylidene dichloride), PA (polyamide), SiOx (silicon oxide), AlOx (aluminium oxide), PVOH (poly vinyl alcohol), EVA (ethylene vinyl acetate), PU (polyurethane).

Other than the properties overview from Kaiser et al. [13], Morris [15] describes multilayer film structures depending on food products. Two multilayer flexible packaging solutions for meat products are illustrated in Figure 2, irrespective of layer thicknesses. To avoid oxygen ingress as one major quality determinant in processed meat products, PVDC and EVOH offer enhanced barrier properties in these examples. The use of PA for meat products is mainly referred as beneficial, on one hand for printability and on the other hand, thermal stability.

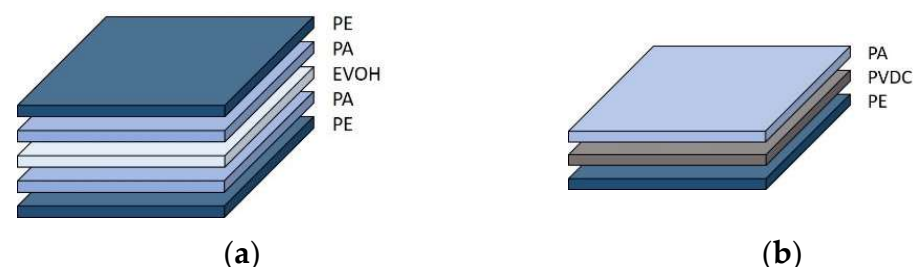


Figure 2. Two exemplary multilayer solutions for meat packaging: (a) 5-layered packaging solution and (b) 3-layered packaging solution. Abbreviations: PE (polyethylene), PA (polyamide), EVOH (ethylene vinyl alcohol), PVDC (polyvinylidene dichloride), PE (polyethylene). Figure adapted from the works in [15,87].

It is not only meat products that require enhanced barrier properties and profit from the use of combined materials; most products that are sensitive to water loss or uptake, oxygen ingress, light, and possible loss of aroma, require barriers to maintain quality over

long periods of shelf-life. The shelf-lives of, for example, specific dairy products, sweets and confectionary, cereals, or processed fruits and vegetables are related to barrier properties of the applied packaging solutions. Various degradation mechanisms (e.g., biological) can be slowed down by proper packaging, as the products are for example subjected to ripening, wilting and oxidation processes, just to name a few. Next to that, the microbiological safety stands in relation to gas/vapor permeability. Packaging can be one key within a hurdle concept, to keep food products at high quality [3,77]. However, the matching of product needs together with the possible barrier ranges of packaging material in Figure 3 shows, that often, one material alone, cannot serve the barrier requirements (water vapor transmission rate (WVTR)/oxygen transmission rate (OTR)) of specific products [88].

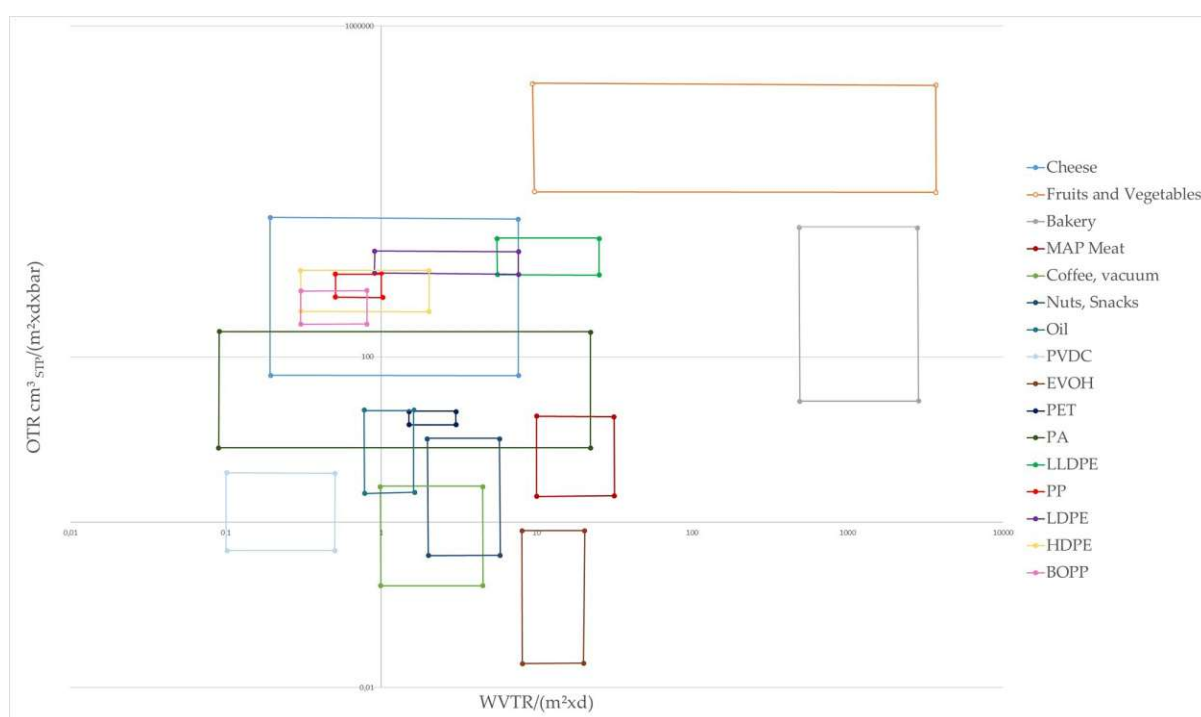


Figure 3. Water vapor and oxygen transmission rates versus the barrier requirements of food products and barrier ranges of polymers for packaging. Modified after the work in [88].

Robertson [1,3] and Morris [77] thoroughly describe the needs of specific food groups through associated quality determining intrinsic and extrinsic factors that can be influenced by packaging applications. They show the tolerable levels of permeation and describe the required storage conditions for a broad range of fresh as well as processed food products.

2.2. Efficiency and Sustainability—Trade-Offs Regarding Recycling

The protection of food through combinations of materials with desired characteristics is highly effective. Thin layers of materials in multilayer flexibles suffice to make use of beneficial properties. This allows the development of lightweight, efficient packaging solutions, which is related to questions of overall sustainability of packaging solutions. Mono-material flexible packaging can also be such lightweight solutions, however, having often inferior barrier properties. This goes hand in hand with packaging efficiency and effectiveness. The complexity of the material can be reduced. Still, thickness and therefore weight increases have also negative environmental consequences. The main question is, what the environmentally favorable solution is when overall, a resource reduction is the goal. In the discussion about multilayer versus mono-material, the focus lays on recyclability trade-offs. One less complex solution might show better recyclability; however, it is probably linked to higher material inputs what is neither environmental favorable [30,51].

In Wellenreuther [16], the comparison of environmental effects (energy demand, raw material demand, and waste) connected to multilayer flexible pouches versus rigid solutions shows beneficial properties in the context of efficiency on the side of the multilayer solution. Branch reports and communication charts highlight optimized product-to-packaging ratios stated as, at a maximum, 10 times lower compared to rigid packaging solutions. In the longer term, this is related to benefits in transportation (weight, space) and in general, a reduction of used associated resources [32,89]. The Flexible Packaging Association [89] summarizes these factors as “beneficial life cycle metrics” of flexible packaging, referring to a reduction of water use, fuel use, and a reduced carbon footprint of products. According to Flexible Packaging Europe [32], flexible packaging makes on average less than 10% of a packaged food products CO₂ footprint. Despite these benefits that are often highlighted through industry near associations, which is part of critical voices arguments, it is clear that the optimal point of packaging between the protection of used resources in food and the resources used for the packaging material itself is where the least possible environmental impact occurs. Food products are expected to keep their quality until consumption and therefore prevent food losses and waste. Parallel, quantitative packaging material input is kept at a low level [2,90]. Both aspects are of high importance in reaching sustainable production and consumption. This is shown by projects and publications analyzing and evaluating the effects of zero packaging as well as the environmental burden of unconsumed food residues. These scenarios clearly show that the protection of the filling good is key to sustainable consumption and still, the input of packaging material should be kept at a minimum. This is an important argument/feedback loop to make use of the highly improved, customized, and often combined material flexible packaging solutions [91]. Efficiency and low carbon footprints are the major benefits of multilayer packaging in comparison to other packaging solutions [14,30,51].

However, the weak spot of multilayer packaging is, that it is difficult to recycle, and its recycling rate is very low [13,18,19]. Ellen MacArthur [21] estimated in 2017 that 26 weight percent of flexible packaging is multi-material, representing 10% of global plastic packaging. Worst case, these 10% are lost for the aspired circular economy, as with the current infrastructure, the properties of the materials cannot reach the ones of virgin material again.

Currently applied mechanical recycling technology consists of shredding, sorted, and washed plastic input material and its re-granulation [4]. The incompatibility/immiscibility of diverse plastic materials in the melting process limits this approach to pure waste streams/fractions, so that many material combinations present in multilayer materials cannot be processed, due to different melting points and thermal stability [43,92]. These material combinations in flexible packaging are therefore considered as non-recyclable with the current sorting and mechanical recycling infrastructure [12]. The incompatibility of polymers in thermal processes is not a new discovery as already described by Nickel [20] more than 25 years ago (Table 2). Describing the incompatibility, differences can be found in the literature [20,93]. However, redesigning to fit the existing infrastructure is currently an absolute priority [7–12].

Although compatibilizing agents can partly solve this problem, they are only used for some applications, inter alia due to high costs [19,48,94]. Uehara et al. [94] described for example the use of maleic anhydride and glycidyl methacrylate. To enable the blending of polymers by compatibilizers, the unknown composition of the material stream is another obstacle to be faced [95]. Pinzón and Saron [96] showed for example the blending of post-industrial LDPE multilayers with up to 20% PA through compatibilization. Furthermore, the potential of blending PET/PE multilayers with compatibilizers was already assessed and described as useful, considering the recyclability of incompatible polymers [94]. More recently, Jönkkäri et al. [92] tested the compatibilization of input material from post-consumer multilayers with virgin LDPE, excluding packaging with non-polymeric layers (paper, cardboard, aluminium). Secondary material thereof is described to be suitable for applications not requiring specific optical properties or high thermal

stability. Without the use of compatibilizers, the extrusion of different types of polymers shows mainly incompatibility towards homogeneous blends and the deterioration of visual and mechanical properties of the secondary material [97].

Table 2. Compatibility of polymers in recycling. Modified after works in [20]. * indicates differences in the comparison to the works in [93,98].

	PE	PP	PVC	PS	PA	PET
PE	+	~ (+ *)	—	—	~ (— *)	—
PP	~	+	—	—	~ (— *)	—
PVC	—	—	+	~ (— *)	—	—
PS	—	—	—	+	~ (— *)	~ (— *)
PA	—	—	—	~	+	~
PET	—	—	—	~ (— *)	~	+

+ (compatible), ~ (partly compatible), — (incompatible). Abbreviations: PE (polyethylene), PP (polypropylene), PVC (polyvinylidene chloride), PS (polystyrene), PA (polyamide), PET (polyethylene terephthalate).

Furthermore, the available waste management infrastructure in collection and sorting is country-specific and influences the recyclability of food packaging [10]. Flexible packaging itself is a heterogeneous waste fraction, which is, although dominated by polyolefins, frequently accompanied by other polymers and non-polymeric material [62,78]. One other reason for the heterogeneity is due to the collection in mixed fractions or “undifferentiated garbage” [14]. Regarding specific material fractions of collected flexible packaging, PE dominates, whereas flexible PP and PET, according to the flow charts in van Eygen [23], are not separately considered in the film category for the widely available mechanical recycling processes. Marrone and Tamarindo [14] supports this perspective: not only multilayer flexibles but also mono-material films are not collected consistently.

Referring further to the lightweight character of flexible packaging, proportionately large amounts of impurities from food residues accompany collected post-consumer flexibles. This leads to possibly high ratios of impurities per packaging weight [43,60,69]. Irrespective of the already high level of contamination through the diverse materials used, major cleaning efforts might be necessary prior to extrusion processes [50,59,64].

Moreover, the typical sorting procedures are not widely optimized for a high-quality sorting of flexible films, although NIR detector (near-infrared) technology could detect material layers [30,97,99]. That flexible packaging is collected separately, then sorted and recycled, therefore depends on economic considerations, related to the mentioned hurdles [19,51]. New approaches to optimize the sorting for this fraction are sought, as this process is a vital pre-request to enhance recyclability and circularity [21].

3. Discussion

As the situation described above shows, multiple criteria are leading to a strong tendency in the European Union, to substitute non-recyclable multilayer barrier films with recyclable solutions based on polyolefins. Taken together, three main factors are found to build the core of the redesign suggestions. The first, for sure, is the mentioned ban of all non-recyclable plastic packaging from the European Market from 2030 on and the even stricter commitments from parts of the food and packaging supply chain [5,100]. The second determining factor is the currently available waste management infrastructure in collection, sorting, and recycling. As many material combinations are incompatible, this prevents the recycling of polymer combinations such as PET or PA with polyolefins, as the layers, in general, are not separated before the melting process [4,13,18–20]. This brings economic factors into play. The waste stream of post-consumer flexibles is dominated by polyolefins, with PE and PP constituting more than 60% of the weight of flexible packaging [26]. The level of other polymer types is small and therefore the establishment of separate recycling streams for PET or PA-based films is not profitable [4,48,49,66]. Decontamination steps to clean plastic waste from residuals such as food, and the small size of many flexible packaging, makes sorting even more demanding [21,84]. In addition, as incineration is

widely accessible, recycling of this fraction is often not profitable [5,7,60,64]. It seems beneficial, that the substitution of polymers incompatible with the mechanical reprocessing of polyolefins could lead to higher market shares of polyolefins, which might increase the efficiency and the economics of the recycling process of flexibles, as the variability of material might find reduction [45,46,70].

3.1. Redesign and Trade-Offs to Fit the Actual Recycling Technology

Suggestions to reduce the material variability to mainly polyolefin material, tolerating EVOH, metallized aluminium layers as well as coatings to a certain extent, have been published widely [10–12,27–29,101–103]. That polyolefins show the best compatibilities with other polyolefins entails the theoretical basis for published redesign options. Moreover, it is possible to blend different grades of post-consumer polyolefins in certain percentages, however, it results in lower quality recyclates. The content of polyolefins should at least reach 90% to be considered as mono-material, which is seen as beneficial composition for recycling [10]. Combinations of polyolefins with other polymer types such as PET or PA are not considered as recyclable in traditionally applied mechanical recycling processes [11,27–29]. Looking at the available infrastructure in Europe, the incompatibility of most polymers in traditional approaches of mechanical recycling and the complex sorting of multilayer flexible packaging, the step to return to already recyclable solutions seems obvious.

Economies of scale for potential valorization are in favor of polyolefins as they dominate packaging applications [4,101].

Considering the need for enhanced barrier properties in the substitution of multilayers, the consensus on redesign suggestions includes the following material combinations:

- mono-polyolefins with EVOH,
- mono-polyolefins with SiOx or AlOx,
- mono-polyolefins metallized [10,11,27–29,103].

The details on how combinations should look vary slightly between the guidelines. Some suggestions are more restrictive than others. The optimal flexible packaging from the recycling point of view is unpigmented/transparent mono-polyolefin material. The use of EVOH and SiOx and AlOx layers does not significantly reduce the quality of secondary materials if these contaminations do not surpass certain critical thresholds. Aluminium laminated and metallized does lead to greying of the recyclate and is therefore not considered as an optimal barrier material to choose. Nevertheless, metallization is mostly tolerated to a certain extent. Possible negative interactions with sorting infrastructure are addressed and discussed in guidelines what leads to stated limitations or investigation needs, for example in cases of surface metallization. The combination of polyolefins with PET, PS, Polylactic acid (PLA), paper, PVC, PVDC, and PA is not recommended. However, you can find statements that PA layers and PVDC coatings as barrier material are under investigation [10,11,27–29]. Table 3 shows slight differences in recommendations for barrier layers for polyolefin films between two popular guidelines. Where one excludes most combinations of polyolefins with common barrier materials, the other allows more options according to weight percent in a certain packaging solution. One interesting point is that EVOH content is not fully harmonized. The information on EVOH levels tolerated in PP film is in one guideline stated as 5% (Ceflex), whereas Recyclclass lists it in “conditional-limited compatibility” in tables of 2020 as “may be suitable”. As the recommendations for EVOH changed quite drastic from accepted 10% to 5% to 1% and in the meantime even “no-low compatibility” (at least for rigid PP packaging—until 2021— back to 6% for specific cases, questions on further developments arise in the case of PP film [12,104–107].

Against this background, Table 4 shows the remaining materials to be used in future multilayer packaging design and highlights design restrictions with regard to mechanical and barrier properties. Future solutions for multilayers are technically still not only one material. However, combinations can be categorized as mono-material, if the amounts of barrier materials stay under tolerated levels. It is evident that, in comparison to Table 1, only a few materials remain for recyclable design.

Table 3. Tolerated materials in multilayer barrier flexible packaging modified after the works in [10,11,27–29].

	EVOH	Metallization	SiOx	AlOx	Acrylic Coatings	PVOH	PVDC	References
PP-film	Conditional–limited	Conditional–limited	Fully compatible	Fully compatible	“any other barrier” no–low compatibility	No–low compatibility		[28,29]
	<5%	Compatible with PE or PP mechanical recycling	<5%	<5%	<5%	<5%	Further investigation	[10]
PE-film	<5%	Conditional–limited	Fully compatible	Fully compatible	“any other barrier” no–low compatibility	No–low compatibility		[11,27]
	<5%	Compatible with PE or PP mechanical recycling	<5%	<5%	<5%	<5%	Further investigation	[10]

Abbreviations: PP (polypropylene), PE (polyethylene), EVOH (ethylene vinyl alcohol), SiOx (silicon oxide), AlOx (aluminium oxide), PVOH (poly vinyl alcohol), PVDC (polyvinylidene dichloride).

Table 4. Materials suggested for recyclable multilayer flexible food packaging. Modified after the works in [10,11,13,27–29,51,85,86].

Mechanical Stability	Oxygen Barrier	Moisture Barrier	Light Barrier	Tie Layer	Sealant
PO	EVOH	PO	Aluminium (metallised)	PU	PO
PET	PVDC	EVA	Paper	PO	EVA
PS	PA	PVDC			PA
Paper	PET	Aluminium (metallised)			PET
	SiOx				
	AlOx				
	PVOH				
	Aluminium (metallised)				

Strikethrough indicates design restrictions. Abbreviations: PO (polyolefins: polyethylene, polypropylene), PET (polyethylene terephthalate), PS (polystyrene), EVOH (ethylene vinyl alcohol), PVDC (polyvinylidene dichloride), PA (polyamide), SiOx (silicon oxide), AlOx (aluminium oxide), PVOH (poly vinyl alcohol), EVA (ethylene vinyl acetate), PU (polyurethane).

The trends for design for recycling also induce trade-offs concerning the substitution of specific material properties, the barrier requirements, the related shelf-life as the further connected products sustainability [21,30,73]. Due to the pressure to reduce EVOH-content and metallization to avoid quality impairment in secondary material properties, the development of novel recyclable barriers, mainly against oxygen, is needed. It must be assured, however, that the redesigned flexible packaging protects the food correctly and that reduced shelf-life does not result from inferior oxygen or water vapor barriers. Many confectionary products for example hardly tolerate the ingress of water vapor or oxygen resulting in rancidity and loss of crispness [21,77].

Thus, a strong research need is present to develop recyclable barriers substituting EVOH and other barrier polymers such as PA and PVDC. A clear tendency is visible that the percentage of allowed EVOH in recyclable packaging solutions is one focus of discussion, as could be seen in the case of rigid PP packaging in 2020 and 2021 [105,107]. The range of currently available barrier options is small with SiOx and AlOx, and most SiOx- and AlOx coatings are currently neither generally suitable for sterilizable packaging nor deep drawing applications, which is of importance in the sector of, for example, convenience foods [77].

The focus on mostly mono-polyolefins with certain tolerated barrier layers for enhanced recyclability of multilayer flexibles should not lead to higher resource consumption, as this would increase the environmental burden. This is particularly important in the specific case of flexible packaging where in recent decades, lightweight solutions have been developed and optimized [30,31].

The elimination of PA, PET, and other polymers in this context also induces the need for further developments of satisfactory substitutions for puncture-resistant materials. Another point to consider is to optimize the sealability of PP-films. The combination of PET on the external side and polyolefins as a sealing layer on the internal side has been used very often. PET (or PA) shows higher melting points than polyolefins, which in general allows good sealing properties [13,15,83].

3.2. Harmonization of Recyclability Guidelines in Europe

Multilayer flexibles are considered as a sustainable packaging solution due to low resource consumption and low carbon footprint but are being difficult to recycle with the collection and recycling infrastructure currently in place. Thus, there is this clear and urgent need for a redesign that balances recyclability and sustainability [16,17,21,84]. The switch from non-recyclable multilayer flexible to easily recyclable, predominantly mono-

material packaging solutions, within the intention to increase recycling rates, however, leaves questions for discussion: If all rigid packaging (excluding beverage packaging) was 100% recyclable but substituted by non-recyclable flexible packaging, the global warming potential would decrease [17]. Questions arise referring to the intended goals of packaging redesign, underlying the increase of recycling rates.

Although replacing one material with another is already not a simple task, employing the best material for each food system is also still necessary. This is a true challenge that only when addressed, will result in its implementation. However, there are already commercial applications of flexible packaging available, that seem to close the gap between recyclability and enhanced barrier needs through, for example, improved orientation processes of mono-polyolefin films, which can be found in web search.

Still, currently, recycling is not the best solution for all types of packaging, if enhanced sustainability is the target of increased recycling rates [25].

To compare future packaging options, a holistic sustainability assessment is necessary. The harmonization of guidelines must build the basis for global standards. It should proactively include changes in shelf-life due to changes in barrier properties and therefore food waste as well as aspects of littering. Holistic and harmonized approaches are vital for the sustainability assessment and the perspective of a common market. The understanding of recyclability must be the same, at least in all European countries. The implementation of a redesign for recyclability needs the support of the packaging industry. This includes the improvement of collection, sorting, and recycling infrastructure to allow a high-quality secondary material production [21,22,108,109]. The discussion currently shows a highly Eurocentric perspective, however, other global regions like the US and Australia are already following [110].

3.3. Novel Recycling Technologies and Secondary Material for Food Contact

Next to the option to fit packaging design into existing infrastructure, other recycling technologies or collection logistics can cope with multilayer films/material combinations. The developments in chemical recycling could lead more quickly to improved secondary materials. Delamination technologies of the single materials from multilayers as a pre-treatment is promising, as it could allow the further use of traditional mechanical recycling. Developments include inter alia

- chemically separating the layers of multi-material,
- recovering the aluminium content of multilayer food packaging by microwave-induced pyrolysis, and
- separate collection of specific multilayers for reggranulation with compatibilizers [13, 42,75,92,95,111].

Nevertheless, these exemplary solutions are either in development or not yet widely introduced, and thus, the focus on the available instead of new recycling technology, still asks for the development of mono-material solutions [13].

Even if the redesign and recycling of flexible packaging becomes successful to a high degree, closing the material cycle faces another obstacle. Apart from a very few exceptions such as HDPE from milk bottles, secondary post-consumer polyolefins are currently not permitted for use in food contact materials [112]. Due to a more complex decontamination in comparison to PET, as well as degradation in reprocessing, polyolefins lag behind as available secondary material. Cecon et al. [113] resumed the hurdles, but also new approaches in recycling technologies that could enable the use of polyolefins as secondary material in food contact in the future.

Still, in the current infrastructure, this above all is one knock-out criterion inhibiting the attempts to achieve truly circular flexibles for food packaging at present.

4. Conclusions

Multilayer flexible packaging is efficient. It combines the properties of polymers and non-polymeric materials to thin, lightweight packaging solutions for foods with and

without barrier needs. The main problem is that it is rarely recycled in the existing waste management infrastructure. This is caused by multiple circumstances. The variability of used materials, the collection infrastructure, the complex sorting, and high levels of food residues outline the situation. Furthermore, the focus on mechanical recycling through combined processing complicates the situation. New solutions in recycling technology exist but are not yet available on a larger scale. This leads to a concentration on mono-material solutions to fit into the existing recycling infrastructure and diminishes the material choice to overcome thermal incompatibilities. The maximum tolerated levels of barrier materials are widely discussed and are in the process of being reduced. The substitution of a specific material is challenging, as only a limited number of barriers are available. In relation to the main purpose of packaging, the products' protection, this could result in negative side effects. A reduction of food shelf-life, higher packaging weights, and derived increased environmental burden are imaginable consequences that need to be considered when taking steps towards the goal of packaging redesign for holistic sustainability.

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Review

Cereal and Confectionary Packaging: Background, Application and Shelf-Life Extension

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Abstract: In both public and private sectors, one can notice a strong interest in the topic of sustainable food and packaging. For a long time, the spotlight for optimization was placed on well-known examples of high environmental impacts, whether regarding indirect resource use (e.g., meat, dairy) or problems in waste management. Staple and hedonistic foods such as cereals and confectionary have gained less attention. However, these products and their packaging solutions are likewise of worldwide ecologic and economic relevance, accounting for high resource input, production amounts, as well as food losses and waste. This review provides a profound elaboration of the status quo in cereal and confectionary packaging, essential for practitioners to improve sustainability in the sector. Here, we present packaging functions and properties along with related product characteristics and decay mechanisms in the subcategories of cereals and cereal products, confectionary and bakery wares alongside ready-to-eat savories and snacks. Moreover, we offer an overview to formerly and recently used packaging concepts as well as established and modern shelf-life extending technologies, expanding upon our knowledge to thoroughly understand the packaging's purpose; we conclude that a comparison of the environmental burden share between product and packaging is necessary to properly derive the need for action(s), such as packaging redesign.

Keywords: food packaging; cereals; confectionary; bakery; food quality; shelf-life; sustainable packaging; active and intelligent packaging; modified atmosphere packaging; vacuum packaging

1. Introduction

Over the past decades, global awareness about environmental, social and economic sustainability challenges, as well as the need for immediate action to limit their negative

short- and long-term impacts, has risen considerably. With regard to environmental sustainability, challenges encompass, but are not limited to, the use of resources, land, water, energy, and generation of associated emissions and waste. In order to facilitate the transition towards a sustainable future, several (inter)national goals, commitments, and legal bases have already been initiated or applied. These include, for instance, the Paris Agreement on climate change and the United Nations Sustainable Development Goals (SDGs) on a global scale, the European Green Deal including the New Circular Economy Action Plan, as well as the Farm to Fork Strategy on European level and numerous implementations into national law systems [1–6].

Regarding food, it is well-agreed in the scientific community and beyond, that a great share of negative environmental impacts such as global anthropogenic greenhouse gas emissions or waste originate from food systems [7–9]. These systems are defined as the whole of actors and activities involved, from production to the disposal of food products of different origins, as well as herewith associated natural, social, and economic environments [10]. Moreover, they are composed of subsystems (e.g., farming) and connected to other systems (e.g., energy). A complex network in which changes (e.g., policies) made in one sector may also affect others. Against this background, different international efforts have been taken to achieve sustainable food systems, which will provide present and future generations with a secure supply of safe food [11].

Packaging is strongly associated with food, allowing, amongst other functions, containment, protection, and transportation of contents, and thus can be seen as an integral part of food systems [12,13]. Nevertheless, nowadays it is the subject of intense debates and even stricter legal requirements, mainly due to massive circularity gaps including, for example, unsatisfactory end-of-life scenarios such as limited recyclability or (marine) litter [14,15]. However, the simple omission of packaging is hardly possible, since a well-chosen packaging system frequently shows positive (indirect) effects on the total environmental sustainability of a food system by, for example, reducing food losses and food waste or increasing transport efficiency [16]. Therefore, when aiming at developing sustainable packaging solutions, it is important to apply a holistic and interdisciplinary approach over the whole life cycle of both food and its corresponding packaging [17].

Since packaging offers a service to the food product and does not fulfil an end in itself, it is often worth starting a packaging development or a redesign process from the food perspective. By gaining profound knowledge of the food product itself, together with the intrinsic and extrinsic factors that affect quality along the food supply chain, further packaging requirements can be defined and considered in the innovation process [12,13,17].

Due to their high environmental impact, the focus of research and development activities is often on (animal protein-rich) foods such as meat or milk [18–20]. Despite their high nutritional value that shouldn't be underestimated, cereal and confectionary products are rather underrepresented, regarding their impact in health but also in economic and environmental sustainability [21–27]. For instance, about 50% of daily required carbohydrates are consumed through bread in industrialized countries. Further, cereals are also an important source of proteins, minerals, and trace elements [28]. Expressed in figures, retail sales of bread alone were expected to reach about 92 billion euros in Europe in 2021 [29]. On the other hand, confectionary products reached a production volume of 14.7 million tons with an annual turnover of 60 billion euros along with an export value of 9.2 euros and an import value of two billion euros in Europe (EU28) in 2019 [30].

In more detail, the present review aims at building a comprehensive basis for future sustainable packaging development activities in the area of cereal and confectionary products by:

- Presenting relevant information on packaging functions and properties of packaging materials,
- detailing product group specific decay mechanisms and frequently used packaging solutions,
- and highlighting packaging-related shelf-life extension technologies.

The text is therefore structured as follows: After the introduction, a general background on food packaging is discussed, followed by product group specific decay mechanisms and packaging solutions. Finally, packaging measures that can extend the shelf-life are presented (see also Figure 1).

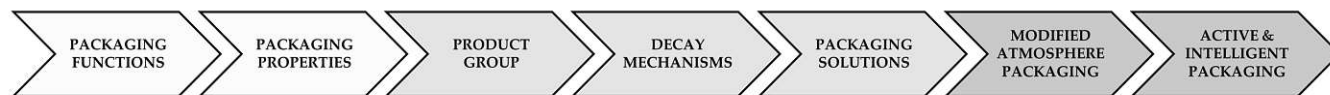


Figure 1. Outline of discussed topics, based on the review's aims.

2. Packaging

2.1. Packaging Functions

No matter how diverse individual products and packaging solutions may be on the market, it is well-agreed in relevant literature that the main functions of packaging can be broken down into a few. Next to the concept of primary and secondary functions, where the former describes in particular the technical functions like storage and transport, and the latter describes functions related to e.g., communication, a more holistic concept is frequently mentioned in the packaging literature. This concept describes the four basic functions of food packaging as (i) containment, (ii) protection, (iii) convenience, and (iv) communication [12,13,31–33].

Although the containment function is often overlooked, it can be considered one of the most essential, since it prevents product loss and contamination and facilitates storage, transportation, and distribution. There are only a few exceptions, where containment and thus packaging is not needed. Such examples are relatively large, chunky products that are often regionally produced and consumed within a short period of time or that show long shelf-life [12,13,31].

The protection function is often recognised as well as highlighted and can be indeed considered as the most important aspect of packaging. It limits or excludes intrinsic as well as extrinsic physical, chemical, and biological factors that may have negative influences on the quality of the respective food product. In the best case, the packaging is even capable of extending the shelf-life of the product. Therefore, it is of upmost importance to match the food product's properties and requirements along the supply chain with packaging to achieve optimal results. Both under- and over-packaging should be avoided since this may result, on one hand, in food losses or waste and, on the other hand, in excessive packaging [12,13,31].

Further, the convenience function refers to the practical aspects or user-friendliness of packaging. As an example, easy-to-open or -empty, microwave- or heat-able, resealable, or portion packaging can be named. These features are more and more implemented in package designs, since they allow to specifically address target groups (e.g., children, elderly, single-households, on-the-go lifestyle) and therefore frequently influence the market success of a product [12,13,31].

Last but not least, the communication function allows for information transfer and marketing. While the former allows to display legally required (e.g., product name, ingredients, shelf-life), necessary (e.g., barcodes), or voluntary (e.g., certificates, cooking recipe) information, the latter enables to transfer an often unique brand image (e.g., form, colour, shape), which may be of great recognition value [12,13,31].

It is worth mentioning that a successful package on the market does not only need a strong product in terms of quality but also an effective packaging, which in a clever way combines the above described four functions of containment, protection, convenience and communication. Otherwise, it may result in a short-term success (weak product and effective packaging), a situation where the potential is not achieved (strong product and ineffective packaging), or even failure (weak product and ineffective packaging) [31].

2.2. Packaging Properties

From a technical point of view, the functions containment and protection are closely linked to the right selection of packaging materials which consequently poses a key decision in the development process. The available material classes cover mainly glass, metal, paper/board, (bio)plastic, as well as composite materials (laminated, coextruded, blended). Composites can consist of two or more components combined to form, for example, multi-layer materials (e.g., plastic-coated cardboard) which frequently show superior functional properties (e.g., barrier) and reduced weight [31], but on the downside also reduced recyclability [34,35]. Touching upon the topic of recyclability, many packaging solutions face obstacles, if it is at the stage of collection, sorting, or in general limited technical recyclability. Not even the use of mono-materials guarantees actual recycling, as it is the case for PET trays versus PET bottles (bottles are highly likely to be recycled). On the other hand, specific combinations of compatible materials, even high barrier films, for example, metalized polyolefins, might be considered recyclable in the appropriate infrastructure [36,37]. Summing up, it can be stated that each of the named materials show advantages and disadvantages (see Table 1) and the decision for a specific material must be based on the prevailing requirements (e.g., product, supply chain, use, end-of-life). Support is often provided by material specifications and declaration of compliance documents. However, it is recommended to test the materials in question under respective conditions by means of a field or laboratory test. This ensures that deviations from the target value can be recognized at an early stage in the development process [12,13,31,38,39].

Table 1. Overview of the properties and applications of most widely used materials for packaging.

Packaging Material	Barrier			Heat Seal-Ability	Mechanical, Physical and Chemical Properties	Application	Reference
	Oxygen	Moisture	Light				
Plastic	Very low	Low-density polyethylene (LDPE)	Low	Yes	Toughness, flexibility, resistance to grease and chemicals, temperature range $-50 - +80^{\circ}\text{C}$	Bags, flexible lids and bottles	[12]
		High					
		Linear low-density polyethylene (LLDPE)			Toughness, extensibility, resistant to grease, temperature range $-30 - +100^{\circ}\text{C}$	(Strech) wrap	
		High-density polyethylene (HDPE)	Extremely high	Yes	Toughness, stiffness, resistance to grease and chemicals, easy processing and forming, temperature range $-40 - +120^{\circ}\text{C}$	Bottles, cardboard liners, tubs, bags	
		Polypropylene (PP)	High		Moderate stiffness, strong, resistant to grease and chemicals, temperature range $-40 - +120^{\circ}\text{C}$	Bottles, cardboard liners, tubs, microwavable packaging, bags	
Glass		Polyethylene terephthalate (PET)	Low	Yes	Stiffness, strong, resistance to grease and oil, temperature range $-60 - +200^{\circ}\text{C}$	Bottles, jars, tubs, trays, blisters, films (bags and wrappers)	[12,40]
	Transparent	Absolute	Low	No	High temperature and pressure stability, brittle, chemical resistance, microwave-able	Bottles, jars	[12,40–42]
	Green		Good				
	Brown		High				
Metal (aluminium, tinplate, tin-free steel)		Absolute		No	High temperature stability	Bottles, cans, tubs, caps	[12,40]
Paper and board		Extremely low	High – extremely high	No	Mechanical stability	Boxes, liners	[12,40,41]

The key properties of packaging materials of interest are physical and mechanical strength, barrier, migration, as well as hygiene. Regarding the physical and mechanical strength, it can be noted that static as well as dynamic stress challenges the packages along the supply chain from packing, storage, and transport to consumer use. Examples for static stress are stacking and increased pressure (vacuum or modified atmosphere packaging—MAP), as well as pointed or angular products. Dynamic stress on the other

hand may be caused by the production process (e.g., printing, forming, filling) or transport (e.g., vibration). The right selection of the material, but also the shape of the packaging, therefore plays a vital role in the success of a primary, secondary or tertiary package (see also Figure 2) [12,13,38,43].

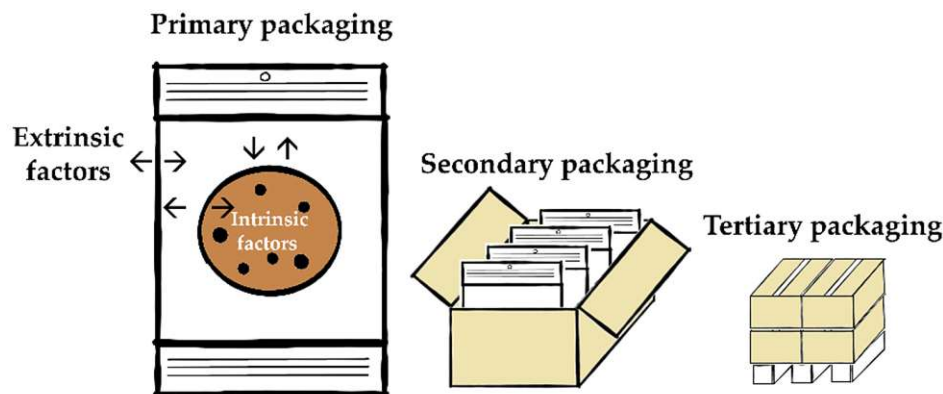


Figure 2. Schematic packaging levels of fine bakery ware (example: chocolate chip cookie), adapted from [12,13,31].

Another key characteristic of materials to be considered is the barrier property. Especially, the barriers against oxygen (O_2) and water vapour (H_2O) transmission are determinant since these can exhibit significant influences on product quality and safety. The former for example can promote oxidation reactions, loss of quality-determining ingredients (e.g., vitamins), and growth of spoilage and pathogenic microorganisms. The latter can influence structural changes such as hardening, agglomeration, or softening of products and promote microbial growth (see Section 3.2). Additionally, barriers against carbon dioxide (CO_2) and nitrogen (N_2), which are the often-used gases in MAP, as well as aroma components, are decisive. Depending on the use case and product requirement, material with an appropriate barrier, i.e., permeation characteristics, should be chosen. Complementary to the above described, the barrier against other substances like fat may be considered [12,13,38,44]. Furthermore, electromagnetic radiation (light) has to be taken into consideration, since oxidative or other chemical reactions as well as structural changes may be induced or accelerated, thus impairing product quality [12,41,45–47].

What is important regarding chemical safety is the migration of compounds from packaging materials into the food. Migration describes the mass transfer of substances from a packaging material into the food product or vice versa. As for the permeation, the driving force behind this phenomenon is the concentration gradient. Additionally, factors such as material, storage temperature, relative humidity, and time play an influencing role [38,39,48].

Against common perception, possible migration of, for example, additives, are not only present in plastic packaging materials. Migration can also be found in other (primary or secondary (recycled)) materials such as glass (e.g., silicates), metal (e.g., corrosion of the metal, additive migration from organic coatings), paper and board (e.g., fillers, contaminations like mineral oils) and may, next to the packaging material itself, find its origin in packaging aids (e.g., labels, closures, coatings) or even set-off processes (e.g., printed and role-to-role processed or stapled materials) [12,13,38]. To ensure safety of food contact materials (including packaging), several legal requirements are in place in the European Union and beyond [39,48–53]. It should be noted that in addition to the migration from the packaging material to the food, migration processes from the food to the packaging can also be observed. This process is also called sorption or scalping and may cause alteration of the product (e.g., flavour loss) as well as reduced reusability of packaging containers due to the re-release of previously migrated substances [12,13].

In addition to chemical safety, packaging materials also play a role in the hygiene and biological safety of food products. Depending on the material used, a barrier against

contamination, microorganisms and animals (e.g., food pests) can be given. To achieve a high standard of hygiene, it is crucial to utilize materials that pose a sufficient barrier and that are free from contamination. Further, it is important to use materials that do not support microbial growth. Lastly, it is important to recognise, that most packaging materials carry a low microbial count when freshly produced due to often high process temperatures (e.g., melting of glass). So, the microbial burden is often a result of recontamination during finishing processes, storage, and application, which can sometimes make it necessary to implement decontamination measures prior to the filling process [38,54].

3. Cereal and Confectionary Products

Against the above-summarized background, food packaging can be seen as a mediator between product and the environment, capable of significantly influencing food quality, safety, and shelf-life [12]. Regarding cereal and confectionary products, the following text aims at summarizing and categorizing the product group, presenting an overview of category specific decay mechanisms, as well as respective packaging solutions.

3.1. Categorization of Cereal and Confectionary Products

As shown by Belitz et al. [28], cereal and confectionary products cover a wide and diverse range of food products. They summarized different products in two groups, namely cereals and cereal products. The first group is mainly made from important staple foods such as wheat, rye, rice, barley, millet, oats and corn. These are used to produce different kinds of products. For example, Smith et al. [55] made the following division: "...unsweetened goods (bread, rolls, buns, crumpets, muffins and bagels), sweet goods (pancakes, doughnuts, waffles and cookies) and filled goods (fruit and meat pies, sausage rolls, pastries, sandwiches, cream cakes, pizza and quiche)".

The group of confectionery products are mainly sugar-based products that, in contrast to cereal products, are predominantly consumed as a "treat" rather than a full meal. These include products such as chocolate, hard candy, and pralines [56,57]. In addition to sweet confectionery, savory snacks can also be found on the market. According to Robertson [13], these include "...a very wide range of products, including potato and corn chips, alkali-cooked corn tortilla chips, pretzels, popcorn, extruded puffed and baked/fried products, half-products, meat snacks and rice-based snacks" [13,58]. In addition to that, there are combinations of sweet and savory snacks like chocolate covered pretzels or sweet popcorn [59].

In the available literature and other sources including statistics, codices and regulations, different approaches to properly (sub)categorize cereal and confectionary products can be found [59–61]. Taking a food and shelf-life perspective, it is reasonable to cluster products that exhibit similar characteristics or spoilage mechanisms. In the European Union, where there is a strong food law [62] in place, a comprehensive list can be, for example, found in the guidance document to Annex II of regulation (EC) No 1333/2008 on food additives [59,63]. For the field of cereals and confectionary, the four groups of confectionary, cereals and cereal products, bakery wares, and ready-to-eat savories and snacks are of special interest. While confectionary is further subdivided into cocoa and chocolate products, other confectionery products including breath freshening micro-sweets, chewing gum as well as decorations, coatings and fillings, cereals and cereal products are divided into whole, broken or flaked grain, flours, milled products and starches, breakfast cereals as well as pasta, noodles, batters and pre-cooked or processed cereals. For bakery wares, a classification into bread and rolls and fine bakery wares is given. Last but not least, savories and snacks are broken down into potato-, cereal-, flour- or starch-based snacks as well as processed nuts. For each of the above-mentioned subgroups, a comprehensive list of product examples is given in the mentioned document [59]. The present review adopts this categorization approach and structures relevant information on cereal and confectionary shelf-life, packaging, and shelf-life extension strategies accordingly (Figure 3).

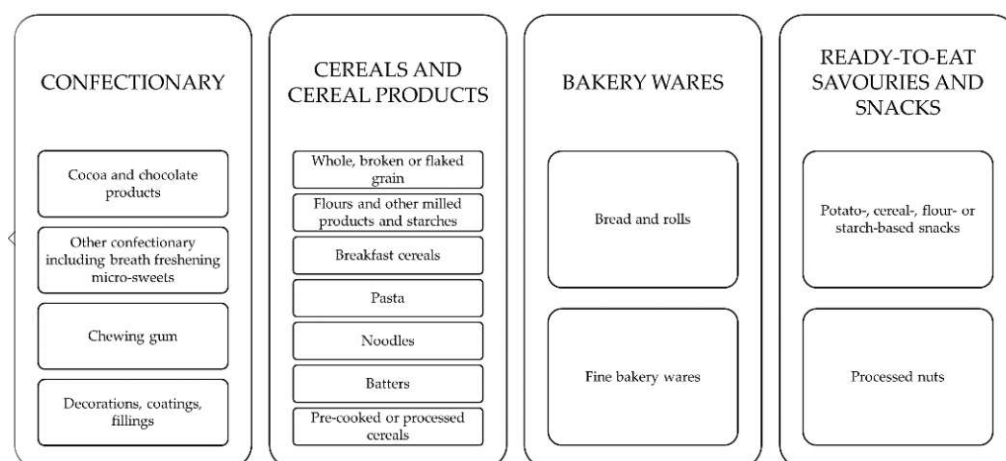


Figure 3. Representation of the followed product categorization. Adapted from [59].

3.2. Decay Mechanisms and Shelf-Life

It is well-established that intrinsic as well as extrinsic factors influence the quality of food and thus its shelf-life [13], which can be defined as the period of time a food maintains its safety and/or quality under reasonably foreseeable conditions of distribution, storage, and use [12,64–66]. Intrinsic factors include, amongst others, pH, water activity (a_w), initial microbial population, redox potential value (Eh), and nutrient content and therefore determine the nature of decay mechanisms of a food product. On the other hand, extrinsic factors determine how fast decay mechanisms proceed. Typical examples are atmosphere, climatic conditions, and illumination. Packaging itself acts as mediator or separator between intrinsic and extrinsic systems [13,67]. The following paragraphs highlight the main challenges of quality maintenance of cereal and confectionary products but do not go into detail about the physical, chemical, or biological bases of these mechanisms (e.g., oxidation). This information can be found in the relevant scientific literature [13,67,68].

Focusing on cereal and confectionary products (see Table 2), moisture content (MC) and water activity (a_w) are some of the most important quality-affecting parameters. Kong and Singh [69] define, that the a_w value is "... the vapour pressure of water above a sample (p) divided by that of pure water at the same temperature (p_0); i.e., $a_w = \frac{p}{p_0}$. It describes the degree to which water is free or bound to other components". They state that this is related to "... the composition, temperature, and physical state of the compounds" [69,70]. This is of importance regarding the potential growth of microorganisms as they depend on free water presence [71].

Table 2. Water activity and moisture content of confectionery products, breakfast cereals, snacks, and bakery products.

Product category	Subcategory	Product	Water Activity [a_w]	Moisture Content [%]	Reference
Confectionery	Cocoa and chocolate products	Chocolate	0.42–0.60	1.2	[72]
		Hard candy	0.25–0.40	2.0–5.0	[73,74]
	Other confectionery including breath freshening micro-sweets	Fudge, toffee	0.45–0.60	6.0–18.0	
		Nougat (white, dark)	0.55	8.00–10.0	[13,75]
		Jelly, liquorice	0.50–0.75	8.0–22.0	[73,74]
		Marshmallow	0.60–0.75	12.0–22.0	
		Marzipan	0.75–0.80	–	[13]
	Chewing gum	Chewing gum	0.40–0.65	3.0–6.0	[73,74]

Table 2. Cont.

Product category	Subcategory	Product	Water Activity [a _w]	Moisture Content [%]	Reference
Cereals and cereal products	Whole, broken, or flaked grain	Oats, grains, cereals	0.34–0.70	8.8–9.2	[13,72]
	Breakfast cereals	Cornflakes	0.25–0.38	1.7–3.5	
		Puffs	0.17–0.20	0.48–1.70	
	Fresh pasta	Fresh pasta	0.91–0.98	≥24	
	Dry pasta	Dry pasta	0.33–0.57	5.4–8.3	
Bakery wares	Fine bakery wares	Sponge cake, muffins	0.84–0.95	21.0–40.0	[76,77]
		Croissant crust	0.59–0.61	8.0–10.0	
		Croissant crumb	0.92–0.94	30.0–33.0	
		Biscuits	0.60–0.63	1.5–3.0	[72,78]
		Wafers	0.13–0.15	2.1	[72]
		Cookies	0.18–0.64	1.4–11.7	
	Bread and rolls	Flat bread (no yeast)	-	33.0–35.0	[79]
		Sourdough bread, yeast bread crumb	0.91–0.95	29.0–40.0	[72]
		Sourdough bread, yeast bread crust	0.88–0.94	26.0–32.0	
		Bagel crust	0.96	38.5	
		Bagel crumb	0.92	31.0	
		Popcorn	0.07	0.28	
Ready-to-eat savouries and snacks	Potato-, cereal-, flour- or starch-based snacks	Chips	0.09–0.27	0.3–1.3	
		Crackers, grissini, sticks, pretzels	0.05–0.54	1.1–5.4	
		Processed nuts	0.15–0.75	0.5–3.1	

With an a_w lower than 0.75, a large proportion of the products listed in Table 2 falls into the group of low-moisture or dried foods that additionally exhibit low (e.g., cornflakes) or high (e.g., crisps) fat content. In this group, water uptake and thus loss of, e.g., crispness, which occurs, e.g., in potato chips and breakfast cereals after gaining moisture at a range of 0.35 to 0.5 a_w , is the main decay mechanism [12,13,69,80]. Other mechanisms include loss of aroma (e.g., flavoured products) or aroma uptake from the products' surrounding due to the often porous structure of the food products. Further, structural changes such as loss of integrity due to e.g., mechanical damage (e.g., breakage), softening, or caking may occur. While microbial growth is the basis for both, low and high fat types, oxidative mechanisms, which may lead to off-odours and -tastes and subsequently to quality loss in terms of overall acceptance, are often linked to the fat content and thus tend to increase with the same [12]. Examples that can be named are nuts, chips, biscuits, and cookies. All in all, this product group can, however, be described as rather stable and therefore storage under dry and ambient conditions is recommended and possible. For example, breakfast cereals and dry pasta stay stable under temperate conditions for 6–18 months and 48 months, respectively [72,81]. Confectionary products like pulled sugar are stable for 6–9 months under temperate conditions (e.g., ~20 °C) [68].

Other products, including chocolate for example, can be allocated to compact foods with high fat content, a group mainly susceptible to the uptake of unwanted flavours and some (often minor) water exchange (uptake or loss) processes [12]. The latter can induce so-called blooming effects [13]. Sugar bloom on the one hand is often provoked by humid

storage or rapid temperature changes and leads to the loss of surface gloss. Fat bloom on the other side is also known to cause quality related issues visible as a fine whitish layer [82]. Growth of microorganisms is, however, of minor importance in this product group. Storage under temperate or chilled conditions is therefore possible for up to 12–24 months [57].

Microbial growth is of major concern in the group of ready-to-eat and ready-to-cook convenience food products (e.g., fresh pasta). At this point, in addition to spoilage microorganisms, pathogenic microorganisms play an essential role [65,83]. Further, water loss and structural changes can be named. Additionally, oxidation can significantly gain importance regarding shelf-life. Accordingly, chilled storage is often preferred [13,67].

The area of bakery products can be divided into fresh bakery wares and ready-to-bake products. The first group (e.g., bread) shows high a_w values (>0.8) and thus short shelf-life, which is heavily influenced by water exchange processes that are often interlinked with structural changes (softening of the crust and drying of the crumb). Connected to this, starch retrogradation, which is the main mechanism of staling, can be highlighted [69]. Further, loss of moisture and hardening with a_w values below 0.5–0.7 [13,69,80] quickly result in low sensory acceptance of the products. While oxidation and rancidity play a minor role in this food category, uptake of flavours as well as microbial spoilage play a more elaborated role in this product group. The latter point is mainly driven by the often visible growth of moulds and yeasts on the food surface. Characteristic microorganisms are *Penicillium roqueforti*, *Hansenula anomala*, *Pichia anomala*, *Candida guilliermondii*, *C. parapsilosis*, *Saccharomyces cerevisiae*, *S. exiguus*, *S. unisporus*, *S. bayanus*, *S. pastorianus*. Additionally, *Clostridium* and *Bacillus* genera are known bacteria potentially affecting bakery wares (spore-forming), with e.g. *Bacillus* spp. causing “rope” or “ropy spoilage” (*Bacillus amyloliquefaciens*, *Bacillus subtilis*, *Bacillus pumilus*, *Bacillus cereus*) [71,84,85]. Oxidation and rancidity play a minor role in this product category. Accordingly, the average shelf-life of fresh bread and cake under ambient conditions is often less than one week [86]. In some cases, chilled or frozen storage is advisable. The group of ready-to-bake rolls show very similar decay mechanisms. However, due to the higher water content, drying and spoilage is even more pronounced. In the case of frozen products, these mechanisms are delayed. A special focus has to be laid on water exchange (freezer burn) and structural damage [87].

3.3. Product Group Specific Packaging

Responding to the above-mentioned predominant decay mechanisms of cereal and confectionary products, the following section aims at highlighting common packaging concepts and material choices (compare also Table 1).

Chocolate packaging has to provide a good barrier against aroma, gas (especially O_2 and H_2O) as well as light. This is conventionally achieved by using aluminium foil of different thickness to wrap the product. Since aluminium alone cannot be heat sealed, the per se excellent barrier of the material is, however, interrupted at, e.g., overlapping areas or gaps. Hence, diffusion (mass transfer) of aroma, gas and other molecules (e.g., mineral oil components) to the product cannot be excluded. Additionally, the originality of the product, an important factor of food safety, may not be ensured [13,67]. For this and other reasons (e.g., communication), many described packaging concepts (still) include an additional packaging layer, namely paper or paperboard [13,27,88–92].

Today, more and more multilayer materials can be found on the market. For example, laminates of LDPE (low density polyethylene) and aluminium allow for heat sealing of the aluminium by at the same time keeping the superior barrier and dead-fold properties of aluminium. Further, multilayer materials including paper or other aluminium replacing barrier materials (e.g., polyvinylidene dichloride (PVdC)) are available. Possible build-ups may include LDPE/aluminium/paper or LDPE/PVdC, respectively [13]. Nowadays, a shift towards packaging made (solely) from (oriented) PP, which exhibits, due to a stretching process, inter alia, improved mechanical and barrier properties, is notable [21,92]. Additionally, cold sealing, is more and more adopted, since it avoids exposing sensitive products, such as chocolate, to elevated temperatures during heat sealing. This alternative

is made possible by applying cold-seal adhesives on the intended sealing areas of the packaging film and pressing of two of the sealing areas together [31].

Individually packed chocolate products, such as chocolate coated bars or pralines, are often bought for hedonistic reasons (e.g., treats, gift function) and thus the communication function (design) of these packages is frequently at the forefront [13,56]. While the functions of containment and protection are already met, these packages often use excess packaging materials and/or layers and for example consist of a (e.g., polyethylene terephthalate (PET)) tray with individual cavities, (e.g., aluminium) wrapping of the individual pieces, a (e.g., paperboard) box, (e.g., polyethylene (PE) or polypropylene (PP)) overwrapping and packaging aids (e.g., labels, stickers). Glass or metal is also used in some cases [13].

Many confections, such as hard candies, gums, toffees and caramels are likewise (twist) wrapped individually. This is either for technical reasons such as provision of an adequate (H_2O) barrier and thus avoidance of moisture loss or uptake, resulting in e.g., drying or agglutination of the product pieces, hygienic reasons or distinction from other products. As for chocolate, tightness of the package should be in the ideal case assured [73]. Due to their in general good barrier properties and sealability, the market dominating polyolefins (PE and PP) as well as PET [93] are also frequently used in this product category (e.g., multipacks) [21,94]. If elevated barriers are needed, different multilayer materials are also adopted. Further, glass and metal packaging can be found on the market and traditional materials include waxed paper, waxed glassine and waterproof, plasticized cellulose fibre [57]. Plain paper and board are, however, hardly used as a primary packaging material, since products tend to stick to the material. The packaging types in this product category are manifold and include, for example, trays, flow packs, boxes (for example cardboard and metal) and jars [13].

Other products such as biscuits, (processed) nuts and fruits are traditionally packaged in regenerated cellulose (trade name Cellophane) fibres (RCF). Therefore, RCF is usually coated with either LDPE or PVdC copolymer and often with a layer of glassine in direct contact with the product if it contains fat. Currently, this combination of materials is replaced by PP, either as plain or pearllized OPP film, coextruded OPP (OPPCoex) film, or acrylic-coated (Ac) on both sides. Plain OPP films require a heat seal coating to improve sealability while coextruded OPP provides superior seal strength. If a high O_2 barrier is required, then acrylic-coated OPP (AcOPP) is used. One side is sometimes coated with PVdC copolymer rather than Ac. In addition, Ac and PVdC copolymer-coated OPP films provide a superior flavour and aroma barrier compared with that of uncoated OPP. Biscuits are often packed in PP and additionally a cardboard box, acting as secondary packaging [13,25].

In comparison to other products, the dry and low in fat group of cereals and cereal products, (such as whole, broken, flaked or milled) grains (e.g., wheat and rice) show rather low packaging demands. Mostly used are paper bags, flexible plastic bags (e.g., PE [95]), as well as cardboard boxes [96,97]. There are also variations of these packages, for example inner flexible plastic bag and a secondary cardboard box. If paper is used and high barriers are needed, LDPE liners for example can be applied [13], also to avoid mineral oil migration [98]. Rigid laminates with paper content and plastic lids usually known in snack product packaging, are also available. Flours for example are commercially packaged in bags or bulk bins [13]. In addition to that, woven PP bags are commonly used in developing countries. However, Forsido et al. [99] discussed that the low moisture barrier led to chemical, physical, sensorial, and microbial changes of flour. Another successful approach for flour packaging that was used for decades, was bags made from cotton twill [13].

The barrier requirements for breakfast cereals packaging are set higher than in the above-mentioned group since crispness, formation of off-flavours, loss of aroma and vitamins or breakage are more critical for consumer acceptance [13]. Consequently, the inner packaging/primary packaging level of these products is a plastic bag, mostly HDPE (high density polyethylene), giving a sufficient water vapour barrier since moisture vapour trans-

mission rates less than or equal to 15 g/m²-day-atm are often required. Sealant polymers such as EVA (ethylene vinyl acetate), ionomer, mPE (metallocene polyethylene), or blends are used for low temperature seals, form-fill-seal packaging, and easy opening seals [95]. In order to increase barrier characteristics, HDPE is also coextruded with a thin layer of EVA or PA (polyamide) and EVOH (ethylene vinyl alcohol) polymers [95,100]. Other O₂ barrier materials for breakfast cereals are PVdC and coated polypropylene-low density polyethylene [101]. In addition, PP-bags are common liners. The secondary packaging/outer packaging is most frequently a fibreboard box [13,22]. Alternative packaging concepts include coated paperboard, plastic cups, as well as metal boxes and glass jars [13,102].

Dried pasta is often packaged in paperboard carton, containing a plastic window. At the moment, most pasta products are packaged in plastic films, such as PE or oriented polypropylene [13,103–107]. For fresh pasta/noodle products, packaging solutions might be different, as appropriate barriers (gas and/or water vapour) and/or MAP (e.g. CO₂:N₂ 20:80% MAP for pasta) is needed [107,108]. The selection of packaging materials for fresh pasta products can also depend on whether or not the product is pasteurized (thus, the package must be able to withstand the pasteurization conditions) and whether or not the product is to be heated in its package (the package must be able to withstand either heating in boiling water or microwave conditions) by the consumer. For products which are not pasteurized nor intended to be heated in their package, a rigid tray of PVC-LDPE sealed with PA-LDPE film is common. When microwave heating is used, the rigid tray is usually made from crystalline polyethylene terephthalate (PET-C), or polystyrene-ethylene vinyl alcohol copolymer-LDPE (PS-EVOH-LDPE) laminate, and the film may be based on PVdC copolymer-coated PET, OPET-EVOH-LDPE, or PP [109].

Packaging of fresh bakery products such as bread is a moisture balancing act. On one hand, moisture needs to be contained to prevent drying of the product and on the other hand, moisture has to be released from the product to avoid softening of the crust and microbial spoilage. Since there is a wide range of products and product characteristics, also a wide range of packaging solutions can be found. Frequently, paper-based materials, LDPE, LLDPE, HDPE bags as well as OPP, either as plain, pearllized, OPPcoex, or Ac/OPP/Ac films are used [13,95,110–114]. The bags are usually closed either with a strip of adhesive tape or a (plastic) clip in order to reduce moisture loss [111,113,115]. EVA polymers are also used for sealability and optics [95]. Perforated LDPE bags are used (for crusty products) in order to prevent the formation of a leathery consistency of the crust due to moisture migration from the crumb [115]. If aroma and taste barriers are needed, PA is used [95]. Vacuum packaging including the use of respective barrier packaging materials is only used in some exceptions (e.g., flat breads) in this product category due to mechanical impairment of the often soft products. MAP rich in CO₂ is whereas more frequently used (e.g., sliced bread, convenience applications). For example, CO₂:N₂ 60:40% MAP for bread, cakes, crumpets, crepes, fruit pies and pita bread. This is also the case for ready-to-bake products, which are intended to have a longer shelf-life [13].

Packaging for fried snack foods such as potato or tortilla chips, which exhibit, due to their production process, low moisture and high fat contents, preliminarily aims at providing a barrier against gases (H₂O and O₂) and light to avoid loss of crispness and increased oxidation/rancidity levels of the product [95]. Hence, these products are mainly packaged in high barrier multilayer films containing aluminium foil or metallisation (e.g., PET/Alu/LDPE; PETmet/LDPE; BOPP/BOPPmet) [31,94,116]. In addition, barrier polymers such EVOH or PVDC can be found in these materials. Further, rigid multilayer paper solutions with aluminium (for example spiral wound paper-board cans) or metal cans are also used. Since extruded and puffed snack foods exhibit lower fat levels and thus primarily rely on a package that provides a barrier against water vapour; these products are less often packaged in metallized materials. An example is OPP/LDPE/OPP [95]. In both scenarios, and whether flexible or rigid packaging is adopted, modified atmosphere packaging is frequently used. For example, the package is usually flushed with an inert gas (N₂) before closing [116]. Additional mechanical protection of the often fragile products

and dry storage is recommended. This might lead to the use of secondary packaging, such as cardboard boxes [31].

4. Shelf-Life Extension

As can be seen from the above text, choosing the right packaging material concept can have a positive effect on quality maintenance and therefore shelf-life of cereal and confectionary products and food in general. Where particularly sensitive products (e.g., high a_w value, high fat content or oxidation potential) are present (e.g., fresh pasta, fried snacks) or an elevated shelf-life has to be achieved (e.g., ready-to-bake rolls, fine bakery wares), modern packaging concepts such as modified atmospheric packaging or active (AP) and intelligent packaging (IP) are used (combined abbreviation: AIP). Manifold different approaches can be found regarding MAP, AP, and IP, each with different relevance for the discussed product subgroups, cereals and cereal products, confectionary, bakery wares and ready-to-eat savouries and snacks. However, for an impression of these, Figure 4 depicts selected examples.

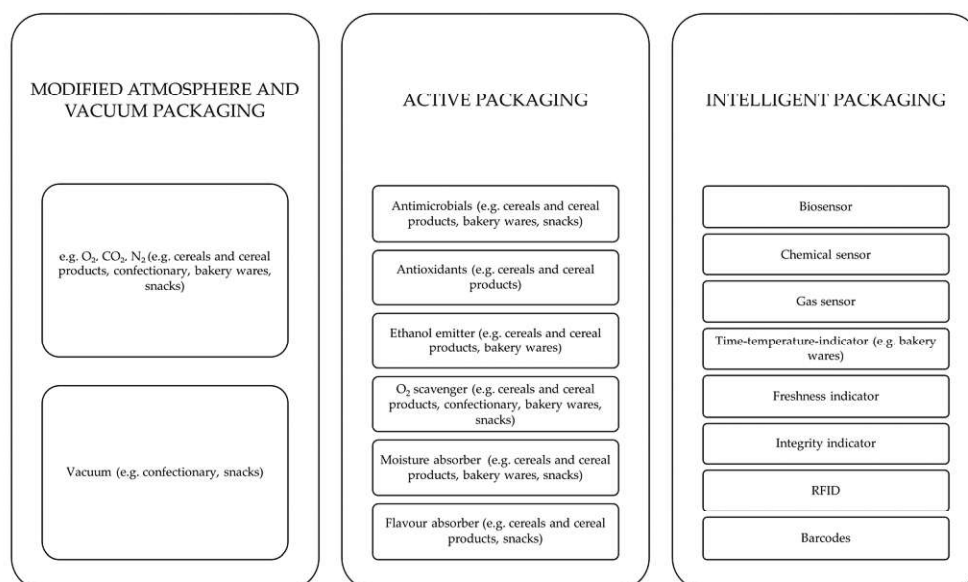


Figure 4. Selected examples of modified atmosphere, vacuum, as well as active and intelligent packaging approaches with certain use cases for cereal and confectionary packaging. Adapted from [13,108,117–140].

Using these approaches, other product preservation actions (e.g., heating, use of preservatives) may be reduced, which supports attempts to reach a healthier diet (e.g., reduction of salt) or a clean label (e.g., avoidance of excess additives) [141]. These allow specifically addressing other remaining challenges in the chemical, biological, mechanical, and physical fields [12,13]. Thus, they are also often implemented in the hurdle technology, a concept of combining diverse adverse factors or treatments to control microbial growth in food products [13,142]. According to studies found, also biobased and/or biodegradable packaging material is experimentally combined with AIP approaches. These materials offer new opportunities, for example in making use of different barrier properties, that allow a certain shelf-life extension [134,135]. Examples for MAP and AP with traditional as well as biobased/biodegradable packaging materials can be found in Table 3.

Table 3. Effects of packaging material selection, active packaging (AP) and modified atmosphere packaging (MAP) on shelf-life extension of cereal and confectionary products. Abbreviations: m = month; d = day; RH = relative humidity; RT = room temperature.

Category	Product	Packaging Material	AIP/MAP Applied	Storage	Shelf-Life	Reference
Confectionary	Dark chocolate with hazelnuts	Alu (commercial)	Air	20 °C in dark	8 m	[119]
		PET/LDPE	Vacuum or N ₂		8–9 m	
		PET-SiOx/LDPE			11 m	
		PET/LDPE or PET-SiOx/LDPE	Oxygen absorber		≥ 12 m	
Cereals and cereal products	Muesli with chocolate and apricots	Paper bag: PAP + PP window	Air	20 °C, RH 55 %	2 m	[143]
		Pouch: PAP/Alu/PE			9 m	
		Can:PAP/Alu + LDPE lid				
	Fresh pasta	PS tray + PVC film	Air	8 °C	20 d	[120]
		PA/EVOH/LLDPE	CO ₂ :N ₂ 22:78% MAP		40 d	
	Fresh pasta filled with cheese	Tray: EVOH/PS/PE wrapped in film: EVOH/OPET/PE	Air	4 °C	7–14 d	[108]
			CO ₂ :N ₂ 50:50% MAP		42 d	
	Gluten-free fresh filled pasta	Tray: PETFilm: antifog PET film	Air	4 °C	14 d	[121]
		Tray: EVOH/PS/PEFilm: EVOH/OPET/PE	CO ₂ :N ₂ 30:70% MAP		42 d	
Bakery wares	Sponge cake	PA/LLDPE	Combinations of oxygen scavengers with / without ethanol emitter	30 °C, RH 60%	≤42 d	[139]
		PVDC/PA/cPP				
	Sliced wheat bread	PET-SiOx/LDPE	Bread	20 °C	4 d	[130]
			Bread + preservatives		6 d	
			Ethanol emitter		24 d	
			Ethanol emitter + oxygen absorber		30 d	
	Ciabatta bread	OPA/PE	Air (control)	21 °C	5 d	[122]
			Air + ethanol spray		11 d	
			CO ₂ :N ₂ 10:90% MAP		12 d	
			MAP + ethanol spray		13 d	
			Air + ethanol emitter		25 d	
MAP + ethanol emitter			30 d			

Table 3. Cont.

Category	Product	Packaging Material	AIP/MAP Applied	Storage	Shelf-Life	Reference
	Wheat bread	HDPE/PE	-	25.8 °C, 275.5 lx, RH 31.2%	2 d	[144]
		Unpackaged bread	-		3 d	
		HDPE/Nanoparticles/PE	Ag-TiO ₂		>6 d	
	Calcium-enriched wholemeal bread	PA/PE bag + cardboard box	CO ₂ :N ₂ 60:40% MAP	20 °C	24 d	[145]
	Whole wheat bread	PA/PE	N ₂	RT	2–3 w	[123]
	Part-baked flat bread (Sangak)	PA/PE	Air	25 °C	9 d	[124]
			CO ₂ :N ₂ 20:80% MAP		18 d	
			CO ₂ 100% MAP		21 d	
	Sliced wheat bread	Tray: APET/EVOH/PEAntifog-film: PA/PE	Air without potassium sorbate & with 0.15% potassium sorbate	20 °C, RH 60%	14 d	[125]
			N ₂ 100% MAP, CO ₂ :N ₂ 30:70% MAP, CO ₂ :N ₂ 50:50% MAP, CO ₂ :N ₂ 70:30% MAP, CO ₂ 100 %MAP;with & without potassium sorbate		21 d	
			Air with 0.30% potassium sorbate		>21 d	
	Bread	Plastic bag	E-Poly-L-Lysine Biofilms1.6/3.2/6.5 mg of E-Poly-L-Lysine /cm ²	RT for 7 days inoculated with <i>A. parasitus</i>	+1 d	[131]
			E-Poly-L-Lysine Biofilms6.5 mg of E-Poly-L-Lysine /cm ²	RT for 7 days inoculated with <i>P. expansum</i>	+3 d	
	Sliced wheat bread	PP/PET/LDPE	Star anise oil, thymol	25 °C inoculated with <i>P. roqueforti</i>	14 d	[132]
	Bread	Starch-based bionanocomposite film	Chitosan, grapefruit seed extract	25 °C, RH 59%	20 d	[133]
	Sliced white pan bread	PP bag	–	30°C	3 d	[134]
		PBAT-PLA bag	Trans-cinnamaldehyde		≥21 d	
	Bread	BOPP	–	25 °C, RH 75%	3 d	[135]
		PLA			6 d	
		PLA-PBSA bag			7–9 d	

4.1. Modified Atmosphere Packaging (MAP)

Leaving quality sensitive products exposed to atmospheric conditions (gas composition of N_2 , O_2 , Ar, CO_2 , traces of other gases) can trigger undesirable changes such as quality-related oxidative decay or growth of (non)pathogenic aerobic microorganisms. On the contrary, modifying the atmosphere inside a packaging can help maintain the quality of a product over an elevated timeframe. Consequently, common mitigation strategies include the reduction of packaging headspace and, thus, total available atmosphere or even removal of the atmosphere (to a value below one percent), which in turn results in vacuum packaging. To maintain these conditions over time, it is necessary to assure an appropriate containment function of the packaging by choosing packaging materials with an appropriate gas barrier and proper sealing. Challenges in this case are often the structure of the products and the corresponding residual oxygen in the packaging in the case of e.g., pores and the collapse of the product in the case of e.g., a soft structure [13,125,146].

A more advanced modification can be found in a so-called modified atmosphere packaging, MAP [147]. Here, an active modification takes place in a two-step process, where first the initial atmosphere is removed (vacuum) and then replaced with a specific artificially composed atmosphere before closure of the barrier packaging. Commonly, in product-dependent concentrations used, colourless and odourless gases in MAP mainly encompass CO_2 and N_2 . Due to its formation of hydrated carbonate species in aqueous phase CO_2 is valued for its bacteriostatic and fungistatic effect, which increases with increasing concentration. Due to the solubility in water and fat, formation of under-pressure in the package and, consequently, possible collapse of the latter is possible. To avoid this and to act as a filler gas, the inexpensive and inert N_2 is applied. Hence, passively, also this gas contributes to quality maintenance of the product. Furthermore, O_2 is a frequently used gas but of little relevance for the cereal and confectionary sector. Its field of application is mostly in meat (e.g., bright-red colour preservation via high-oxygen MAP) and fish products and to lower extent in plant products [145,148,149]. More recently, permitted noble gases such as argon are subject to research but not broadly applied on cereal and confectionary products [150,151]. Depending on the chosen MAP gas composition, food shelf-life can increase manifold (50–400%) and with this advantage along the supply chain can be recorded (e.g., less food waste, longer remaining shelf-life, less frequent production and transport). However, disadvantages linked to MAP, in general encompass the need for more sophisticated packaging materials and filling equipment, costs for gas and increased packaging volume [13].

Regarding the food categories at the centre of the present review, confectionary products are less frequently in the centre of research and application of MAP than cereals and cereal products, bakery wares or ready-to-eat savouries and snacks (see Table 3). One case of MAP use, however, is reported by Mexis et al. [119], for dark chocolate with hazelnuts. The authors found, that when conventionally used aluminium packaging together with storage under surrounding atmosphere was replaced with a PET/LDPE or PET-SiO_x packaging and vacuum or N_2 , the shelf-life (dark storage at 20 °C) was increased from 8 to 8–9 and 11 months, respectively. Also Kita et al. [152], investigated the effects of different packaging types and shelf-life extension strategies for chocolate coated products (fruits and nuts). They analysed air, vacuum and MAP ($N_2 \geq 98\%$) of coated cherries, figs, hazelnuts and almonds in long term storage conditions in three different types of packaging. PP film closed with a clip was chosen for air, PP film sealed for vacuum and metallized sealed film for MAP. They resumed that the best packaging solutions for the chosen chocolate coated products, ensuring quality (for example bioactive compounds, antioxidative activity) were, on one hand, air and vacuum packaging for fruits, vacuum packaging for hazelnuts and MAP for almonds.

In the category of cereals and cereal products, and in more detail in fresh pasta, MAP often contains elevated amounts of CO_2 (up to 80%) and corresponding low N_2 values (balance) [13,108,120,121]. For instance, Lee et al. [120] conducted a comparative study on fresh pasta packaged under air (PS tray with PVC film) and under $CO_2:N_2$ 78:22% MAP

(PA/EVOH/LLDPE). As a result, the shelf-life was doubled from 20 to 40 days at a storage temperature of 8 °C. Even higher rates of shelf-life increase for fresh filled pasta were shown in two other studies [108,121]. In the first case, samples included fresh pasta filled with cheese in a sealed tray (EVOH/PS/PE) with a barrier film (EVOH/OPET/PE) and two different atmospheres (air; CO₂:N₂ 50:50% MAP). Quality maintenance was increased from 7–10 days up to 42 days [108]. Similarly, in the second case, gluten-free fresh pasta was packaged in trays (control: PET; test: EVOH/PS/PE) sealed with films (control: PET; test: EVOH/OPET/PE). Shelf life under air was compared to CO₂:N₂ 30:70% MAP. Here, an increase from 14 to 42 days was notable [121].

Turning to bakery wares such as (pita)bread, cakes, crumpets, crepes, (fruit)pies, Robertson [13] reports a frequent use of CO₂:N₂ 60:40% MAP. However, in the scientific literature, a more diverse application of CO₂:N₂ MAP can be seen. For example, Rodriguez et al. [126] investigated extending the shelf-life of bread using MAP packaging in a combination with preservatives. The research referred to bread slices packaged in a 60 µm bag. The results showed that in the samples without added preservative, and CO₂:N₂ 50:50% MAP, the increases in shelf-life were 117% and 158% (at 22–25 °C and 15–20 °C). For the samples with calcium propionate addition and in N₂ 100% MAP, shelf-life was increased by 116%. Furthermore, calcium propionate addition and CO₂:N₂ 20:80% MAP increased the shelf-life by 150% and 131% at 22–25 °C and 15–20 °C. When the CO₂ concentration was increased to 50%, the increased shelf-life of the samples with added preservative was 167% at 22–25 °C. For the same settings at 15–20 °C the increase was even 195%. Fernandez et al. [149], conducted a similar research with soy bread. They as well used different settings of MAP and preservative adding but expanded the question of packaging options. They used two multilayer packaging solutions, high and medium barrier. The high barrier was LLDPE/PA/EVOH/PA/LLDPE, whereas the medium barrier solution was LLDPE/PA/LLDPE. As controls, LDPE and air atmospheres were used. The combination of high barrier packaging in CO₂:N₂ 50:50% or CO₂:N₂ 20:80% MAP without calcium propionate addition extended the shelf-life of the samples by at least 200%.

Turning to ready-to-eat savouries and snacks (e.g., crisps) Sanches et al. [128] investigated inter alia the effects of different packaging atmospheres under 40 °C and room temperature on multiple crisp samples, linked to lipid oxidation. They included marketed products under unknown MAP concentrations, air, N₂, vacuum and oxygen scavengers in the analysis. Reflecting changes in the fatty acid profile of the crisps, it was resumed that changes in the package's atmospheres, mostly cutting out oxygen, was crucial for the shelf-life of the crisps. Vacuum packaging options would also allow stable lipid profiles, however, they are not suitable for easily breakable crisps. Del Nobile [129] was similarly questioning the optimal packaging for crisps, however, focused on finding the best headspace gas composition for two different multilayer film packages (metallized PP and PVdC coated PE) through simulated storage. He proposed that N₂ combined with water vapour would lead to a shelf-life extension up to 80%.

4.2. Active and Intelligent Packaging (AIP)

While MAP is firmly established in the market, active and intelligent packaging has not yet reached its full potential in food packaging applications but is at the threshold of more widespread use in the European market and subject to intense research and development activities [153–155]. Accordingly, the following paragraphs aim at outlining the concept of AIP and highlighting applications most relevant for cereal and confectionary packaging.

Just as conventional packaging applications, AIP define as food contact materials as given in Regulation (EC) No 1935/2004. While conventional packaging has to be sufficiently inert not to transfer substances to the food in quantities that endanger human health or bring an unacceptable change of the food product (composition, organoleptic properties), AIP are intentionally designed not to be inert. This allows them to actively maintain or even improve the quality or shelf-life of food products [39]. Hence, AIP deliberately includes “active” components that are either aimed to be released to the food or that aim at absorbing

substances from it. This justifies the division of active packaging into so-called releaser and absorber systems. However, a clear distinction is made to traditional substance releasing materials (e.g., wooden barrels) in food contact. The use of active substances aimed to be released to the food must also comply with the Directive 1333/2008 on food additives and should be authorized accordingly by applicable community provisions [63]. Furthermore, specific requirements regarding labelling and information, avoidance of misleading consumers as well as safety assessment and authorisation is given [39]. In addition to Regulation (EC) No 1935/2004, Commission Regulation (EC) No 450/2009 gives specific rules for the use of AIP (e.g., community list of allowed substances for use and evaluation of these) [39,156].

In response to major challenges in food quality and safety [12,13], key technologies in the area of active packaging are emitters (e.g., CO₂, ethanol, antimicrobials, antioxidants) and scavengers (e.g., O₂, CO₂, ethylene), absorbers (e.g., H₂O, flavour and odour), self-venting packages, microwave susceptors, and temperature control packaging [13,40,157–165]. Intelligent packaging on the other hand refers to packaging that monitors the food product and provides information about its condition [39]. Related key technologies are mostly indicators and sensors (e.g., time, temperature) and linked processing and communication systems (e.g., (printed) electronics). Further, tamper evident packaging and anti-counterfeiting applications exist [163,166].

Due to their effectiveness, the growth forecasts for AIP in the coming years are high, but it must be emphasised that the sustainability of such sophisticated packaging solutions should be evaluated case by case [167]. In addition to the actual reduction of food losses and food waste, factors such as, e.g., the recyclability of AIP, which may include metal-based components, should be evaluated [153,163,168,169].

Going into detail about cereal and confectionary packaging (see also Table 3), an application example for oxygen absorbers is in sliced bread. Where O₂ concentration decreased below 0.1% within a few days of packaging, microbial shelf-life was shown to be extended. It was reported that there was no effect on sensory quality [170]. Oxygen absorber can also be used in combination with MAP. In 2003, Del Nobile et al. [127] showed that the application of CO₂:N₂ 80:20% MAP in the packaging of durum wheat bread prolonged the shelf-life from 3 to about 18 days at 30 °C. However, if the packaging film itself possesses a high barrier against oxygen, neither the use of scavengers nor MAP are necessary to achieve the desired shelf-life of white bread [171]. Finally, an oxygen scavenger system, consisting of a multilayer coextruded bag associated with an oxygen scavenger, was tested in different storage conditions (accelerated storage, room temperature, refrigerator), for its effect on preservative-free tortillas shelf life. The results indicated a protective effect of the packages including the oxygen scavenger system. Specifically, the weight and thickness of flour tortillas under room temperature conditions could be maintained, opposed to respective decreases detected in control packages (consisting of LDPE/LLDPE). In parallel, yeast and mold growth were held back in the packages containing the oxygen scavenger versus control (room temperature and accelerated storage). Under refrigerated conditions, a shelf-life up to 31 days was estimated, however, independent of the use of oxygen scavengers [172].

It has been also shown that the use of ethanol emitters extend shelf-life even without establishment of an additional modified atmosphere. For ciabatta, a shelf-life of 16 days, at 21 °C could be obtained, packaged in air atmosphere and ethanol emitter addition [122].

Antimicrobial, antifungal, and antioxidative agents as active food packaging include multiple research topics. Options include the applications of essential oils, edible films, and nanocomposites, which are often used with products susceptible to microbiological degradation, e.g., sliced bread. For example, oregano essential oil has been observed to be a successful application against yeasts and moulds in sliced bread. It was applied in the form of antimicrobial sachet at concentrations of 5, 10, and 15% (*v/w*) at room temperature [136]. In addition to that, methylcellulose edible films produced with clove and oregano essential oil have displayed antimicrobial activity against spoilage fungi in bakery products and have improved sliced bread shelf-life to 15 days, at 25 ± 2 °C [137].

Also, cinnamaldehyde was used as an active ingredient to increase the shelf-life of sliced bread. It was incorporated in gliadin films (5%), which allowed to keep the quality of the product for 27 days of storage at 23 °C [173]. Next to having antimicrobial effects, essential oils are also antioxidative agents that can be included in packaging material like HDPE, LDPE, EVA. Zhu et al. [138] for example tested this approach with sesame essential oils for the packaging of oat cereals. However, there are also biological threats that could shorten the shelf-life of cereal and confectionery products. Essential oils from garlic, black pepper, ginger, fennel, and onion already have been tested as insect repellents for grain packaging. All these tested essential oils were characterized by significant fumigant insecticidal properties. For example, allyl mercaptan deriving from allium plants added as a sachet with rice flour, was proven as potential protective active packaging against *S. oryzae* contamination leaving sensory properties unaffected [174]. In general, the incorporation of essential oils in packaging materials is a growing sector [175,176]. One background can be that they are waterproof, so it could be the ideal material for the incorporation into a film, which will turn it from a conventional packaging material to an active one, increasing both its value and its functionality [175].

One further option of active packaging is the targeted use of composites at the nanoscale, whether organic (oils/proteins/carbohydrates) and/or inorganic, e.g., clays. This topic is of interest as active agents might have different properties in smaller scales. Materials of which at least one of its external dimensions belongs to the nanoscale (1 to 100 nm) are considered nanomaterials [177,178]. They are characterized for their unique properties such as high surface-area-to-volume ratio, fine particle size, and high reactivity [179]. One common area of research interest is represented by publications including essential oils. For example, bio-nano-composite films prepared with corn starch incorporated with chitosan nano-clay, and further enriched with a variety of ratios of grapefruit seed extracts have been studied. It was shown that this solution was capable of inhibiting fungal proliferation for a period of 20 days, compared to that of 6 days in bread packaged samples with synthetic plastic, indicating a successful active packaging approach to extend the shelf-life of bakery products [133]. Furthermore, two different formulations mainly consisting of essential oils from several plants were evaluated for their potential antifungal properties in maize grains. Specifically, in a recent study, bioactive EVOH films including various essential oils have been characterized. Cinnamaldehyde, citral, linalool and isoeugenol were investigated to decrease the activity of *A. steynii* and *A. tubingensis* strains. It was shown that the ochratoxin A production by these strains in partly milled maize grains could be reduced significantly. The inhibitory effect was the highest in EVOH with cinnamaldehyde, followed by isoeugenol and citral [180]. In parallel, EVOH copolymer films incorporated with essential oils from *Origanum vulgare*, *Cinnamomum zeylanicum* and/or their major active constituents have been studied. The results showed that carvacrol and cinnamaldehyde were effective in decreasing *Aspergillus flavus* and *A. parasiticus*-induced aflatoxin production in maize, respectively. Overall, cinnamaldehyde showed the highest inhibitory effect, followed by combinations of EVOH with essential oils from *Origanum vulgare*, *Cinnamomum zeylanicum* and carvacrol [181].

Next to these highly discussed organic nanoparticles, inorganic particles like Ag (silver) and TiO₂ (titan dioxide) have also been applied to packaging solutions, for example cereal products, due to their antimicrobial effects [182–185]. However, there is a concern on potential risk of nanoparticles migrating into food, although limited data showed that obtained values were within the limits set by the legislation [185–189]. It was shown that Ag-TiO₂ nanocomposite incorporated in HDPE considerably extended shelf-life and microbiological safety of bread in comparison with control sample stored in an open atmosphere or in HDPE bags [144]. Not only the characteristics of plastic packaging can be optimized by the inclusion of nanoparticles. The modification of paper with Ag-TiO₂-SiO₂ (silicon dioxide) or Ag/N-TiO₂ composites can improve the paper's material characteristics. It was shown that such paper was capable to extend the shelf-life of bread

by 2 days in comparison to the control, in both ambient (18–20 °C) and refrigerated (0–4 °C) conditions [190].

Research in optimizing packaging with nanostructures goes even further to high-tech materials. An example is a packaging material with a montmorillonite layer. It was shown that montmorillonite composite polyamide 6 nano-fibres placed over PP films, increased the shelf-life of bread by 2 days at room temperature, due to inhibition of microbial growth [191].

Intelligent packaging, on the other hand, is a special packaging technique aiming to monitor the quality of the packaged food and to predict or measure the safe shelf-life better than a best before marking date [122,130,171,192–194]. It provides functions beneath the ones considered as conventional e.g., protection and containment and is used to monitor the condition and provide quality information of packed foods to the consumers [158]. Different indicators, such as time-temperature, microbial growth, product freshness, pack integrity etc., are used as intelligent packaging systems. High temperatures and/or temperature fluctuation are often correlated with food deterioration as result of detrimental biochemical reactions combined with microbial growth. Depending on the food sensitivity specific intelligent indicators can be applied to specific food products. The time-temperature indicator measures the change that imitates the targeted quality characteristics with the same behaviour under the same time-temperature exposure. The pH and enzymatic indicators can also give information about the quality of food [195]. Commercially available time-temperature indicators can be used to monitor quality changes of many perishable and semi-perishable foods. Among other products, these indicators have been applied to canned fruitcake for 10 days' storage at constant (12, 25 and 37 °C) temperatures. Sensory analysis, as quality characteristic of the product, was correlated with indicator response [140,196].

Reflecting the above chapters and findings, it can be summarized and confirmed that, if chosen correctly, cereal and confectionary packaging, as well as food packaging in general can make a valuable contribution to maintaining the quality and safety of food [12,13,17]. Accordingly, it can also help to prevent food losses and waste, an important point when it comes to making our food systems more sustainable [11,16]. This point is also taken up in the SDGs and influences current political efforts such as the European Union's Green Deal [2,3,6].

However, packaging redesign or optimizations should not simply be carried out without evaluating the effects on ecological, social, and economic sustainability as objectively as possible. This is the only way to avoid possible hidden trade-offs [17].

In addition, close cooperation between a wide range of disciplines is required. In this context, and among others, material science, sustainability science and social sciences, and humanities can be mentioned in addition to food science and technology. The latter in particular has, however, an important enabling function [197,198]. The future focus here could be on the points of promoting (i) diverse and sustainable primary produce, (ii) new processes and systems for sustainable manufacture, (iii) reduction of food and material waste along the supply chain, (iv) safety and traceability, (v) affordable and balanced nutrition, (vi) healthy diets as well as (vii) digitalization. MAP and AIP are important approaches in this context, which are particularly present in the points (ii), (iii) and (iv) [198].

5. Conclusions

The ongoing discussion about packaging optimization towards the enhancement of the sustainability of certain products, asks for a profound review of the status quo in specific food groups. Cereal and confectionary were found to be underrepresented in recent publications addressing this topic, despite their global economic and ecologic importance. To take the right steps aspiring more sustainable production and consumption of goods, it is essential for practitioners along the food supply chain to thoroughly understand packaging functions (containment, protection, convenience, communication), properties

(physical and mechanical strength, barrier, migration, hygiene), product group specific decay mechanisms, used packaging solutions, and shelf-life extension strategies.

Commonly available packaging solutions vary in material selection (glass, metal, plastic, paper), as well as in shape (rigid, semi-rigid, flexible) and size. Therefore, each packaging solution offers unique benefits and limitations regarding its optimization potential. Important decay mechanisms mediated by packaging in cereal and confectionary products and snacks include inter alia oxidative mechanisms and changes in moisture content. Especially for products for which quality is easily impaired through such mechanisms, packaging solutions and technologies extending the shelf-life need to be considered as ways to improve the products' sustainability. This, in combination with a proper material selection, includes the applications of MAP and AIP (e.g., scavengers, indicators, active ingredients) as well as novel approaches (e.g., nanotechnology).

However, sustainability improvement includes different other aspects. After the proper understanding of the packaging's purpose in these certain product categories and subcategories, the question of burden shares between the environmental impacts of the food product itself in comparison to its packaging must be considered along the whole life cycle. Thus, further research is deemed necessary to investigate data from related Life Cycle Assessment (LCA) studies and to combine the findings with the current status quo, in order to derive proper redesign steps for cereal and confectionary products. However, LCA is by default limited to environmental analysis and does not cover all sustainability dimensions. The inclusion of economic and social aspects would finally provide a holistic picture on how to attain more sustainable products.

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Review

Cereal and Confectionary Packaging: Assessment of Sustainability and Environmental Impact with a Special Focus on Greenhouse Gas Emissions

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Abstract: The usefulness of food packaging is often questioned in the public debate about (ecological) sustainability. While worldwide packaging-related CO₂ emissions are accountable for approximately 5% of emissions, specific packaging solutions can reach significantly higher values depending on use case and product group. Unlike other groups, greenhouse gas (GHG) emissions and life cycle assessment (LCA) of cereal and confectionary products have not been the focus of comprehensive reviews so far. Consequently, the present review first contextualizes packaging, sustainability and related LCA methods and then depicts how cereal and confectionary packaging has been presented in different LCA studies. The results reveal that only a few studies sufficiently include (primary, secondary and tertiary) packaging in LCAs and when they do, the focus is mainly on the direct (e.g., material used) rather than indirect environmental impacts (e.g., food losses and waste) of the like. In addition, it is shown that the packaging of cereals and confectionary contributes on average 9.18% to GHG emissions of the entire food packaging system. Finally, recommendations on how to improve packaging sustainability, how to better include packaging in LCAs and how to reflect this in management-related activities are displayed.

Keywords: food; packaging; cereals; confectionary; snacks; life cycle assessment; LCA; environmental impact; CO₂ footprint; food losses and food waste

1. Introduction

The sustainability of food and, in particular, its packaging continues to be at the center of public and political debate. In order to make objective and knowledge-based decisions, it is of utmost importance to understand the requirements of a food product on its packaging on the one hand and to be able to select the optimal packaging solution for the respective purpose on the other hand. While the former has already been covered in the review paper “Cereal and Confectionary Packaging: Background, Application and Shelf-Life Extension” [1], the present review aims to address the important issue of sustainability and assessment thereof.

Recently, it has been shown and further substantiated by Crippa et al. that food systems are accountable for a major share, namely 34%, of global anthropogenic greenhouse gas (GHG) emissions (data representing 2015). The authors also showed that this percentage predominantly originates from agriculture and land-use and land-use change activities (71%). The remaining fraction (29%) represents activities along the food supply chain such as processing, distribution (e.g., packaging, retail, transport), consumption and corresponding end-of-life scenarios. Being of increased importance and use, packaging resulted in a 5.4% share, which was calculated considering relevant materials and industries (e.g., pulp and paper, aluminum, metal, glass). This value is slightly above the shares for transportation (4.8%) and the cold chain (5%) [2].

The seemingly relatively small contribution of packaging to total GHG emissions in relation to food products against the background of current discussions about packaging and sustainability has also been shown by Poore and Nemecek [3]. The authors likewise calculated a 5% share of packaging but also showed that the results for product groups differed greatly from one another. For instance, alcoholic beverages, such as beer and wine, exhibited packaging-related emissions of around 40% (with glass packaging as the main driving impact factor), while fruit and vegetables showed packaging-related emissions of around 10 to 20% [3]. This difference in the impact ratio between packaging and food for different products has also been shown by other authors and studies [4–7]. For example, Verghese et al. stated that packaging of meat, fish and eggs accounts for 2% of GHG emissions, while packaging for dairy as well as fruits, vegetables and nuts account for 10 and 12%, respectively [6]. Heller et al. underlined this by visualizing that resource- and emission-intensive food products, such as meat or milk, tend to have a high food-to-packaging ratio, while less resource- and emission-intensive food products, such as leafy greens, show a small ratio [7].

Especially for food products with a (very) high impact, these results point out the importance of the protective function of packaging [6–10]. Optimizing and sometimes increasing packaging can reduce food losses and waste along the food supply chain while at the same time reducing the overall environmental impact [11]. For food products with a low impact, on the other hand, more precise consideration must be given to which packaging (e.g., material) should be used and which trade-offs must be considered [10–14]. Therefore, the sustainability (including ecological, economic and social dimensions) of product packaging systems is the subject of current research and finds more and more attention in policies and legislation [15–17].

Due to the great importance of high-impact foods (e.g., products of animal origin such as meat and milk [18]) and foods with high food losses and waste (e.g., fruits and vegetables), publications on these topics are a priority in the scientific literature. This is reflected by different studies and reviews [3,18–22]. However, to the author's best knowledge, no comprehensive work taking into account the important group of cereal and confectionary products [23–25], their packaging and related GHG emissions exists. This shortcoming is also underlined by different authors [26–32]. Against this background, the aim of the present review is to:

- Contextualize packaging and sustainability as well as sustainability assessment methods;
- Display and discuss how and to what extent food packaging is included in existing life cycle assessments (LCAs) in the cereals and confectionary sector;
- Point out the environmental impact of cereal and confectionary packaging in relation to the food product with a special focus on GHG emissions;
- Highlight improvement strategies to optimize (cereal and confectionary) packaging systems as well as LCA of the same.

This provides a valuable basis for decision makers as well as practitioners in research, development and innovation to take further steps towards sustainable food packaging.

2. Packaging and Sustainability

2.1. Sustainable Packaging

2.1.1. Definition

Despite its common usage, the term “sustainable packaging” is defined and utilized in different ways by various stakeholders along the food supply chain and beyond [33]. Accordingly, several approaches, frameworks and methodologies with differing foci, principles, criteria and connected indicators can be found in the relevant literature [34]. These, amongst others, encompass legal texts on packaging and packaging waste [35,36], guidelines for producers and retail focusing on specific topics such as design for recycling [37–41], as well as more holistic packaging sustainability frameworks [42–45].

A condensed but comprehensive framework is that of the Sustainable Packaging Alliance (Australia) [42]. This so-called Packaging Sustainability Framework defines a total of four principles, namely that sustainable packaging must be (i) effective, (ii) efficient, (iii) cyclic and (iv) safe. In this context, “effective” means that the respective packaging is fit for purpose and fulfils its essential functions (e.g., containment, protection, communication, convenience [46–48]) with as little effort as possible. “Efficient”, on the other hand, refers to packaging that minimizes resource consumption (e.g., materials) as well as emissions (e.g., CO₂) along its life cycle and “cyclic” emphasizes that it is necessary to keep resources in the biological (e.g., bio-based or biodegradable materials) or technical (e.g., recycling, use of recycled materials) cycle. Furthermore, “safe” focuses on packaging that does not pose a risk to people (e.g., migration of harmful substances from the packaging material to the food product) or the environment (e.g., pollution) along its life cycle [42,43,45,49].

It is important to point out that the above four principles are closely interrelated and that (increased) efforts in one area can lead to positive or negative changes in another [43]. The latter case and corresponding trade-offs are represented, for example, by the use of multilayer flexible food packaging. While this often offers a high level of product protection (e.g., barrier) with low material input and correspondingly low emissions (e.g., CO₂), the combination of different materials (e.g., different plastics, aluminium, paper) makes it difficult to recycle them [50]. Another possible trade-off is the reduction or minimization of packaging. While this is desirable in principle, underpackaging can lead to undermining the effectiveness of a packaging system, resulting in increased food losses and/or waste and corresponding environmental impacts. Overpackaging, on the other hand, also leads to elevated environmental impacts due to the excess material used [43].

2.1.2. Development

Taking this into account, finding the optimum point (as little as possible, as much as necessary) with balancing the above-mentioned principles is of the utmost interest in a packaging (re)-design process. Since “THE” sustainable packaging is not a specific, existing product that can be applied to any given (food) product, but rather a system that must be constantly adapted to the changing needs of, for example, the (food) product, the value chain, consumers and legal requirements, the resulting “sustainable” packaging solutions can be as diverse as the initial factors [43].

Consequently, developing a successful packaging solution not only at the primary but also at the secondary and tertiary packaging level [51] is a complex and critical undertaking that requires dedication, investment and, most importantly, a holistic and collaborative approach [43,48,52]. While holistic refers to life cycle thinking and assessment, collaborative refers to pro-active and dedicated action of not only single actors but connected and communicating companies, supply chains, science and research as well as stakeholders such as governments or consumers. This allows the development of (eco)efficient and effective solutions that enable the transition from a linear to a circular economy and show benefits in multiple dimensions (ecologic, economic, social) [43,52–56].

To evaluate or compare different developed packaging solutions with regard to ecological, economic and social aspects, different criteria, indicators, metrics and evaluation methods can be used. While economic and social effects can be assessed using, for instance,

Life Cycle Costing (LCC) [57–61] and Social Life Cycle Assessment [62–65], ecological effects are usually assessed using a (full) Life Cycle Assessment (LCA) ([66–69], simplified (or streamlined) LCA, non-LCA tools or scorecards (see also Figure 1) [70–72].

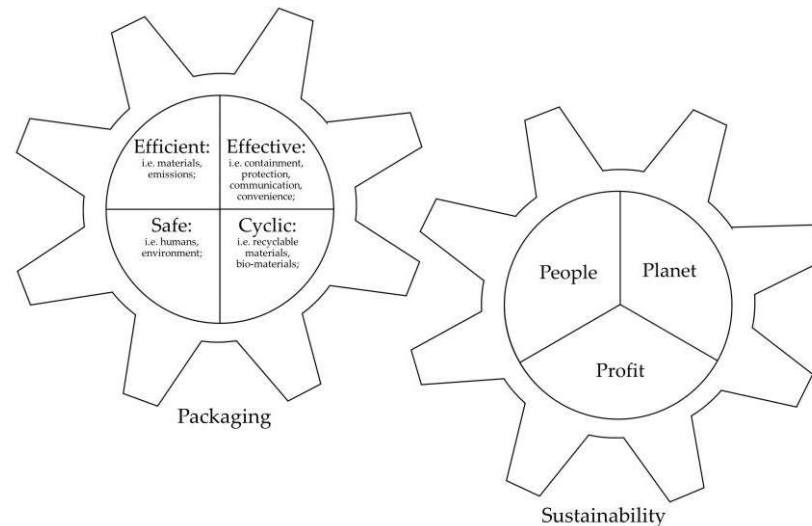


Figure 1. Principles of sustainable packaging and their impact on ecological, economic and social sustainability. Graphic based on [42,43,46].

2.1.3. Challenges

Sustainable packaging development frequently involves high production costs, long development time and technical difficulties [43,54]. Therefore, many sustainable packaging solutions are not implemented without significant sales increase or cost reduction. Findings also show that sustainable packaging ambitions often stay on the firm's strategic level because companies might prioritize a product's market potential and a limitation of commercial risks over sustainability considerations on an operational level. As a result, sustainable advances in packaging development frequently remain limited [73].

Companies' sustainability commitment is also reduced if such packaging solutions' commercial success is questionable or if it does not positively influence consumer behavior [53]. Unfortunately, from the consumer perspective, sustainable packaging does not always refer to a truly sustainable solution but to a specific design, which evokes explicitly or implicitly the perception of sustainability via its structure and its visual and informational cues [74,75]. Moreover, consumer perception of sustainable packaging is controversial: some consumers have a generally positive attitude toward sustainable packaging [76,77], and others regard such packaging as an environmental villain due to the way the media have recently communicated about packages. However, in general, they have limited awareness, recognition and knowledge of the different sustainable functions (such as labels, materials, disposal processes, and manufacturing technologies) of such packaging solutions [78–80] and often focus their environmental concerns solely on the packaging's end-of-life [56]. They also associate sustainable packages with certain risks (lower perceived quality, lower functionality, less attractiveness, perceived contamination), which leads to lower perceived functionality and lower willingness to purchase [76,81]. Consumers can also be easily deceived by packaging communication [82], and some even perceive sustainable claims as greenwashing, especially when these claims are not in line with their subjective sustainable packaging expectations [80,83]. It is, therefore, important to study and include consumer insights in sustainability packaging analysis and also include other necessary steps to avoid failures [43].

2.2. Life Cycle Assessment

One of the first LCAs focusing on food packaging was initiated by the Midwest Research Institute (MRI) for the Coca-Cola Company in 1969 [70,84–86]. In 1974, the same institute conducted a follow up of this study for the United States Environmental Protection Agency [87]. Similarly, Unilever has performed several LCA studies for various product groups such as margarine and ice cream in the late 1980s. Since then, and in the context of the need for more sustainable products and processes, numerous further studies have been conducted in this research field [85–95]. Building on this, LCA has also increasingly found its way into more than just industrial decision-making [96]. For instance, a comparative LCA study on different beverage packaging formed the basis of the political decision of the German Federal Ministry for the Environment with regard to the German deposit system on disposable packaging (single-use deposit) in the early 2000s. However, since conditions (e.g., legal framework, economy, inventory data) are not static but constantly adapting, the study was repeated recently and is again influencing policy-making [97,98]. Being just one example, it is expected that LCA will be more and more applied to improve policy- and decision-making in the future (e.g., waste management policies) since it offers transparent and valuable information about the actual sustainability of a product or process. However, a sound methodology and expert knowledge in conducting such analyses is a prerequisite to achieving meaningful output [99–101].

A full LCA should consider the following life cycle stages: raw material extraction and preprocessing (cradle), transportation of processed materials to the manufacturing site, production of components, assembly of the system, transportation to market (gate), use phase and end-of-life with transportations of the used equipment to the intended waste treatment plant, e.g., landfill (grave) or recycling/material recovery (back to cradle). An LCA study can be: (i) partial, referring to some phases of the product's lifecycle, i.e., cradle-to-gate, (ii) semi-complete, including landfilling or partial recycling, i.e., cradle-to-grave or (iii) complete, employing all life time phases and including material upscaling aspects as described in the circular economy principles, i.e., cradle-to-cradle [34]. The Product Environmental Footprint (PEF) is a multi-criteria method for modelling the potential environmental performance of a product, and it can easily be inferred through the LCA results, especially in cradle-grave or cradle-cradle approaches [102,103].

According to the guidance provided by the International Standardization Organization (ISO) in ISO 14040 and ISO 14044, an LCA study is generally carried out by iterating four distinct phases [66,67]:

In the first step, i.e., Goal and Scope, the objectives of the study are defined to clarify the intended application and the reasons for the study, including the target audience. Scope, on the other hand, describes the product system, as well as the functional unit (FU) and the system's boundaries. The selection of the FU is a basis for comparing similar products. Thus, a typical FU relates to the overall product function rather than focusing on a particular physical property, while it is normally time-bounded and can correlate the expected duration of use and desired quality under certain circumstances. The meaningful selection and definition of system boundaries is a crucial task as it determines the overall type of the LCA, i.e., whether it is a cradle-to-gate, a cradle-to-grave or a cradle-to-cradle approach [104].

During the second step, i.e., Life Cycle Inventory analysis (LCI), a comprehensive inventory of energy, materials and environmental inputs-outputs is created, identifying and quantifying all related data at every stage of the life cycle. The collection of data and determination of total emissions and resource use take place alongside a detailed definition of entailed production processes. All collected data are scaled based on the preset functional unit for the studied system. Lack of data availability and quality is a typical drawback and can usually refer to studies related to non-standardized procedures. Other inhibiting factors are geographic variations regarding the quality of raw materials and energy sources, production methods and relevant environmental impacts [105].

The next and third step, i.e., Life Cycle Impact Assessment (LCIA), is the phase of an LCA with particular respect to sustainability assessment. During the impact assessment, the potential environmental impacts associated with identified inputs and outputs are categorized into different categories. During LCIA, emissions and resource extractions are translated into a limited number of environmental impact scores by means of so-called characterization factors. There are two mainstream ways to derive these factors, i.e., at the midpoint and at the endpoint level. Midpoint indicators focus on single environmental problems, for example, climate change or acidification, while endpoint indicators present environmental impacts on three higher aggregation levels, i.e., (i) effect on human health, (ii) biodiversity and (iii) resource scarcity [106].

In the fourth step, i.e., Interpretation, the results of the inventory analysis and the impact assessment are interpreted and combined in order to make a more informed decision. During this phase, a comparison of the results with previous studies is made in order to determine whether they are aligned with the literature. Furthermore, a sensitivity analysis can be performed to validate the consistency of the findings. ISO standards provide a general framework of an iterative nature. Thus, if the outcomes of the impact assessment are incomplete for drawing conclusions, then the previous LCA steps must be repeated until the final results support the initial goals of the study [107].

As LCA is by default a holistic method that accounts for multiple environmental impact categories, carbon footprint analysis evaluates the GHG emissions generated by a product, activity, or process that contributes to global warming, and it is a subset of a complete LCA. Thus, it is always based on international standards such as ISO 14040/14044, ISO 14067, PAS 2050, and the GHG Product Life Cycle Standard [66,67,108,109].

One important aspect of applying LCA in food packaging is to quantify the inherent direct and indirect effects in order to assess the environmental sustainability of the sector. Direct effects of packaging include impacts from the production and end-of-life of the related materials. Additionally, indirect effects derive from life cycle losses and waste that occur in different phases of the food supply chain [110].

3. Sustainability of Cereal and Confectionary Packaging

3.1. Literature Analysis

To display and discuss how and to which extent packaging is present in existing LCA studies in the cereal and confectionary sector and to point out the environmental impact (focus on GHG emissions) of the packaging in relation to the respective food product, a literature search in different databases was conducted, similar to Molina-Besch et al. [111]. Firstly, and for the identification of relevant LCA studies, the keywords “Life Cycle Assessment” and “Carbon Footprint” were used. Secondly, to identify relevant food products, keywords given in the guidance document in Part E of Annex II of the regulation (EC) No 1333/2008 on food additives were used. (Sub)categories considered were: confectionary products (cocoa and chocolate products, other confectionaries including breath-freshening micro-sweets), cereals and cereal products (whole, broken or flaked grain, flours and other milled products, breakfast cereals, pasta, noodles, batters, pre-cooked or processed cereals), bakery wares (bread and rolls, fine bakery wares) as well as ready-to-eat savorys and snacks (potato-, cereal-, flour- or starch-based snacks, processed nuts) [112]. The first keywords were combined with “or”. The second keywords were individually added using “and”. Articles written in English and published since 2009 were considered for review. Of these, relevant studies including food, packaging and related LCA results were analyzed in detail. Where results (on packaging) were included in graphics (e.g., bar chart) but not in numeric form, the online tool Web-Plot Digitizer was used to extract the data [113]. Further, for each study, the percentage of packaging-related GHG emissions was taken from the results or extracted (calculated) where necessary.

Based on the available data set, commonalities and differences between the studies were investigated in a multi-step approach based on ISO 14040 and 14044: (i) goal and scope, (ii) life cycle inventory, (iii) life cycle impact assessment and (iv) interpretation [66,67]. This

stands in contrast to Molina-Besch et al., who focused primarily on (i) and (iv) [111]. Since the present review not only aims to highlight how packaging is included in the studies but also to point out improvement opportunities for packaging and assessment, the authors also focused on LCA methodology, represented by (ii) and (iii).

As it is well known that the direct comparison of results from different LCA studies (e.g., due to different goals and scope, data used, cut-offs) is difficult [111,114,115], the present study aims at rather comparing approaches, magnitudes and ranges than exact values.

3.2. Results

3.2.1. Goal and Scope

Focus

In total, 28 LCA studies covering 108 products in the categories of confectionary, cereals and cereal products, bakery wares and ready-to-eat savorys and snacks fulfilled the above-given criteria (see also Table 1). Within these studies, products from the confectionary category (total 42%) and especially the sub-category of cocoa and chocolate products were assessed most frequently (38%). On the contrary, the sub-category of other confectionaries, including breath-freshening micro-sweets, only resulted in a low number of entries (4%). Products covered were, for example, jelly and foam sweets as well as sugar and milk-based confectionary. This focus on cocoa and chocolate products may be due to the high economic relevance of cocoa [23,24] and is well in line with, for example, the findings of Miah et al. [26], who stated that diverse confectionary products are underrepresented in LCA studies and that chocolate products dominate the literature body.

Table 1. Reviewed cereal and confectionary life cycle assessment (LCA) studies ($n = 28$).

Category	Sub-Category	LCAs * $n = 28$		Products $n = 108$		Greenhouse Gas Emissions		
		n	%	n	%	Food-Packaging System [kg CO ₂ eq]	Packaging [kg CO ₂ eq]	Packaging (%)
Confectionary	Cocoa and chocolate products	9	32	41	38	3.28	0.25	9.86
	Other confectionary including breath-freshening micro-sweets	2	7	4	4	2.80	0.16	4.68
Cereals and cereal products	Whole, broken or flaked grain	2	7	9	8	12.53	0.14	1.25
	Flours and other milled products and starches	2	7	3	3	0.65	0.04	5.30
	Breakfast cereals	2	7	4	4	0.87	0.15	19.68
	Pasta	4	14	10	9	1.33	0.10	7.24
Bakery wares	Bread and rolls	5	18	20	19	1.03	0.04	4.37
	Fine bakery wares	3	11	12	11	1.93	0.04	11.22
Ready-to-eat savorys and snacks	Potato-, cereal-, flour- or starch-based snacks	1	4	1	1	0.43	0.04	8.14
	Processed nuts	1	4	4	4	1.87	0.33	20.10
Overall (average)						2.67	0.13	9.18

* Some LCA studies covered more than one (sub)category. Therefore, given numbers do not sum up to $n = 28$ or 100%.

A total of 24% of the products were located in the area of cereal and cereal products. On the forefront in the sub-category of whole, broken or flaked grain (8%) was rice. For the sub-category of flours and other milled products and starches (3%), oat, potato and wheat were represented. Further, the sub-category of breakfast cereals (4%) was covered by

one known brand's products as well as porridge. The sub-category of pasta (9%) included different products made from different raw materials. Interestingly, the category of bakery wares (30%) showed an elevated number of packaged products in the sub-categories of bread and rolls (e.g., (sliced) bread) (19%) as well as fine bakery wares (e.g., biscuits, cakes) (11%).

Last but not least, the category ready-to-eat savories and snacks only displayed one product example (5%), namely crisps, for the sub-category of potato-, cereal-, flour- or starch-based snacks (1%) and some examples for the sub-category of processed nuts (e.g., pistachio) (4%).

Aim

Analyzing the studies with regard to packaging, it quickly becomes clear that the focus (overall goal and scope) is mainly on the food products themselves. Molina-Besch et al. [111] name these types of studies *food LCAs*, whereas studies with a focus on the impact of the packaging system are called *packaging LCAs*. In total, 7 out of 28 studies explicitly mentioned packaging in one form or another in their aim. While some studies seem to mention packaging in passing, others go more into detail. For example, Boakye-Yiadom et al. [116] mentioned “environmental impacts associated with the production of a packaged chocolate”, Cimini et al. [117] included “pasta in 0.5 kg polypropylene (PP) bags” in their aim, and Volpe et al. [118] focused on “bags of” nuts. Büsser and Jungbluth [119], on the other hand, aimed at analyzing “the environmental performance of packaging with respect to its function within the life cycle of chocolate” and Espinoza-Orias et al. [120] included “... the influence on the carbon footprint of several parameters ... including ... type of packaging (plastic and paper bags) ...”. Further, with an explicit focus not only on the direct but also indirect effects of packaging, Svanes et al. [121] aimed to “... establish environmental hotspots; to examine the role of ... packaging ... and to identify potential measures to reduce this wastage”, and Williams and Wikström [11] aimed to “... analyze the potential of decreasing environmental impact of five food items ... through the development of packaging that reduces food losses in the consumer phase”. These studies are, however, exceptions and mirror the findings of Molina-Besch et al. [111], who likewise, but for a wider product range, found that packaging is currently insufficiently considered in LCAs.

Functional Unit

The strong focus on the food product itself is also reflected by the functional units given; slightly more than half of the authors do not even name packaging in this regard [27,30,118,120–131]. Those who do [11,26,28,29,31,32,116,117,119,132–134] almost exclusively (with the exception of Nilsson et al. [132]) give the functional unit as “one kilogram of product in the respective packaging”. This corresponds to a formulation as laid down in the Product Category Rules (PCR) rules of the International Environmental Product Declaration (EPD) system [31,135,136], as well as other sources [104,137].

In this context, EPDs, as such, which are based on LCAs, should also be discussed in a short excursion. According to the definition of ISO 14025, these are so-called Type III environmental declarations. Specifically, they are independently verified and registered documents that make the environmental impact of products transparent and comparable over their entire life cycle. Type I and II stand for third-party and self-declared eco-labels, respectively [138,139]. Interestingly, the EPD Library (search criteria: product category food & beverages; PCR bakery products) already contains more than 100 EPDs [140]. These are highly relevant for the present review with regard to the categories of cereals and cereal products as well as bakery wares, but outside the scope (e.g., scientific literature) defined in chapter 3.1. Moreover, the EPDs are structured very similarly to each other. Accordingly, these will not be analyzed in detail in the coming chapters but will be used for comparison and discussion where appropriate.

System/Scope

While a considerable amount of the studies reviewed followed a cradle-to-gate or a gate-to-gate approach [116,118,119,122,123,125,127,131–133,141], the majority considered the product life cycle in a cradle-to-grave approach [11,26–32,117,120,121,124,126,128–130,134]. The latter is a prerequisite for assessing not only the direct environmental effects of packaging (impacts caused by production and end-of-life) but also the indirect environmental effects of the same (influence on, e.g., food waste and transport efficiency), a research field gaining more and more importance due to the high environmental impacts of food systems and the valuable role of packaging in avoiding or reducing food losses and waste [19,43,111,142,143]. The packaging-relevant direct and indirect effects in this context are: primary packaging (direct), secondary and tertiary packaging (direct), transport from producer to retail (indirect), food waste in transport, distribution and retail (indirect), food transport, storage and preparation by households (indirect), food waste in households (indirect), packaging end-of-life (direct) and food waste end-of-life (indirect) [111].

On closer examination of the studies with a cradle-to-grave approach, it becomes apparent that some did not include all key LCA steps necessary to evaluate the indirect effects of packaging at the point of sale or consumption. Transport (from producer to retail as well as to households), however, was covered in almost all the studies in the form of distance travelled. Factors influenced by the packaging, such as transport efficiency due to efficient and/or lighter packaging, on the other hand, were not in the foreground [11,26–32,117,120,121,124,126,128–130,134]. Regarding food losses and waste during transport, distribution and retail, Miah et al. [26], for example, gave information on the percentage of waste generated at the different life cycle stages for confectionary. Likewise, Sieti et al. [130] did the same for breakfast cereals. Cimini et al. [117] even named package breakage as a reason for waste during distribution. Additionally, Svanes et al. [121] explicitly calculated the direct and indirect effects of waste at the production, retail and household level for bread and rolls. Further, information on food waste was included by Espinoza-Orias et al. [120] for bread and rolls, Konstantas [29] for cakes, Miah et al. [26] for confectionary, Cimini et al. [117] for pasta and Sieti et al. [130] for breakfast cereals, making this the most-noticed form of indirect effects. Direct connection to the (packaging-related) cause was again not in focus. Data were rather derived from reports instead of actual conducted studies for the respective food product under consideration [120,144].

In the reviewed studies, considerations of end-of-life (e.g., recycling, landfill, incineration) were varied. Some studies excluded the end-of-life phase altogether [116,122,123,125,127,128,131,133]. Some cited similar studies that excluded end-of-life due to many different scenarios that needed to be considered, making it difficult for standardization and comparison [116]. The remaining studies included end-of-life in some respect, either as end-of-life of packed food and/or end-of-life of the actual packaging solutions (often referenced as simply post-consumer waste, but also as the full packaging system, including primary, secondary and transport packaging). Though the end-of-life of packaging solutions was not often regarded as very significant in the results (as compared to other life cycle phases), commendably, some studies took a long and detailed look at the issue [117,120,121,129,130,132]. The inclusion and study of end-of-life scenarios are currently important, as with novel emerging products and materials, established waste management systems are continuously presented with new challenges to protect humans and the environment [145].

In terms of system boundaries, the picture is similar for EPDs. In principle, an attempt is made to cover the entire life cycle in three successive steps, namely upstream (e.g., raw material production, packaging and auxiliary material production), core (e.g., food production) and downstream (e.g., distribution up to shelf, primary packaging end-of-life). While most EPDs are limited to the named examples (e.g., EPD on crispbread [146]), others go beyond and include, for instance, domestic food losses or food preparation (e.g., cooking) (e.g., EPD on pasta [147]).

3.2.2. Life Cycle Inventory

Table 2 lists the LCA studies reviewed and gives a comprehensive overview of the product (sub)categories, product names, the given packaging-related information, as well as the percentage of packaging-related GHG emissions.

Table 2. Reviewed cereal and confectionary life cycle assessment (LCA) studies: information on packaging and its percentage share of total greenhouse gas (GHG) emissions.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
Confectionery	Cocoa and chocolate products	Chocolate-covered hazelnut	Modified atmosphere in LDPE bag, label	Box	-	17.80	[118]
		Chocolate-covered almond	Modified atmosphere in LDPE bag, label	Box	-	6.00	
		Dark chocolate	Aluminum foil, cardboard	-	-	13.02	[32]
		Chocolate (100%)	Aluminum foil, paper	-	-	8.56	[122]
		Malty chocolates (in bags)	Aluminum foil	Corrugated cardboard boxes	LDPE stretch-film, LDPE consumer plastic bags	13.00	[28]
		Chocolate-coated wafers (contlines)	Aluminum foil	Corrugated cardboard boxes	LDPE stretch-film, LDPE consumer plastic bags	8.00	
		Milk chocolate (molded)	Aluminum foil	Corrugated cardboard boxes	LDPE stretch-film, LDPE consumer plastic bags	6.00	
		Milk chocolate	Aluminum foil, paper	-	-	6.94	[119]
		Dark chocolate				11.90	
		White chocolate				6.10	
		Chocolate with sultanas				10.42	

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
		Milk chocolate confectionary	Aluminum foil	Corrugated board box		2.27	
		Dark chocolate confectionary	PET tray, corrugated cardboard component	Corrugated board box	Not considered	5.18	[26]
		Milk chocolate biscuit confectionary	PP film	Corrugated board box		3.00	
		Dark chocolate	PP			4.71	
		Dark chocolate	Aluminum foil, fiber-based layer (cardboard)	-	-	24.87	
		Dark chocolate	Aluminum foil, fiber-based layer (Kraft paper)			18.82	
		Milk chocolate	PP			2.20	
		Milk chocolate	Aluminum foil, fiber-based layer (cardboard)	-	-	11.65	[129]
		Milk chocolate	Aluminum foil, fiber-based layer (Kraft paper)			8.82	
		White chocolate	PP			2.26	
		White chocolate	Aluminum foil, fiber-based layer (cardboard)	-	-	11.94	
		White chocolate	Aluminum foil, fiber-based layer (Kraft paper)			9.04	
		Extra dark chocolate, 65 g strip				23.64	
		Dark chocolate, 65 g strip	Paper covered Aluminum foil, paper sticker	Paper box	Cardboard/ carton box	23.35	
		Milk chocolate, 65 g strip				9.31	[116]
		Flavored milk chocolate, 65 g strip				9.26	

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
		Extra dark chocolate, 100 g bar	Aluminum foil)	Printed paper wrapper	Cardboard/ carton box	12.12	
		Dark chocolate, 100 g bar				11.98	
		Milk chocolate, 100 g bar				4.77	
		Flavored milk chocolate, 100 g bar				4.75	
		Extra dark chocolate, 300 g pouch	Paper covered aluminum foil, paper sticker	Paper box	Cardboard/ carton box	13.94	
		Dark chocolate, 300 g pouch				13.77	
		Milk chocolate, 300 g pouch				5.49	
		Flavored milk chocolate, 300 g pouch				5.46	
		Conventional monoculture chocolate (min. transport)	Aluminum foil, paper	-	-	8.71	
		Conventional agroforestry chocolate, (min. transport)				11.84	
		Organic agroforestry chocolate, (min. transport)				13.24	
		Conventional monoculture chocolate, (max. transport)				5.79	
		Conventional agroforestry chocolate, (max. transport)				7.03	
		Organic agroforestry chocolate, (max. transport)				7.50	
	Other confectionaries, including breath-freshening micro-sweets	Jelly sweets	PP bags	Not included	Not included	8.75	[132]
		Foam sweets	PP container			1.88	
		Sugar confectionary	Aluminum foil, paper	Corrugated board box	Not considered	5.26	[26]
		Milk-based confectionary	PP film	Corrugated board box		2.85	

[123]
based on
[32,122]

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
Cereals and cereal products	Whole, broken or flaked grain	Rice (IT)	Plastic bag	-	-	1.95	[124]
		Rice organic (IT)				1.33	
		Rice (US)				0.36	
		Rice parboiled (US)	Cardboard box			0.91	
		Rice upland (CH)				1.82	
		Minimal tillage white rice	LDPE bags			1.46	[125]
		Minimal tillage brown rice				1.82	
		Organic cultivation white rice				0.62	
		Organic cultivation brown rice				1.02	
		Flours and other milled products and starches				Oatmeal	-
	Potato flour					7.69	
	Wheat flour		-	-	-	2.17	[141] based on [148]
	Breakfast cereals	Breakfast cereals	Printed board folding-box, HDPE bag/liner	Corrugated-board box, HDPE stretch film/wrap	Corrugated pallet layer pads, Wooden pallet	15.00	[27]
		Dry ready-made porridge	LDPE bag, cardboard box ("bag in box")	Not considered	Not considered	9.93	[130]
		Wet ready-made porridge	Glass jar, cab (aluminum and plastics)			38.02	
		Wet ready-made porridge (scenario)	Pouch, cap			15.77	
		Pasta	Dried short pasta 0.5 kg	Re-closeable PP bag	Carton, adhesive label, scotch tape	Stretch and shrink film, label, EPAL wood pallet, different layers of cartons	5.90
	Dried long pasta 0.5 kg		Re-closeable PP bag	3.40			
	Dried short pasta 0.5 kg		Paperboard box	13.90			
	Dried long pasta 0.5 kg		Paperboard box	9.40			
	Dried short pasta 3 kg		PE bag	8.20			

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
Bakery wares	Bread and rolls	Dried long pasta 3 kg	PE bag			3.10	
		Pasta	Paper	Cardboard paper, plastic film	Corrugated board	1.00	[133]
		Pasta (wheat, 0% straw)	Low-density PET film, cardboard box, printing	Corrugated board, PP film	Pallet	10.00	[127]
		Pasta (wheat, 80% straw)				10.20	
		Pasta (egg)	-	-	Pallet	7.26	[128] based on [149]
		White bread (medium slices, 40 g)	PE bag			1.61	[120]
		Wholemeal bread (medium slices, 40 g)				1.73	
		White bread (thick slices, 57.5 g)				1.67	
		Whole meal bread (thick slices, 57.5 g)				1.80	
		White bread, medium slices (generic study)				2.73	
		Wholemeal bread, medium slices (generic study)				2.91	
		Brown bread, medium slices				2.84	
		White bread, thick slices (generic study)				2.86	
		Wholemeal bread, thick slices (generic study)				3.07	
		Brown bread, thick slices (generic study)				2.99	
		White bread (medium slices, 40 g) (generic study)				5.31	

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.
		Wholemeal bread (medium slices, 40 g) (generic study)	Wax coated paper bag			5.66	
		Brown bread, medium slices (generic study)				5.51	
		White bread (thick slices, 57.5 g) (generic study)				5.56	
		Whole meal bread (thick slices, 57.5 g) (generic study)				5.95	
		Brown bread, thick slices (generic study)				5.80	
		Bread (wheat)	Paper bag (paper and polylactide)	-	-	11.58	[131]
		Rye bread	LDPE bag, plastic clip	Returnable plastic box	-	6.10	[134] based on [11]
		Bread	PET and paper	HDPE box	HDPE trolley, extra packaging used by consumers	7.07	[121]
		Bread	LDPE bag, PS clip	Returnable plastic box	-	4.59	[11]
		Biscuits	Tray, wrap, cardboard case, plastic film	-	-	17.62	[31]
Fine bakery wares		Crackers	PP film	Cardboard box	LDPE film, LDPE shopping bag	7.00	[30]
		Low fat/sugar biscuits	PP film		LDPE film, LDPE shopping bag	6.00	

Table 2. Cont.

Category	Sub-Category	Product	Primary Packaging Level	Secondary Packaging Level	Tertiary Packaging Level	GHG [%]	Ref.	
		Semi-sweet biscuits	PP film	Cardboard box	LDPE film, LDPE shopping bag	6.00	[29]	
		Chocolate-coated biscuits	PP film		LDPE film, LDPE shopping bag	4.00		
		Sandwich (Chocolate cream) biscuits	Metallized (aluminum) PP film		LDPE film, LDPE shopping bag	8.00		
		Sandwich (vanilla cream) biscuits				7.00		
		Whole cakes	PP, cardboard folding box		Cardboard	LDPE wrap, consumer shopping bags		7.00
		Cake slices	Cardboard folding box, LDPE		Cardboard	LDPE wrap, consumer shopping bags		19.00
		Apple pie	Cardboard folding box, LDPE, aluminum foil		Cardboard	LDPE wrap, consumer shopping bags		24.00
		Cupcakes	Cardboard folding box, LDPE, paper		Cardboard	LDPE wrap, consumer shopping bags		24.00
		Cheesecake	PP, cardboard folding box, LDPE		Cardboard	LDPE wrap, consumer shopping bags		5.00
Ready-to-eat savories and snacks	Potato-, cereal-, flour- or starch-based snacks	Crisps	OPP and (aluminum) metallized OPP	Not included	Not included	8.14	[132]	
	Processed nuts	Pistachio	Modified atmosphere in LDPE bag, label	Box	-	12.80	[118]	
		Almond				12.90		
		Hazelnut				29.80		
		Peanut				24.90		

Packaging

Focusing solely on packaging, in the category of confectionaries and the sub-category of cocoa and chocolate products, the primary level of packaging was in most cases aluminum foil [26,28,32,116,119,122,123,129] or combinations of aluminum foil with fiber-based packaging materials like paper [26,116,119,122,123,129] and board [26,32,129]. In

some packages, additional packaging aids such as paper stickers were used [116], and information on finishing (e.g., print) [116] was given. Plastic packaging was less prominently represented. Found examples included chocolate-covered products (nuts) packaged in labelled plastic (low-density polyethylene (LDPE)) bags containing a modified atmosphere based on N₂ [118], dark chocolate confectionary in a polyethylene terephthalate (PET) tray including a (corrugated) cardboard component, milk chocolate biscuit confectionary [26], as well as different chocolates [129] packaged in polypropylene (PP). Regarding the primary packaging concepts presented, product-typical solutions aimed at maintaining the product quality were given throughout. For example, the necessary barrier functions against light, oxygen, water vapor as well as aroma were met in almost all cases. In the cases where only plastic packaging (e.g., milk chocolate biscuit confectionary [26]; dark chocolate [129]) was mentioned and not further specified if a light barrier [150] in the form of a colored material or a secondary packaging level made of, e.g., cardboard was present, product quality and thus shelf-life may be potentially impaired [46]. The secondary packaging level of other products was exclusively fiber-based packaging, namely (corrugated) cardboard boxes [26,28,118], paper wrappers or boxes [116].

In the sub-category of other confectionaries, including breath-freshening micro-sweets, primary packaging concepts were similar to those given above and met product requirements which mainly covered protection from moisture uptake or loss [46]. Jelly and foam sweets [132], as well as milk-based confectionaries, were packaged in PP, while sugar confectionaries were packaged in aluminum foil and paper [26]. Secondary levels, where mentioned, were paper [26].

Cereals and cereal products, including the four sub-categories of whole, broken or flaked grain, flours and other milled products and starches, breakfast cereals as well as pasta, frequently used [46] plastic [117,124,125] and fiber-based [124,133] primary packaging concepts or a combination thereof [27,127,128,130]. All packaging concepts given aim to protect low-moisture or dried products (especially, e.g., breakfast cereals [27]) with low fat content from mainly water vapor, aroma, mechanical damage or oxidation [47]. In the case of ready-made wet porridge, a glass jar with an aluminum-plastic lid and alternatively a multilayer pouch with a cap was mentioned [130]. Secondary packaging levels were not thoroughly described, but if mentioned, they were mainly corrugated cardboard boxes [27,127,133] or cartons [117]. Additionally, high-density polyethylene (HDPE) [27], PP [127] or other unspecified plastic films [133] and labels [117] were named. One study even listed scotch tape used for closing cartons [117].

Comparing this with the EPDs found for this product group, one can see a strong overlap of packaging concepts. Flours and other milled products, for example, are likewise packaged in fiber-based solutions (paper bags) [151,152]. Additionally, bulk packaging (paper sacks, big plastic bags) is mentioned [153]. Breakfast cereals are packaged in plastic bags in paper box solutions [154], and pasta is packaged in either plastic [155–167], cardboard [156,157,168] or a combination thereof [147,157,158,169,170]. Additional packaging levels, where given, frequently included cardboard boxes, interlayers, pallets and plastic (stretch) films [147,154,155,158–162,165–170].

The shelf-life of bakery wares is significantly influenced by water exchange processes as well as interlinked structural changes, aroma uptake and (microbial) spoilage [46,47]. To limit this and prolong shelf-life, products in the sub-category of bread and rolls were primarily packaged in polyethylene (PE) bags [120], LDPE bags with (polystyrene (PS)) clips [11,134] or (wax-coated) paper bags [120]. Further, material combinations such as paper and polylactide (PLA) [131] or paper and PET [121] were used. Secondary packaging was (HDPE [121]) plastic boxes. In two sequential studies, it was stated that these were returnable [11,134].

The EPDs belonging to this product category, on the other hand, show only one packaging concept, namely that of a plastic bag with an associated clip. Additional packaging levels again include cardboard boxes and plastic films [171–183].

The sub-group of fine bakery wares showed a more diverse and elaborated packaging spectrum. While primary packaging for some biscuits was solely PP or a metallized PP film [30], others were packaged in multiple levels [29,31]. The latter may be due to higher product requirements in terms of quality. For example, cream fillings of biscuits as well as cakes [29,30] exhibit higher moisture and fat content and thus spoil more easily [46,47]. Additionally, elevated packaging [29,31] may be due to the fact that these products are more hedonistic than, e.g., cereal products such as breakfast cereals [184]. Secondary packaging in all given cases was cardboard/cardboard boxes [29,30].

The more diverse and elaborated packaging spectrum is also reflected in the EPDs. Here, different multilayer materials with or without paper are described. Additionally, different combinations of plastic or paper board trays, films, banderoles and/or boxes are given. Additional packaging layers are comparable to the above-mentioned ones [146,185–217].

Last but not least, the category of ready-to-eat savories and snacks, including potato-, cereal-, flour- or starch-based snacks using the example of crisps, were primarily packaged in a multilayer film made of oriented polypropylene (OPP) and metallized OPP [132], a common solution found in this category due to the superior gas and light barrier allowing stable product quality in terms of, e.g., crispness and lipid oxidation (rancidity) [46,47]. Processed nuts were packaged in LDPE bags with a label. Additionally, a modified atmosphere was applied [118] to protect the oxidation-sensitive products [46,47]. Secondary packaging (box, unspecified) was only given for the last-mentioned product [118].

Insofar as stated, tertiary packaging of all considered product (sub)categories was mainly represented by plastic materials such as (LDPE) (stretch-)films [28–30,117] and shrink-films [117] as well as (wooden) pallets [27,127,128]. Further materials described were cardboard/carton boxes [116], corrugated pallet layer pads [27] and labels [117]. In one case, an HDPE trolley was given [121]. Besides this, some authors even calculated consumer (plastic) bags in [28,30,121]. However, for the majority of products, no information on tertiary packaging levels was available.

Summing up, it can be seen from the reviewed studies taken together in Tables 1 and 2 that predominantly plastic and aluminum packaging solutions were used in direct product contact. Further, it can be observed that packaging-specific information is not always given and that the detail of the same varies remarkably. Regarding the packaging levels, most authors give information on the primary packaging level, whereas secondary and especially tertiary levels are less frequently given [31,32,119,120,122–126,128–132,141]. In some cases, secondary and/or tertiary levels are even intentionally excluded [26,130,132]. Miah et al. [26], for example, justify not considering tertiary packaging (cut-off), for example, by the low weight percentage that comes from the tertiary packaging. Similarly, so do Sieti et al. [130]. Consequently, in many cases, only the primary packaging, and not the whole packaging system, is analyzed. This fact is also shown by Molina-Besch et al. [111]. Interestingly, different authors also seem to delineate packaging levels differently. For example, some authors include stretch films, which are often used to secure pallets [48], in secondary packaging [27,127,133], whereas others include them in tertiary packaging levels [28]. Additionally and interestingly, the EPDs under consideration distinguish between primary packaging and packaging for transport and do not go into detail about secondary/tertiary packaging levels (e.g., EPD on American sandwich [175]).

Furthermore, the level of detail of the information is deviating strongly. While some authors only mention the material, others include further information on, for instance, packaging containers (e.g., bag, tray, foil) [11,26–32,116–120,122–125,127–129,131–134], packaging aids (e.g., labels, adhesive tape, clips) [11,27,116–118,134], packaging weight [26–30,32,116,122,123,127,129,132,133], or dimensions [27,116], material composition (e.g., recycled content) [27,28,32,131], multilayer structure [27,30,132], usage of modified atmosphere packaging [118] or finishing processes such as printing [27,127]. EPDs usually reduce the information to the material used (e.g., EPD on crispbread [187]).

In some cases, information is directly included in the scientific paper, while in other cases, it is given as the supplementary material of the studies [26,28–30,32,117,118,123,127,129,130,134]. In addition, it is noticeable that packaging-specific information is often not given condensed at the beginning of the paper (e.g., materials and methods section, life cycle inventory) but spread over the text. Moreover, differences were also notable with regard to the data source. While some authors used primary data (e.g., specifications, information from companies), others used secondary data or based their calculations on assumptions. The most detailed information on packaging was found in the study by Cimini et al. [117].

Packaging End-of-Life

Regarding the packaging end-of-life, particularly waste management, country-specific scenarios are most frequently considered in studies where packaging (material) is mentioned and a cradle-to-grave approach is followed. This applies to, for example, rates of recycling, incineration or landfilling. For instance, Konstantas et al. [28] focused on chocolate production and consumption in the United Kingdom and included post-consumer waste management activities for the corrugated cardboard (recycling > incineration with energy recovery), aluminum (recycling > landfill) and plastic packaging (landfill > incineration with/without energy recovery) components. Additionally, efficiencies of the corrugated board and aluminum recycling processes were counted in. Further, authors who include disposal routes are, inter alia, Miah et al. [26] (United Kingdom), Bianchi et al. [129] and Cimini et al. [117] (Italy). Further, EPDs usually include primary packaging end-of-life (e.g., EPD on durum wheat semolina [151]).

Interestingly, most of the statements in the studies under review, as well as EPDs, are made based on, for example, reports on the national recycling rates of (packaging) materials (e.g., Cimini et al. [117,218]). The actual recyclability of the specific packaging solutions is, however, hardly addressed or analyzed in the reviewed studies [130,132]. This, however, is a knowledge field gaining importance and momentum in recent years [50], which is accompanied by different (e.g., design for recycling) guidelines [41], instruments and certificates (e.g., cyclos-HTP [219]). This becomes interesting, for example, in the case of very small packaging components or multilayer materials, for which the necessary sorting and recycling facilities often are not applied or even do not exist to date [52]. Accordingly, it is necessary to discuss whether the specified end-of-life scenarios are actually realistic and to what extent the results change.

Data Quality

It is well known that an LCA is only as reliable as the sources and dataset base it is built upon. Multiple sources and handbooks on LCA even state that data quality may largely determine LCA results [220]. In LCA, there are two main categories of data: primary and secondary. While primary data refers to actual data collected from sources of the investigated life cycle step (farmer, manufacturer, distributor etc.), secondary data refers to information from literature and databases. Quality thereof is, among other factors, determined by the recentness of the data and the model, geographical coverage, variability, representativeness and reproducibility [43,144]. The investigated studies took varied approaches to data quality issues. The sources for packaging LCA data were secondary in the majority of studies [11,26–30,32,116,118,120,122,125,128–130,134,141], whereas the remaining studies used primary and a mixture of primary and secondary data for packaging [31,117,121,123,126,127,131–133]. The actual sources of primary data were in-depth interviews and questionnaires with packaging producers, and for secondary data, the sources were the Ecoinvent and GaBi databases. Two of the studies were reviews that used published reports and results of other studies (published in journals), including their supplementary materials [11,141].

Espinoza-Orias et al. [120] and Jensen and Arlbjorn [134] took up the topic of data quality and usability of the like for sustainability assessment in the product category of bakery wares, specifically in the sub-category bread and rolls. The former authors even

compared calculations between mainly primary and secondary sourced data (generic study). Other studies worth commenting on from the perspective of their attention to data quality are Usva et al. [126], who created a whole set of criteria for data quality and development and explained them fully in the text, as well as Cimini et al. [117], who used PAS2050 requirements for data quality, including geographic and time scope as well as technology references. This is in line with the CEN/TR 13910:2010 report on criteria and methodologies for LCA of packaging, which mentions the importance of giving special attention to time, geography and technology aspects within the data collection phase of LCAs [221].

3.2.3. Life Cycle Impact Assessment

Impact Assessment Method and Impact Categories Used

As selected for, all of the examined studies assessed at least CO₂ emissions/global warming potential (GWP)/carbon footprint of the food packaging systems [118,120,124,125,128,133,134,141]. In most cases, several other impact categories were also included. Examples are ozone depletion, fossil fuel depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication and human toxicity [11,26–32,116,117,119,121–123,126,127,129–132]. The chosen impact categories depended on the used assessment method (e.g., ISO 14044 [67]) and the focus of the study in general. Using the above example of Espinoza-Orias et al. [120], two methodological approaches, namely PAS 2050 and ISO 14044 [67,108], were used. The former was used because it lays a focus on primary data, and the latter was used because the use of secondary data is allowed more. The aim was to compare the approaches and identify their influence on LCA results. It can be seen from this concrete example that the comparability of the studies is neither consistently given nor envisaged in this paper due to different scopes and applied assessment methods.

While carbon footprint is also covered by EPDs, other impact descriptive categories are, for instance, ecological footprint as well as water footprint (e.g., EPD on breakfast cereals [154]).

Sensitivity/Scenario Analysis

Of the present studies, only a few authors did not conduct a sensitivity/scenario analysis [122,124–126,128,132,141]. The others used this analysis to check for the robustness/generalizability of their results by alternating input data such as country of production [11,30,32,116,117,119,120,123,127,129,131,133,134]. Contrary to expectations, only a handful of studies included packaging in one or the other way in their sensitivity analysis [26–29,31,118,130]. For example, Volpe et al. [118] conducted an uncertainty and sensitivity analysis and concluded that abroad consumer markets and thus the final destination of (glass) packaging affect the LCA output (carbon footprint) significantly. However, the data for glass refers to nut spread cream packaged in a glass jar, which was excluded from the present review due to the product group exclusion reasons. Details for plastic bags used for the other products included in the present review were not given. Furthermore, Miah et al. [26] alternated packaging materials in an improvement analysis. Here, aluminum and PP were substituted with recycled material, paper with unbleached paper, and corrugated board with white lined board, while PET stayed unchanged. This led to “... a mix change in total environmental impact across all five confectionary products ...” and, on average (across all confectionary products analyzed), an increase in GWP. Jeswani et al. [27], in the other case, exchanged some of the carton boxes with standalone HDPE bags in a hypothetical scenario, which resulted in a lowering of GWP. Additionally, Noya et al. [31] analyzed alternative waste management practices for packaging materials (increased recycling rates) with the result that the environmental burdens for the global process decreased (including climate change). Significance was, however, shown only for products with higher packaging requirements (plastic and cardboard). Last but not least, Konstantas et al. [29] focused on packaging losses (2 to 10%) in the manufacturing process and concluded that the results are not sensitive to packaging losses. Next to packaging, it

can be mentioned that Miah et al. [26] and Noya et al. [31] also included food waste (reduction) in their analysis but did not interlink this with packaging (re)design. Surprisingly, although Williams and Wikström [11] had packaging embedded in their target, they did not conduct a corresponding sensitivity/scenario analysis.

3.2.4. Interpretation

Environmental Impacts and Mitigation Measures

While Table 2 exhibits values of packaging-related CO₂ emissions of different cereal and confectionary products on a single food item level, Table 1 provides an overview of product (sub) category-related emissions. As can be seen, single values range from 0.36 to 38.02% and in total, average packaging-related CO₂ emissions account for 9.18%. Despite the fact that different studies are hardly comparable due to, for example, different aims, scope, system boundaries and input data, it becomes apparent that the average value lies clearly above the estimated general global values of about 5% by Crippa et al. [2] and Poore and Nemecek [3]. However, the values well reflect the wide possible variation previously found by, among others, Poore and Nemecek [3], Verghese et al. [6] and Heller et al. [7]. When going into detail about the different (sub)categories, interesting tendencies and hotspots can be found. These are discussed in the following paragraphs.

In the category of confectionary and, further, in the sub-categories of cocoa and chocolate products as well as other confectionaries, including breath-freshening micro-sweets, where average CO₂ emissions (see Table 1) are 9.86 and 4.68%, respectively, the authors indicate that (raw)material sourcing is the main environmental impact driver. The provision and, in particular, the agricultural production of cocoa derivatives, milk powder and sugar can be highlighted. This is also reflected by the environmental impacts of the respective products (Table 1). Boakye-Yiadom et al. [116] offer an illustrative example, where milk chocolate yielded significantly higher than dark or extra dark chocolate due to the high impact of the animal-derived food ingredients. Further, associated manufacturing processes and (fossil) energy consumption as well as (international) transport are ranked particularly high in the studies under review [26,28,32,116,118,119,123,129,132]. Further, reduction of (food)waste is mentioned as one way to cut carbon emissions [26,132]. In relation to packaging, behind the above-mentioned factors, significance has also been reported by different authors [26,28,116,118,119,129]. In this context, the main focus is on material choice [116,118,129]. In their work, Bianchi et al. [129] were able to show that a single PP layer is better than a combination of commonly used aluminum/fiber-based packaging solutions. Material (aluminum) substitution, if possible, is also on the agenda of Boakye-Yiadom et al. [116], who alternatively recommend using recycled or weight-reduced packaging solutions. Due to a lack of data, especially regarding thematic coverage, the studies [26,28,116,119] as well as Pérez-Neira et al. [123] do not go into detail about packaging but mention the importance of packaging optimization. Last but not least, collaboration with science and industry to develop packaging materials and solutions with lower impact were discussed by Miah et al. [26] and Boakye-Yiadom et al. [116].

Turning to cereals and cereal products, one can see that the average packaging-related CO₂ emissions from whole, broken or flaked grain, flours and other milled products and starches, breakfast cereals as well as pasta are 1.25, 5.30, 19.68 and 7.24% (see Table 1), respectively. The significantly higher value for breakfast cereals is justified by the fact that wet porridge in a single-use glass jar was included in one study [130]. This is a packaging solution known for its high environmental impact, mainly due to very high process temperatures and, thus, energy needed in the production of the same [43]. Accordingly, the authors suggest replacing this with a lightweight plastic packaging solution (pouch), which exhibits 15.77 instead of 38.02% with regard to CO₂ on a single product level [130]. A further change in material in the sub-category of breakfast cereals was proposed by Jeswani et al. [27], who found that replacing the well-known plastic bag and carton box combination for breakfast cereals with (standalone) plastic packaging (bags or pouches) could reduce carbon emissions. A possible preference for plastic packaging (PE bags) instead of paperboard

boxes was also communicated by Cimini et al. [117] for dried pasta. The same authors also highlighted the correlation between high packaging density and the reduced packaging and transportation need for long pasta (e.g., spaghetti) in comparison with short pasta (e.g., spiral-shaped) due to the different shape and thus volume of pasta per functional unit. Furthermore, in the broader sense, relevant findings of packaging included the necessity to find the right trade-off between packaging function and environmental impact [141], to combine and prioritize actions [27,117], to engage relevant stakeholders (industry and government) to find best-practices and standards (e.g., packaging, types, mass reduction, recyclability) [130] and to intensify LCA applications and transparently communicate the results thereof (e.g., labelling) [124,141]. All in all, the packaging focus in this product category was less distinct than in the previous one, and the emphasis was mainly on the optimization of agricultural production and the provision of products [27,117,124–127,141], reformulation of recipes [128,130] and changing consumer habits. Here, for instance, the cooking of pasta [117,127], the consumption of cereal products with (cow's) milk [27] or the use of ingredients of animal origin (egg, milk) [128,130] were related to higher impacts.

Since no EPDs for whole, broken or flaked grain are available to date [140], only comparisons of flours and other milled products and starches [151–153], breakfast cereals [154] and pasta [147,155–170] can be made at this point. Here, the average values are found to be 3.22, 12.37 and 8.56%, respectively. Although, as stated above, direct comparison is difficult, interestingly, a similar ranking can be identified. Therefore, flours and other milled products and starches score the lowest, while pasta and breakfast cereals, in ascending order, score higher. A possible explanation for this is the level of complexity of the packaging solutions. While milled, powdery products are densely packaged in simple bags, more volume-taking pasta is packaged in more stable and elaborately designed packaging solutions partly combining different materials. Breakfast cereals, in the present case, exhibit even higher packaging effort with a plastic bag and an additional cardboard box.

In the case of bakery wares, such as bread and rolls, as well as fine bakery wares, an average contribution of packaging to the CO₂ emissions of 4.37 and 11.22% was found (Table 1). As expected, raw material (e.g., wheat, milk, palm oil, sugar) sourcing is the main environmental impact driver [29–31,120,121,131,134]. This is (not in strict chronological order) most often followed by processing and correlated energy use [29,30,131,134] as well as consumption (e.g., refrigeration, toasting) [120,134], although Svanes et al. [121] achieved a different result here. Further, waste at retail [121] and consumption level [120,121] as well as transport [30,31,120,131,134] and packaging are mentioned. The latter again played a less important role in other selected studies [29,30,120,121,131]. Of the packaging-related impacts, Konstantas et al. [30] named primary packaging as the most contributing factor. Several mitigation measures similar to the above product categories (e.g., efficient raw material sourcing) are given in the reviewed studies [11,29–31,120,121,131,134]. Regarding packaging, four main points were discussed by the authors, namely, portion size [120,121], packaging re-design [11,121] and light-weighting [29] as well as proper end-of-life management [31,134]. In the case of right-sizing portions, Espinoza-Orias et al. [120] as well as Svanes et al. [121] proposed that smaller sizes of bread (e.g., loafs) would reduce the amount of wasted bread (due to, e.g., spoilage) at the consumption stage but at the same time increase the need for packaging which, in the case of reduced food waste, still could lead to an environmental benefit—a finding that has already been shown in other contexts. Packaging re-design, on the other hand, included the substitution of a PET/paper packaging material with a material based on cellulose fibers and a perforated paper bag coated with PE on the inner side. While the former alteration allowed the bread to be kept fresher for one day, the latter solution allowed the product to be perceived as fresh even four days after production, which could lead to an environmental benefit since the impacts of producing the packaging alternatives are almost the same as with the packaging in comparison. The authors, who laid a strong focus on indirect packaging effects in their work, pointed out that further (large-scale) tests and the inclusion thereof in LCAs would be necessary to validate the results [121]. Studies on shelf-life extension strategies and waste prevention

were also asked for by Williams and Wikström [11], who additionally highlighted that good product packaging should not encourage consumers to re-pack their products at home. This is a measure that could avoid unneeded extra packaging material. The latter also represents a recent research field where the understanding of consumer habits and social norms are focused, and food and packaging researchers are asked to more closely collaborate with social sciences and humanities [222]. Turning to the light-weighting of packaging, Konstantas et al. [29] calculated in their study on different cakes that a material reduction of 30% could lead to a significant drop in the GWP of cakes (except for whole cakes and cheesecakes). Food safety and shelf-life, however, must not be jeopardized as a result. The topic of end-of-life (improved waste management strategies and recycling rates [31,134]) was discussed by Jensen and Arlbjorn [134], who pointed out explicitly that hotspots should not only be identified on the basis of their impacts but also on the basis of their potential for change and that the awareness for possible burden shifting from one life cycle stage or impact category to another by just focusing on, for example, GWP values, should be kept at a high level.

Comparing the values found for the category of bakery wares and the sub-categories bread and rolls [171–183] as well as fine bakery wares [146,185–217] with the EPDs, values of 17.03 and 14.86% were found. In both cases, the values are higher than the ones from the studies under review. Possible causes for this may be, amongst others, the packaging material or the database used. The latter is frequently given to be mainly based on primary data. In the case of Italian bread (pagnotta), for example, it is stated that generic data contributes less than 10% to the calculation of environmental performance [182].

Lastly, in the category of ready-to-eat savories and snacks, which include potato-, cereal-, flour-, or starch-based snacks as well as processed nuts, the average contributions of packaging to the CO₂ emissions were 8.14 and 20.10% (Table 1). Since these products were also covered by the already discussed research from Nilsson et al. [132] and Volpe et al. [118] in the product category of confectionary products, no further detail on packaging can be named at this point.

Significance of the Results

In their parallel (mainly primary/secondary data) studies on bakery wares (loaves of sliced bread), Espinoza-Orias et al. [120] conclude that data quality is key for not only the accurateness of the LCA results but also for honest sustainability communication. While secondary LCI data may be useful for rather uncomplicated (company) internal detection of hotspots or projections at the (inter)national level, high-quality primary data is needed for communication to consumers via, e.g., carbon labelling [138]. Similarly, Jensen and Arlbjorn [134] conclude that high-quality data is needed to achieve robust results.

In relation to impact assessment, Williams and Wikström [11] address food losses and food waste as well as packaging optimization in their conclusion. Here, they call for the inclusion of these indirect packaging impacts in food and packaging LCAs to examine how waste and, in consequence, negative environmental impacts can be diminished. Further, they highlight that legal texts should more strongly include the topic of food losses and food waste prevention by appropriate packaging solutions.

When talking not only about one impact category (e.g., GWP), a multi-criteria decision analysis (MCDA) as used, for example, by Miah et al. [26] can be helpful. This allows to compare different environmental impact categories together and to ease decision-making and benchmarking. Accordingly, MCDA is increasingly being used in LCA [223].

4. Improvement Strategies

As described at the outset, food systems are responsible for a large proportion of environmental impacts, especially GHG emissions, worldwide [2]. Increasing efficiency in food production and, above all, reducing food losses and waste can, therefore, directly contribute to lowering the global footprint [19,224]. In the last decade, the focus has therefore been on targeting, measuring and reducing GHG emissions. Along with that,

efforts by different stakeholders have been conducted or started, and respective policies have been outlined [52,225]. Packaging is playing an increasingly important role in this context. While efforts initially focused on the reduction of the direct environmental impacts of packaging (e.g., material use), today, the focus is increasingly on the indirect impact (e.g., reduction of food waste), as it has been recognized that this has a potential leverage effect [13,34,52,110,226,227]. However, the actual inclusion of the indirect impact in research, development and innovation activities lags behind [111], as has also been shown by the present review. Accordingly, strategies for the acceleration of the implementation are needed. In this context, Wikström et al. [52] elaborated a research agenda including 5 packaging-related issues. These include: (i) quantitatively understanding packaging's diverse functions and the influence on food losses and waste in the context of the (in-)national food system, (ii) more thoroughly understanding trade-offs between packaging and food losses and food waste, (iii) further improving representation thereof in LCA and (iv) designing processes and related methods as well as (v) setting stakeholder incentives such as profitable business models. To support this transition, the following text aims at aggregating possible points of action in the area of packaging, LCA and management beyond the topic of cereal and confectionary packaging.

4.1. Packaging

Starting with packaging, recommendations or suggestions found in this and other studies and texts can be very well set in the context of the existing Packaging Sustainability Framework with its four principles (effective, efficient, cyclic, safe) [42,43] (see also Table 3). This may act as a basis for future improvement regarding the reduction of the direct and indirect environmental impacts of food packaging. However, it must be clearly pointed out that there may be trade-offs and that verification of the respective product packaging system is essential [42,43].

Table 3. Recommendations for improving the sustainability of food packaging based on the structure given by [36,46].

Sustainable Packaging Principle	Recommendation	Reference
Effective	Usage of packaging fit for purpose	[43,44,46]
	Provision of appropriate shelf-life	[43,111] based on [228–230]
	Employment of shelf-life extension strategies	[11,231]
	Avoidance of over-engineering	[43]
	Holistically integrate primary, secondary and tertiary packaging levels	[43]
	Provide packaging with high consumer value	[10,11,43,111] based on [229]
	Target-group oriented packaging with consumer value	[10,11,43,111] based on [229]
Efficient	Right-sized portions	[111,120,121] based on [120,228,229]
	Provide clear and understandable communication	[11,37,43]
	Optimize packaging with regard to function and environmental impact	[26,28,29,37,43,111,116,119,123,141] based on [27,232–245]
	Rethink material choice and packaging design	[10,27,43,111,116–118,121,129,130] based on [27,120,233,235,236,238,240,244,246–251]
	Increase transport efficiency	[43,111,141] based on [232,237,244]
	Decrease energy demand along the supply chain (e.g., process and transport)	[43,111] based on [243]
	Focus on renewable resources (materials and energy)	
Cyclic	Avoid unneeded packaging	[111] based on [252]
	Prevent and reduce food and packaging waste along the supply chain	[26,43,111,132] based on [242];
	Use reusable, returnable or refillable (primary, secondary, tertiary) packaging solutions	[43,111] based on [240,246,252,253]
	Design packaging for recycling	[35,37,39,41,43]
	Design packaging from recycling	[37,43,111,116] based on [230,231,244,248,249]
Safe	Use bio-based and/or bio-degradable materials	[37,43,44,111]
	Assure proper end-of-life management	[31,43,134]
	Promote a circular economy	[35,36]
	Focus clean production	[35,37,43,44]
	Install ecological stewardship	[37,43]
	Reduce possibility for litter formation	[43]

Going into detail about the effectiveness of food packaging and analyzing the findings with regard to packaging that is fit for its purpose and, thus, is satisfactorily fulfilling its containment, protection, communication and convenience function [43,44,46,47], one can see that authors currently lay a focus on protection and convenience. Regarding protection, which is enabled by the often-overseen basis function of containment [46,47], the provision of an appropriate or prolonged shelf life is frequently mentioned [43,111,228–230]. In this context, the application of well-established and modern shelf-life extension practices [11], such as modified atmosphere packaging (MAP) [46,254] or active and intelligent packaging solutions (AIP) [46,47,255–257], can be named. Attention, however, should be paid to the possible over-engineering of packaging and not losing a holistic view of the packaging system. With regard to over-engineering, it may be reasonable to re-assess the actual product requirements and avoid unneeded packaging, as well as reduce packaging complexity or components, where possible. This can be supported by, for example, market research or research on consumption patterns [43]. With regard to a holistic view, the interlinkage between primary, secondary and tertiary packaging must be considered, since changes on one level may also necessitate changes on other levels. For instance, a reduced or less mechanically stable primary packaging (material) may induce the need to design the secondary or tertiary packaging to be more stable [43,111]. With respect to the convenience aspect of packaging, several authors take up the topic of developing packaging with a high consumer value or target group orientation. This includes, *inter alia*, packaging that is easy to open, reclosable or easy to empty and, in general, does not frustrate or even encourage consumers to re-pack products at home [10,11,43,46,111,223,258]. A point emphasized several times is also the right-sizing of portions to avoid food waste at the consumer level. This is a measure that, despite the increased packaging effort, can lead to a lower total environmental impact [111,120,121,228]. Next, the communication function of packaging, which has been somewhat overlooked by studies, could additionally play a significant role in food waste prevention in the future, as it can have a considerable influence on consumer behavior [12,33,259,260]. Examples of implementation would be easy to read and understand directions on how to store, prepare and use products or information on how to interpret best-before or consume-by dates, as well as how to dispose of the packaging [11,37,38,43].

Turning to the cluster of recommendations on efficiency, it can be seen that in the past, an emphasis was placed on this topic by many authors and that three hotspots are reoccurring. These are packaging itself, transport and energy. In the case of packaging, the majority of authors are looking for a sweet spot, a point where minimal packaging is used, but at the same time, the quality of the product is not affected. The same applies to product waste. In this context, however, it is necessary to mention that the impetus should come from the area of optimization rather than the pure minimization or elimination of packaging. This is reported to be a target-oriented approach to find a satisfactory balance between effort and impact [28,29,37,43,111,116,119,123,141,144,261]. Further emphasis in the scientific literature is laid on material choice or substitution as well as the (re)design of product-packaging systems. For example, some authors change traditional packaging concepts such as a bag in a box to a free-standing plastic bag or a glass jar to a plastic pouch. (Re)design examples, on the other hand, are packages exhibiting a perforation, a wide neck or that stand upside-down. All are attempts to increase the efficiency of product emptying and thus product waste, which may also be achieved by altering the product itself (e.g., rheology) [11,27,43,111,116–118,120,121,129,130]. Further, the use of, for example, concentrated products is discussed. This can also lead to reduced packaging effort. The latter is also of interest for transport efficiency. Here, packaging weight, avoidance of void volume and stack-ability stand in direct correlation to transport efforts (e.g., frequency) and thus impacts. The measures applied are, next to packaging weight, the packaging-to-product ratio, cube utilization (volume) and pallet utilization. Alternatively, and where possible, bulk shipping could also be a way to increase efficiency [43,111,141,261]. With respect to energy, choosing materials with low embodied energy and further increasing

the efficiency of production processes and transport as well as detachment from fossil energy sources can be named. In addition to this, the consumer stage should not be underestimated. Here, a product-packaging system that does not need to be, for example, stored under refrigerated conditions or long-life packaging (e.g., aseptic packaging) may have advantages compared to other solutions [43,111].

As for the other areas, for cyclic packaging, different recommendations are given in the scientific literature. Clustering and (potentially) ranking them could be a valuable approach to link them with the well-established waste hierarchy, which is laid down by the EU Waste Framework Directive. Here, waste prevention as well as (preparing for) reuse are the most favored options. Behind this, recycling (including the technical and biological cycle) and energy recovery are mentioned. The least preferred option should be waste disposal through a landfill [36]. Through clustering, it becomes clear that most of the points discussed by different authors already focus on the upper part of the waste hierarchy. While the prevention of waste has already been discussed in the paragraphs above, reuse strategies given include reusable, returnable and refillable solutions not only at the primary packaging levels but also at the secondary or tertiary levels. Examples are (plastic) trays and crates, molded plastic containers for specialty products, (beer) kegs, intermediate bulk containers, roll cages or (wooden or plastic) pallets. It is important to consider that strategies may work in one case but not in another. Therefore, it is necessary to identify if the respective business-to-business or business-to-consumer case allows for such solutions. Situations where this often works well are those where short distribution distances, frequent deliveries, a small number of parties or company-owned vehicles are present. Therefore, a (custom) closed-loop system can be maintained [43,111]. Where reuse is not possible but waste is still generated, the collection, sorting, and forwarding of the respective waste fractions for recycling should be the main target [36,262]. To support this, the past years have shown a steep increase in guidelines focusing on design for recycling [37,39,41,43,261,263]. While these today focus mainly on mechanical recycling, chemical recycling may also be in focus in the upcoming years. A constant point of discussion is, however, the trade-off between lightweight multilayer materials exhibiting a small environmental footprint and their recyclability [50,264]. Next to designs for recycling, designs from recycling are increasingly the focus of science and industry since they are often associated with reduced primary material and energy consumption. The use includes materials of all categories, such as glass, metal, paper and board, as well as plastic. In the latter case, it must be, however, highlighted that at the moment, mainly recycled PET is used as primary food packaging material. Most approval processes for, e.g., PE and PP are still pending due to safety concerns [50,265]. Another trend in the past years is the increased production and use of bio-based and/or bio-degradable materials (e.g., polymers) [266]. The latter may be used in scenarios where entry into the environment is foreseeable. This could be either in the form of controlled (home or industrial) composting or in the form of uncontrolled littering. This could, in certain circumstances, reduce the amount of food waste going to landfill. While there is still a debate about the actual advantages (e.g., lower carbon footprint, material properties, bio-degradability) and disadvantages (e.g., agricultural impacts, competition with food production, end-of-life management, costs) of bio-plastics in different fields of applications [267], it is well agreed that all materials, regardless the material type, should be kept in the circle as long as possible and that proper end-of-life management is needed to reduce environmental impacts. Therefore, the transformation from a linear to a recycling and ultimately to a circular economy can be accelerated [35,36,262,268,269].

Last but not least, the area of safe packaging seems not to be in the forefront focus of the reviewed literature since the effects are mainly noticeable in other impact categories than GHG emissions. What can be said is, however, that the avoidance of hazardous substances (including GHG active substances) as well as cleaner production (e.g., avoidance of volatile organic components) can, next to ecological stewardship and litter reduc-

tion (e.g., small parts of packaging), support the transition towards a more sustainable future [35,37,43,44,261,268].

4.2. Life Cycle Assessment

In the past, a large number of LCAs were carried out in the food sector. It is clear that not every issue requires the inclusion of packaging. However, where packaging has been included in LCAs in one way or another, this often has not been sufficiently addressed [13,111]. The following paragraphs, therefore, aim to provide suggestions that show the potential to improve the quality of future studies and the validity of packaging-related conclusions drawn from them. To structure this, the multi-step approach based on ISO 14040 and 14044, (i) goal and scope, (ii) life cycle inventory, (iii) life cycle impact assessment and (iv) interpretation, is used again for this purpose [66,67] (see also Table 4).

Table 4. Recommendations for improving food packaging life cycle assessments (LCAs) based on the structure given by [66,67].

Life Cycle Assessment Stage	Recommendation	Reference
Goal and scope	Holistic representation of the food packaging system	[43,111]
	Inclusion of all packaging levels	[43,111]
	Inclusion of direct and indirect packaging effects	[43,52,111]
	Awareness of interrelation	[43,111]
	Integration of Circular Economy principles within the goal and scope of food packaging LCAs	[270–272]
	Special attention to time, geography and technology aspects	[130,221,273]
Life cycle inventory	Focus on appropriate and reasonable high-quality data and software	[43,52,120,134,144]
	Provision of data transparency and consistency	[274]
	Usage of common language (definitions)	[51]
	Inclusion of details on packaging	[41]
	Inclusion of actual packaging recyclability and recycling quotas	[39,41]
	Inclusion of food and packaging waste	[111]
	Inclusion of consumer attitudes and behavior	[111]
Life cycle impact assessment	Use and build upon standards	[66,67,102]
	Include sensitivity or scenario analyses	[52,66,67,111] based on [12,13,275]
Interpretation	Discuss limitations	[43,52,111]
	Address trade-offs and burden-shifting	[31,134]
	Use multi-criteria decision analysis (MCDA)	[31,134]
	Only give sufficiently substantiated recommendations	[52,138]

Starting with the goal and scope of a packaging-related LCA, it has to be stressed that the holistic representation of the entire food packaging system is a prerequisite for all further steps. This means that packaging relevant points beyond production and waste management have to be included. These are, for example, indirect effects such as food waste

or transport efficiency along the supply chain. Further, all packaging levels, from primary to tertiary packaging, should be considered, and awareness of their interrelationship should be given. This is relevant, for example, in comparative studies where different packaging variants are included [43,111,221].

Another issue that is worth addressing is the increasingly important concept of the Circular Economy. A new legislative initiative undertaken by the European Commission in adopting the Circular Economy Action Plan in 2015 had a significant impact on the field of packaging. This initiative led to changes in existing directives and the imposition of stricter rules as well as the introduction of the Product Environmental Footprint (PEF) circularity formula [270].

Further, the CEN/TR 13910:2010 report on criteria and methodologies for LCAs of packaging also mentions the importance of time, geography and technology aspects within the goal and scope definition as well as data collection phases of LCA. These time and technology aspects are important due to the characteristically short life cycle of packaging (e.g., design changes). The geographical aspect considers different supply chains across several countries and continents [221].

Building upon this sharpened approach, it is further necessary to increase efforts in the area of life cycle inventory to achieve meaningful results. First and foremost, data quality can be mentioned here [43,120,134]. Although it is well-known that data gathering can be quite resource-intensive (e.g., time, budget), ideally, primary data (e.g., directly (on-site) collected data) should be used. However, if not otherwise possible, secondary data (e.g., database, reports, statistics) may also be taken. Furthermore, in some cases, assumptions may be necessary [43,52,120,134]. With secondary data selection, there is also another issue. LCA software very often comes bundled with specific databases, and there is evidence that the choice of software used for environmental analysis can affect the relative comparisons between differing package system options and, therefore, the decisions that will be made. This effect is magnified by the natural inclination of the user to employ data sets that are “convenient” when using specific software packages [276]. Regardless of the source, however, it is helpful to present the information in the studies themselves or in the appendix in a transparent and bundled manner in order to promote the progress of the research field as well as comparability. This is a point that is increasingly requested by different stakeholders and encouraged by scientific journals on LCA such as The International Journal of Life Cycle Assessment and Environmental Impact Assessment Review [220,277]. Moreover, care should be taken to use widely accepted definitions (e.g., ISO standards) to avoid the misinterpretation of, for example, packaging levels [51].

In relation to primary, secondary and tertiary packaging, it is advisable to collect information that exceeds the one on the base material used. This refers to information on the packaging material (e.g., exact material, size, additives, barrier, color, print), packaging aids (e.g., closure, liner, gasket, valve) and decorations (e.g., labels, adhesives, decoration, size) [41] as well as any other relevant points such as modified atmosphere packaging (MAP) [46,254] or active and intelligent packaging (AIP) [46,47,255–257]. Although, at first glance, it may seem a bit far-fetched, addressing these points helps to assess the actual recyclability of a packaging solution in a target market or region (e.g., by using (inter)national guidelines) and potentially point out improvement possibilities [39,263]. Looking at the markets in more detail, it should be noted that some (federal) states have different collection, sorting and recycling practices, which means that recovery rates may differ in some cases from the average values for a country [278]. Accordingly, more focus should be placed on these currently rather underrepresented points to further increase the validity of LCA results.

Further, more attention should be paid to food and packaging waste generated at different supply chain stages (e.g., production waste, loss during transport and retail) and where the remainder of this waste is. Especially in efficiency-driven countries, data up to retail is often available. At the consumer level, however, the data situation is often less satisfactory. Therefore, more attention should be paid to better understanding consumer

behavior and attitudes in the future. Points of interest could be consumers' preference for food/packaging, un/re-packing habits, storage and use of products, food waste as well as engagement in separation and disposal of packaging and preference for, e.g., bio-based and biodegradable/compostable packaging materials [56,111].

Turning to the LCIA, it can be reiterated that existing (e.g., ISO) and recently developed standards (e.g., PEF) provide a solid basis for the calculation of environmental impacts [66,67,102,103]. In the context of these, sensitivity or scenario analyses are mentioned, as they are a method to check for the validity of results or to describe possible variations/situations [66,67]. Applying this supports the authors if, for instance, different assumptions have to be made or the importance of different packaging attributes is to be tested [52,111]. A possible approach in relation to, for example, food waste originating from different packaging solutions would be the following: (i) examination of the situation (e.g., amount, reason) and gathering of supporting primary (e.g., experiments) or secondary data (e.g., literature), (ii) identification, definition and evaluation (e.g., experiments) of influencing packaging attributes, (iii) scenario development (e.g., alteration of packaging size) and evaluation as well as (iv) calculation and interpretation of results [52] based on [12,13,275].

Last but not least, interpretation of results has the potential to be improved in future LCAs. Depending on whether the respective study has a packaging focus (*packaging* LCA) or not (*food* LCA), different recommendations can be found in the literature. For *packaging* LCAs, awareness about limitations (even implicit ones) of the conducted study as well as transparent reflection thereof in the corresponding discussion can be highlighted [43,52,111]. This should include, once more, currently underrepresented points such as interdependencies of packaging levels, consumers or waste-related issues [52,111,221]. Furthermore, trade-offs and possible burden-shifting can be addressed using, for example, single-score values or multi-criteria decision analysis (MCDA) [31,134]. Where such critical discourse is, e.g., due to space limitation, not possible, giving recommendations or directions for packaging (re)design should therefore be refrained from. On the contrary, it would be more beneficial to underline the need for further research. The latter also applies to *food* LCAs [111].

4.3. Management

When it comes to promoting sustainable food packaging systems, different challenges and opportunities exist. The challenges include, for example, established economic systems that are traditionally strongly oriented toward growth and profit and are slow to implement necessary changes. In addition, there is often a need for improved holistic sustainability awareness, networking and exchange with the economic environment. This finds reflection until the single company and department level [43,52].

In order to more easily overcome the activation energy required for a change, various catalytic measures can be adopted on different levels (see also Table 5). At a meta or policy level, which rather reflects a top-down approach, incentives [52,111] such as corresponding legal frameworks, facilitation for exemplary companies [15,268,279], as well as support or funding for research, development and innovation can be named [222,280]. This motivates companies along the food supply chain to develop new business models in which saving resources and reducing or avoiding food losses and food waste are valued and gains and risks are shared equally [52]. Further impetus provides strong engagement and the cross-linking of relevant stakeholders (e.g., industry, government [130]) to promote best practices (e.g., recyclable packaging), standards, as well as an open (science) approach [274,281,282]. Education offensives at different levels are also seen as helpful. Therefore, for example, more and more schools and universities include packaging in their curricula [283].

Table 5. Recommendations for management-related activities to promote sustainable packaging.

Recommendation	Reference
Give incentives	[52]
Develop new business models	[52]
Engage and connect stakeholders	[130]
Follow an open (science) approach and promote best practices and standards	[274,284]
Promote education	[283]
Develop companies to sustaining corporations	[43,285]
Strengthen collaboration and communication	[26,116,130]
Avoid double efforts	[26,116,130]
Identification of environmental hotspots and potentials for change	[27,117]
Combine and prioritize actions	[27,117]
Extensively test (re)designed packaging solutions	[43,46–48]
Communicate sustainability aspects transparently and provide evidence	[121,138]
Avoid misleading or greenwashing	[124,141,286]

Next to this, the bottom-up approach also bears huge innovation potential. In particular, a lot can be expected from companies that, with reference to the sustainability phase model, have already left the phases of rejection, non-responsiveness, compliance and efficiency behind them and are already operating at the levels of strategic proactivity and a sustaining corporation [43,285,287]. As above, the cooperative approach should be emphasized here. For instance, science and industry can collaborate to develop improved food and packaging solutions, or communication along the supply chain can promote overall sustainability and avoid double efforts [26,43,116,130].

At the company level, the management of sustainable packaging development should target the identification of environmental hotspots and potentials for change (see also Section 4.2) as well as combining and prioritizing actions (see also Section 4.1) [27,117]. Here, it is especially important that supposedly more sustainable packaging approaches or solutions are also tested extensively (e.g., packaging performance, product quality, shelf life and waste, consumer attitudes and handling, environmental impact) in order to ultimately bring a product onto the market that is successful in all dimensions [43,46–48,70]. In times like these, when different consumers and other stakeholders are becoming increasingly aware of the sustainability of food packaging [74], it is vital to communicate the developments made in a transparent manner and provide factual information about the sustainability aspects of packaging. Explicit (e.g., text, labels, certificates) and implicit (e.g., pictures and graphics, colors, haptics, font, shape) communication thereby can take place through a variety of channels [56]. This can include, for example, on the packaging itself, but also on websites or various other advertising channels [121,138,140]. Whichever way is used to communicate, it is particularly important that there is no misleading or greenwashing [124,138,141,259,286] in this context, which is picked up in a recent initiative on substantiating green claims by the European Union [255,288,289].

5. Conclusions

In the past, it has been shown that packaging can have positive environmental effects, especially when it protects resource-intensive food products and thus prevents losses and waste of the same. This is an essential point when it comes to reducing GHG emissions associated with the global food supply chain. In the present review with a focus on LCA studies, it was shown that the average contribution of packaging to the overall footprint of the product packaging system is 9.18% for the product group of cereals and confectionery, which has not been the explicit focus of scientific literature to date. This value is approximately twice as high as the estimated value for global GHG emissions for packaging but fits in well with previous dimensions for packaging of various food groups, which range from a few percent to more than one-third. In this context, however, it must be emphatically pointed out that direct comparisons in this area are not permissible or are

difficult to carry out, as the studies differ greatly in some cases. The results can therefore be seen more as a size estimate.

In addition, the present review provided valuable information about the type and quality with which packaging has been included in analyses so far. In particular, it showed that packaging was often not in focus, and if it was, it was often not sufficiently included at all levels (primary, secondary and tertiary). It also showed that mainly direct (e.g., material) and not indirect impacts (e.g., food waste, transport efficiency) were considered and that data quality and presentation could be improved.

Based on these evaluations and including further literature, recommendations for the sustainable design of food packaging, its analysis by means of LCA and innovation-supporting management could be given. In the area of packaging, it can be particularly emphasized that packaging must be designed to be effective, efficient, recyclable and safe, and that interrelationships between the individual packaging levels must always be considered. With LCA, on the other hand, it is necessary not to lose sight of packaging from the beginning, including the definition of the goal and the scope, through the LCI process over LCIA to the interpretation and issue of recommendations. In addition, to obtain accurate results, primary data should be used whenever possible, while secondary data are recommended for a rough estimate of influences. LCA practitioners should also refrain from issuing packaging-related recommendations if these have not previously been sufficiently included in the studies. In this case, the reference to the need for further studies is more appropriate. Last but not least, the management-related part dealt with how innovation can be fueled at different levels and showed that collaboration as well as transparent and honest communication of sustainability aspects within the supply chain and towards the consumer is a key instrument for realizing sustainability at all levels.

Against this background, the authors see considerable research and development potential in the areas of better coverage of the cereal and confectionary product group, optimization of packaging and evaluation of the actual influence of the same, the meaningful design of LCAs, the demonstration of indirect packaging effects along the supply chain, new business models and models for cooperation as well as communication of sustainability aspects.

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Article

(Not) Communicating the Environmental Friendliness of Food Packaging to Consumers—An Attribute- and Cue-Based Concept and Its Application

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Abstract: While consumer understanding of and preferences for environmentally friendly packaging options have been well investigated, little is known about the environmentally friendly packaging attributes communicated to consumers by suppliers via packaging cues. We thus propose a literature-based attribute-cue matrix as a tool for analyzing packaging solutions. Using a 2021 snapshot of the wafer market in nine European countries, we demonstrate the tool's utility by analyzing the cues found that signal environmentally friendly packaging attributes. While the literature suggests that environmentally friendly packaging is increasingly used by manufacturers, our analysis of 164 wafer packages shows that communication is very limited except for information related to recyclability and disposal. This is frequently communicated via labels (e.g., recycling codes, Green Dot) and structural cues that implicitly signal reduced material use (e.g., less headspace and few packaging levels). Our attribute-cue matrix enables researchers, companies, and policymakers to analyze and improve packaging solutions across countries and product categories. Our finding that environmentally friendly packaging attributes are not being communicated to consumers underscores a pressing need for better communication strategies. Both direct on-pack and implicit communication should help consumers choose more environmentally friendly packaging. Governments are encouraged to apply our tool to identify communication gaps and adopt labeling regulations where needed.

Keywords: packaging; environmentally friendly; eco-friendly; sustainable; consumer; strategy; attribute; cue; marketing; wafer



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1. Introduction

From an environmental perspective, food packaging is both boon and bane. As a boon, it preserves food and supports its efficient transport; thus limiting the waste of food and resources [1–4]. However, the bane of packaging can seem overwhelming: nearly 200 kg of packaging waste is generated each year in the European Union per inhabitant [5]. A large part of that waste goes to incinerators or landfill [6], but much of the packaging ends up in the environment [7]. As the packaging market is expected to grow [8] and many of today's packaging solutions are less environmentally friendly than they could be, both waste management and packaging systems call for redesign [9,10].

Packaging has become an environmental villain, a necessary evil, or even an unnecessary cost position that ought to be minimized [11,12]. The European Commission's action

plan for the circular economy aims at developing a sustainable, low carbon, resource efficient, and competitive European economy. Developing environmentally friendly packaging is one of the key items on its agenda [13], and thus a keen area of interest to scholars and practitioners [14,15].

Developing environmentally friendly packaging, however, is a difficult task. It is a balancing act between competing demands. Packaging must satisfy environmental requirements, food protection and logistics requirements, production and marketing requirements, and strategic and operational requirements. Such solutions cannot be developed by one company in isolation but only in the context of multidisciplinary product-packaging development teams [14]. These need to involve the entire supply chain: suppliers of raw material, products and packaging, brand owners, retailers, collectors, and recyclers [12].

It further complicates packaging development that consumers are not always eager to embrace environmentally friendly designs. Consumers perceive compromises between environmental friendliness and functional performance that they are unwilling to make [16,17]. Environmentally friendly packages are usually negatively associated with convenience, which leads to lower perceived functionality and a reduced willingness to purchase [16]. Consumers also harbor false beliefs about the benefits of alternative packaging materials (e.g., recycled, bio-based, or bio-degradable plastic) [17,18]. The willingness to purchase environmentally friendly packaging is further limited by time pressures and the cognitive overload caused by much information and a disinclination to process it [10]. In their defense, though, communication on sustainability is often misleading, which creates confusion and discomfort among consumers who are unable to differentiate between environmentally friendly packaging and packaging that just claims to be [19].

Still, for an environmentally friendly packaging solution to succeed in a consumer market, it has to meet with consumer acceptance. To better understand what that entails, this study adopts a consumer-based perspective on environmentally friendly packaging. That means we examine attributes and cues explicitly or implicitly perceived as sustainable by consumers.

Consumer perception does not necessarily agree with life cycle assessments (LCA), nor does it recognize the economic and social pillars of sustainability. However, it is critical for acceptance of a packaging solution. The fact is, consumers often harbor a simplified understanding of a packaging's environmental impact and rely on behavioral routines and simple heuristics such as colors, material, or recycling options [10,20]. Additionally, sometimes they are outright wrong in their assumptions or evaluations of packaging [14,20–22]. That is why the consumer view of what makes a package environmentally friendly and how that friendliness can be recognized will not necessarily align with what is known by science of the environmental impact of a given solution [23].

This leads to a dilemma for packaging designers. If they base their design decisions solely on environmental assessments such as LCA, the design might fail in the market. However, if they base their designs on consumer perceptions, they might end up with environmentally inferior solutions. Hence, designers need to fulfill two objectives. First, packaging must fulfill engineering (or scientific) requirements. Designs must fit existing infrastructure (including machinery, available material, and food product needs), comply with changing regulatory environments, and have a comparatively low environmental impact as assessed by tools such as LCAs [22]. Second, packaging should communicate its benefits to consumers in a way that will be understood and recognized [10]. Thus, companies need to understand what consumers think makes a packaging solution environmentally friendly, i.e., the attributes and what they think and how they can recognize these attributes, i.e., the perceptual cues that signal environmental friendliness [23].

While research on environmentally friendly packaging has gained momentum with all stakeholders along the food and packaging supply chain [24], it has often focused on assessing environmental friendliness from a scientific view or from the demand-side perspective, i.e., consumer attitudes and perceptions or acceptance of environmentally friendly packaging solutions (e.g., ocean plastic). To the best of our knowledge, research

has overlooked communication on the supply side, i.e., packaging choices available to consumers in the market. A well-structured mapping of packaging solutions in the market, one reflecting consumer perceptions of environmental friendliness, is needed to provide more effective messaging to consumers.

The present research aims at providing such a tool—an attribute–cue matrix combining two hitherto separate theoretical perspectives—to analyze packaging solutions across countries and product categories. To demonstrate the tool’s utility, we apply it to a snapshot of the wafer market as found in nine countries: Austria, Denmark, Finland, Greece, Hungary, Poland, Portugal, Slovakia, and Turkey. To the best of our knowledge, this field study is also the first comprehensive market analysis of environmentally friendly packaging communication in a specific product category across multiple countries.

How is our research useful for stakeholders in the packaging sector? First, while we apply the attribute–cue matrix to a sub-market of the food sector, it can be used to analyze any packaging solution in business-to-consumer (B2C) industries. That gives companies a practical tool to analyze their own packaging solutions and benchmark them against specific competitors or the industry. Any gaps derived from these analyses can be used as a point of departure for improving communication to the consumer at the point of sale.

Second, the attribute–cue matrix provides governments and regulators with a tool to survey how companies implement packaging solutions that claim to be environmentally friendly. Any inconsistencies found can then be addressed, if needed, by changes in regulations. The matrix also points out attributes and cues that a company does not yet use in its packaging solutions. These missed opportunities can serve as a starting point for new strategies, just as the matrix can help policymakers draft new regulations or project the impact of potential future regulations. The tool can also help environmental pressure groups and non-governmental organizations (NGOs) to document the state of packaging and communication approaches in specific industries and build their strategies from there.

Finally, for researchers in marketing and strategy, our combined conceptualization of attributes and cues provides a launch pad for cross-national and cross-industry studies of packaging strategies from the consumer perspective. This is especially important since a strong theoretical understanding of consumer perception of environmentally friendly packaging is still lacking [9,10,25] and existing knowledge is rather fragmented [15]. Therefore, we combine two theoretical perspectives: attributes that capture what consumers think makes a packaging solution environmentally friendly and cues, the core concept of cue utilization theory, that show how consumers think they can recognize these attributes. Moreover, we contribute to cue utilization theory by adding new cues that can be used in future research to analyze communication via packaging.

Our matrix, however, not only supports comparative research into strategies across countries, industries, or market segments on the supply side, but it also enables evaluating consumer attitudes and behavior against company strategies. This can potentially reveal gaps between the focus of a company’s messaging and what is important to consumers. Moreover, because we expand the concept of cues to include one sensory and three structural signals new to the literature, our attribute–cue matrix extends the strategic range of messaging to consumers.

The remainder of the paper unfolds as follows: in Section 2, we explain the theoretical foundations underlying our attribute–cue matrix. We then describe how we acquired empirical data from the multiple wafer markets and how we applied the matrix. In Section 3, we present our results. In Section 4, we discuss potential reasons for the packaging strategies found, after which we present implications for companies and policymakers. We conclude with avenues for further research.

2. Materials and Methods

2.1. Attribute–Cue Matrix

The attribute–cue matrix aims at identifying the messages cued by packaging that companies can use to communicate the environmentally friendly attributes of their packaging.

The framework can be used both for analyzing consumer perceptions and behavior and for analyzing company packaging strategies. The concept of stimuli contents vs. formats that Ketelsen et al. have used for analyzing past studies (not products) ties in with our approach [15].

In its essence, the matrix combines packaging attributes that consumers perceive as environmentally friendly, e.g., biodegradability, with cues that explicitly or implicitly communicate the given attribute, e.g., a label indicating biodegradability. We derived both attributes and cues from previous consumer research on packaging perceived as environmentally friendly, using attributes proven to matter to consumers in their decision making. We also include attributes related to the efficient use of packaging, e.g., space-saving packaging, for the same reason.

From a consumer perspective, attributes are those characteristics that make a package environmentally friendly. These attributes can relate to various phases of packaging life: in raw material production, for example, consumers regard the use of recycled material or renewable material as environmentally friendly. In the post-use phase, consumers pay attention to biodegradability and recyclability. Table 1 summarizes these attributes, grouped by packaging life stages. The third column indicates previous studies that have shown the relevance of the respective attribute to consumer decision making. In the compilation of the attributes, we drew on Herbes et al. [21].

Table 1. Pro-environmental attributes of packaging solutions.

Stage in Packaging Life	Pro-Environmental Attribute	Source
<i>Material production</i>	Reused packaging	[26,27]
	Recycled materials	[18,19,28–30]
	Renewable materials (bio-based)	[18,20,22,23,25,31–33]
<i>Packaging production</i>	Less packaging	[34–38]
	Local/regional production	*
	Environmentally friendly production	[25]
<i>Transport and use</i>	Lightweight	*
	Space-saving	[39]
	Reusable	[23,25,26,40,41]
<i>Post-use</i>	Recyclable	[19,23,25,29,30,35,42,43]
	Bio-degradable	[23,25,29,30,40,44]
<i>General (no specific stage)</i>	Environmentally friendly in general	[40]

* newly proposed attributes.

From a producer perspective, attributes describe packaging design choices, for example, the choice to use bio-based plastics for producing a pouch or to design the polymers for the pouch so they are bio-degradable. To communicate these attributes so they can enter into consumer purchasing decisions, designers need appropriate cues.

Cues are about communication. They are how companies communicate pro-environmental attributes of their packaging. This might be done by describing what part of the packaging is from a certain material, say ocean plastic. Cues describe how consumers recognize, or think they can recognize, pro-environmental attributes. Cues are necessary, because consumers often cannot experience directly the pro-environmental attributes of packaging. How, for instance, would a consumer know that the polymers for a pouch were bio-degradable? This is where cue utilization theory [45] comes in, when product characteristics cannot be objectively evaluated by observation. To reduce complexity, consumers make conclusions about products from the configuration of cues available [46]. Attributes that cannot be directly observed are called credence attributes [47]; for these, consumers have to trust the information provided by manufacturers on the package [48,49]. For example, the biodegradability of packaging is an attribute neither visible nor otherwise sense-perceptible. A consumer has to trust a manufacturer's claim.

One attribute may be recognized through several cues. For example, consumers might think they can recognize renewable or recycled material by its color, but they may also look for a label or text on the packaging confirming the material's origins.

Cues, however, can be treacherous if consumers have wrong ideas about packaging. Companies may deliberately mislead consumers by capitalizing on these wrong ideas, for example, using brown tones and coarse surfaces for packaging that is not from recycled or renewable material [15]. Some consumers, on the other hand, interpret pro-environmental cues as greenwashing, especially when claims diverge from expectations for environmentally friendly packaging design [25,28]. The multiple meanings of environmentally friendly packaging and the unclear packaging messages (e.g., labels) can create ambiguity, especially when environmental information is incorporated into a single metric or cue [50].

We chose to group environmental friendliness cues as experienced along the consumer journey: from first seeing the package at the point of sale, to then looking at the package closely, touching it and later, after the purchase, opening and using it (consumption). In the compilation of cues we drew on Herbes et al. [10].

We then added one new sensory cue and two new structural cues that consumers experience when using a product. They include, first, the sensory cue of how loosely or tightly a product is packaged, signaling how much packaging volume could have been saved. Next the product-to-packaging weight ratio, a structural cue, which though never measured directly by consumers does leave an impression. If the ratio is too low, consumers will read the cue as “overpackaged.” The second new structural cue we added is the number of packaging levels, which along with packaging waste pieces, is experienced directly by consumers when opening a product. The calculus of perception is as follows: the more levels, the more waste pieces, the less environmentally friendly.

We would like to point out that, in contrast to most other cues, these cues do not require a conscious marketing decision on the part of the manufacturer. Manufacturers may design lightweight packages (e.g., few packaging levels, few packaging pieces) for other reasons than consumer communication, such as savings in material or in logistic costs.

Table 2 presents the cues used in our analysis. These can all be found on or in the packaging itself, a constraint we imposed on our analysis since only these cues can be directly influenced by the manufacturer. Other cues consumers have been shown to use are the so-called social cues, information provided by retailers, friends, and family [10].

Table 2. Cues on pro-environmental attributes of packaging solutions.

Consumer Journey	Cue Type	Cue	Source
Point of Sale	Visual (from distance)	Color	[10,39,40]
		Label/logo	[10,39,51,52]
		Image/picture	[22,53,54]
	Sensory (touching/picking up)	Haptics/texture/material	[10,12,22,25,55,56]
	Informational (reading)	Loose/tight packaging	*
		Text	[10,27,28,39,53,54,57]
Consumption	Structural (use-phase)	Product-to-packaging ratio	*
		Number of packaging levels	*
		Number of packaging waste pieces	[10]

* newly proposed cues.

Figure 1 presents the attribute–cue matrix, combining the attributes and cues described in Tables 1 and 2. The matrix contains a total of 108 possible attribute–cue combinations, of which 49 are identified as practically applicable (colored white in Figure 1). For example, the fact that packaging is from renewable materials can be explicitly communicated through a label and text, and implicitly through images, surface texture, and color. Certain cues, such as labels, images, and text could be called all-purpose-cues, because they can be used to provide attribute-specific communication for all attributes. Other cues are more limited

in their communication power; haptics for example, can be taken as a cue for renewable materials but not much else.

			CUES								
			CONSUMER JOURNEY								
			View Visual Cues			Touch Sensory Cues		Read Informational Cues	Consume Structural Cues		
			Color	Label	Image / picture	Haptics / texture	Tightly packed	Text	P2P ratio	Packaging levels	Waste pieces
ATTRIBUTES	LIFE CYCLE STAGES PACKAGING	No stage	-								
		Material production	Reused								
			Recycled								
			Renewable								
		Packaging production	Less packaging								
			Local production								
			Environmentally friendly production								
		Transport and use	Light-weight								
			Space-saving								
		Post-use	Recyclable								
			Reuseable								
			Bio-degradeable								

Figure 1. Attribute–cue matrix. Abbreviation: P2P ratio (product-to-packaging ratio).

2.2. Sampling

To examine the environmentally friendly packaging options available to consumers in the market and to provide a snapshot of which messages about which attributes companies send to consumers through their packaging, a field study was conducted (with similarities to the field study of Deng and Srinivasan [58]). Wafer products were purchased from retail outlets to serve as data for the analysis.

Wafers are in the product group of cereals and confectionary; they were chosen for the study as a prime example of the impact that packaging can have on consumer decisions at the point of sale (POS). Among wafers, many different packaging options for similar products are available. The product category includes multiple sizes and packaging formats (types, material, shapes), as well as flexible packaging solutions such as fold wraps, flow packs, stand-up pouches and laminated paper bags, rigid plastic trays and boxes, metal-based boxes, and cardboard boxes.

Moreover, sustainable production and packaging of confectionery goods is a main area of interest for packaging redesign [59]. Sweets in general depend heavily on packaging [60] to take advantage of seasonal trade through colorful special editions. The main quality-related criteria for packaging confectionary products are protection against light, oxygen, and water vapor transmission [61]. To provide these high barriers, packaging designers often use material combinations that might yield non-recyclable packaging solutions [62]. However, the industry aspires to make progress in sustainable packaging. Indeed, an increasing number of news articles have appeared recently about the environmentally friendly aspirations of the confectionery industry [63].

The data collection portion of our field study ran from January to May 2021 in nine different countries—Austria, Denmark, Finland, Greece, Hungary, Poland, Portugal, Slovakia, and Turkey to cover as many products as possible. In each country, available packaging solutions in the wafer category were collected. Collections were made by a local researcher following these instructions: (1) define one shopping area (street, district, etc.); (2) within one week, visit all shops selling confectionary products in that area; (3) purchase all available wafer products (uncoated, chocolate, or nut-based filled wafers with at least two layers

of wafers and one layer of filling); (4) repeat the shopping trip after 4–6 weeks to search for new products; and (5) send all (unopened) products accompanied by the shopping trip information to the research team members in Vienna for analysis. If researchers found the exact same packaging solutions in different “product series” of one brand with different sizes or fillings/flavors that matched the criteria, they were asked to purchase the cheaper option. This procedure resulted in a sample of 189 wafer products overall, of which 25 were excluded for being duplicates or not meeting the defined criteria for, i.e., flavor selection.

2.3. Analysis and Coding

Analysis of this data meant the careful examination of cues and the attributes companies communicate. The packaging examination was designed to best imitate the consumer journey and be as realistic as possible, so the analysis included not only the visual examination [64,65] but also the description (e.g., material, packaging type) and physical examination [66] of packages, including manually opening the packages. First, the content analysis [67] of packaging information was conducted; all environment-related textual and visual attributes were compiled in an Excel database. Second, the physical examination of packages was conducted, which included the opening, emptying, and exploring of disposal information of each package in a way that most closely resembles average product usage.

Coding used a combination of deductive and inductive approaches [67,68], since it started with environmental attributes and cues identified by previous research (deductive approach). Then during the analytical phase, new codes were added (inductive coding) to the category system—one sensory and two structural cues. One researcher coded the packages while two researchers assisted and revised coding to ensure objectivity and reduce rater bias. Codes were also re-examined by a fourth researcher, before the final coding scheme was developed (see Table A1 (Appendix A) for examples of coding rules).

After coding, the wafer data was processed through the attribute–cue matrix to obtain the frequency of use of each practically applicable attribute–cue combination. Based on these frequencies, we identified three main groups of cue usage. We then prepared the data for visual analysis using a heat map where cues used by the majority of products ($\geq 50\%$) were marked red, cues used by a sizeable percentage ($\geq 20\%$) were marked orange, and cues rarely used ($< 20\%$) were marked yellow. Other combinations, which were applicable but not used at all, remained white.

3. Results

In total, 164 different wafer products were included in the analysis (see Figure A1 (Appendix B) for pictures of all collected packages, $n = 189$). The top three contributing countries for packages were Austria (33%), Turkey (20%), and Poland (13%). Other countries in the sample had shares of 10% or lower ($n = 164$, after discarding 25 as non-qualifying).

3.1. Descriptives

Flexible solutions were used by 88% of the products analyzed, whereas 11% of the products combined flexible (i.e., flow packs, fold wraps) and rigid elements, mostly plastic, rarely cardboard trays. Only one solution contained wafers as a bulk product in a solely rigid packaging solution, similar to a bucket with a lid and handle. Packaging made solely from plastic (excluding labels and clips) dominated the sample, making up 87% of the solutions. Information about the packaging being made from polypropylene (PP) and/or the recycling code/number five was frequently found. Only 13% of the packaging solutions included paper or cardboard elements, irrespective of labels including multilayer material (fold wraps, stand-up-pouches with paper layers) as well as boxes, trays, and inlays.

Referring to the surface haptics, 17% of the packaging surfaces were found to be coarse and/or matte as opposed to sleek and shiny. Investigating another sensory cue, the perception of excess air (headspace), found 79% of the solutions to be packed tightly, meaning the product could not move around in the package. Some solutions, such as trays

in flow packs, were found to be intermediate (3%), i.e., between packed tightly and loosely. About one-fifth were packed loosely (18%).

The packages in the sample showed a variety of labels. Most of them related to the products, fewer to the packaging. One could find regional labels referring to local production, local certification schemes, as well as international certification standards commonly applied in the food production industry. Labels referring to certain ingredients, giving information about the cultivation or production of mostly cocoa, were frequently present. Labels relating to the packaging solution, e.g., the composition of the used materials and, less often, information about certified production standards in fiber-based solutions (paper, cardboard), for example, were found less often. Only one packaging solution in the 22 samples including paper carried a label related to agroforestry certification. Independent of the communicated material, the use of arrows arranged in a triangle or circle, with and without recycling code/number and the Green Dot, indicating collection or recycling context (76%), were found as well. Although symbols with recycling context/logos could help with correct post-use treatment by consumers, 39 of the collected packages did not contain the recycling code/number or a triangle/circle with arrows or the Green Dot on the outer packaging.

Surprisingly, text-based information referring to packaging was also quite rare (19 samples). Even though it is an all-purpose cue, text related to the packaging solution appeared on very few packages, stating, i.e., that the packaging solution is recyclable or that it is important to separate waste. On some packaging solutions one could find specific collection systems mentioned, i.e., for specific regions. Partly, the text-based information was available in combination or within a symbol, for example, stating in words which container to use for collection. These cases are reflected in the text-based share, not in the percentage of labels. More often, one could find, next to legally required labeling, information about the production, the ingredients and flavors, promotions or, for example, the brand values. As for the packaging solutions, the production or supplying company was communicated, but with logos rather than text. This was also the case for materials communicated as certified for food contact (FCM, fork, and glass). Moreover, none of the packages claimed to be bio-plastic/bio-based or of an environmentally friendly origin.

In terms of design, a total of 49 (30%) packages applied green as one of three main (most dominant) colors in the font of the brand name or the background color. If no brand name was found on the front of the pack, the product name was taken instead. Counting packages that were coded as being solely green, merely 7 (4%) of the wafers were found to have such a packaging design. Addressing images and pictures, one could find a multitude of different designs in backgrounds, brands, and product names on the wafer packages. Many of these images and pictures were, however, not found to be nature related (i.e., buildings, people, furniture, kitchen appliances, etc.) or, secondly, found to directly present the specific products (i.e., wafers), represent related processed ingredients (i.e., cocoa powder, chocolate, milk, cream, flour, etc.) and ingredient-related plants (i.e., hazelnuts, leaves of hazelnut trees, cocoa beans, cocoa plants, leaves of cocoa plants, vanilla blossom, ears of wheat, etc.). One could also find images and pictures of animals, but mostly cartoon style. All other additional images and pictures that were found to be nature-related (excluding the ones representing ingredients, animals, drop, and petal shapes), were rather limited and included trees, leaves and flowers, grass, mountains, landscapes, sun, moon, stars, clouds, etc. Counting only these, 18 (11%) packaging solutions carried one or more of such images or pictures.

The structural cue “product-to-packaging ratio” (written product weight versus emptied packaging) showed a broad range. The least efficient sample had a ratio of 1.75:1 whereas the most efficient solution had a rounded product-to-packaging ratio of 109:1. The most efficient solution was one package of 500 g wafers in a 4.6 g transparent flow pack. The sample’s average product-to-packaging-ratio rounded was 38:1, what was taken as a benchmark to identify the more efficient ones within the sample. In total, 79 (48%)

packaging solutions had a higher ratio than this, meaning even higher efficiency, while the remaining 85 packages were less efficient.

Two other structural cues were investigated—the number of packaging levels (elements) that have to be opened to access the wafers, and the number of waste pieces of packaging that accumulate after consumption. Of the purchased products, 21% were multipacks with single packaged units (15% with 2–15; 4% with 6–10; and 2% with 11–25 pieces). However, only 15% of the purchased packages counted as having at least two levels to open. The difference between these two shares results from multipacks with single units that were held together by stickers, and therefore not considered as one level to open. The remaining 85% of packaging solutions required opening only one packaging element to access the wafers. Some solutions also included tear tapes/strips as well as text and/or graphic arrows to indicate where best to open the package.

The number of single packs and packaging levels goes hand-in-hand with the number of waste pieces generated by consuming the products. In 73% of the cases, only one piece of packaging waste accrued. Clearly, this number is smaller than that of levels to open, because partly open elements (such as trays) were counted as waste pieces, but not necessarily ones to open. Furthermore, opening multipacks was calculated as accessing one unit, which also accounts for the difference between waste pieces and levels to open. Only 2% of the packaging solutions produced more than 15 pieces of packaging waste; these cases were very small packages of less than 15 g of product.

3.2. Heatmap Based on the Attribute–Cue Matrix

Analyzing the wafer packaging data through the attribute–cue matrix yields the heatmap shown in Figure 2. Attribute–cue combinations that are not applicable appear as dashed cells, while practically applicable combinations not used appear in white. Of the 49 practically applicable attribute–cue combinations, only 12 (24%) were used by at least one product. Only four cues were hot (red $\geq 50\%$), with two cues lukewarm (orange $\geq 20\%$).

			CUES								
			CONSUMER JOURNEY								
			View Visual Cues			Touch Sensory Cues		Read Informational Cues	Consume Structural Cues		
			Color	Label	Image / picture	Haptics / texture	Tightly packed	Text	P2P ratio	Packaging levels	Waste pieces
ATTRIBUTES	LIFE CYCLE STAGES PACKAGING	No stage	30 %		11 %	17 %		12 %			
		Material production									
		Reused									
	Packaging production	Recycled									
		Renewable									
		Less packaging					79 %		48 %	85 %	73 %
	Transport and use	Local production									
		Environmentally friendly production									
		Light-weight							48 %		
	Post-use	Space-saving					79 %				
		Recyclable		76 %							
		Reuseable									
		Bio-degradeable									

Figure 2. Heatmap of environmentally friendly cues that were utilized. Abbreviation: P2P ratio (product-to-packaging ratio).

Traveling left to right in Figure 2, along the consumer journey, “color” was partially ($\geq 20\%$) used, so it shows up orange. Labels were used more often, but primarily to indicate

post-use: 76% of sampled packages carried labels relating to sorting or recyclability, reflecting recycling codes/numbers and the Green Dot. Images and pictures that communicate naturalness without any link to a specific stage in the packaging life were sufficiently present to move this cue from cold to cool, but still yellow in Figure 2.

Moving to the physical experience of the packaging, coarse and matte packaging textures, evoking a sense of naturalness, appeared as a cue with the same frequency category as images and pictures, leading to a similar yellow coding. The second sensory cue, “tightly packed”, was a hot signal for two different attributes (“less packaging” and “space-saving”). Text as an informational cue was used sparingly, leading also to its yellow coding.

Moving to the consumption phase, shown in the leftmost columns in Figure 2, more structural cues appear than in the other phases. This leads to more and hotter fields. A low number of packaging levels were used by around 85% of the packages. An optimized product-to-packaging ratio was found in more than 48% of the samples (the more efficient ones above average), producing the two orange fields and reflecting less packaging use in production and transportation.

The last structural cue along the consumer journey as well as the packaging’s life cycle stage, is given by accumulated waste pieces after consumption. This cue led to a hot field, as 73% of the packaging solutions only generated one piece of packaging waste.

Other cues were either not used or limited to a fraction of the products in the sample.

4. Discussion and Conclusions

This study developed a tool, the attribute–cue matrix, for analyzing the effectiveness of packaging solutions in communicating their environmental credentials to decision-making consumers. Only when consumers can recognize environmentally friendly packaging options will they be able to choose them. Without that demand-side perspective, even the best packaging solutions can go for naught.

We demonstrated the matrix through a field study of the wafer market in nine European countries—Austria, Denmark, Finland, Greece, Hungary, Poland, Portugal, Slovakia, and Turkey. While the matrix provides a powerful and versatile heuristic for academics, marketing managers, and policymakers, the results of the field study, based on 164 wafer packages, highlight more current topics relevant to communication and environmental specialists. The results show that even in the ever-popular wafer market, the supply side rarely communicates the potentially perceivable environmental attributes of its packaging solutions, compared to what would be possible.

These results are surprising, since environmentally friendly packaging is at the forefront of both academic and applied research. That it is not (yet) observable at the point-of-sale is thought-provoking, since here consumer perception of environmental friendliness and not the objective facts enter into a purchasing decision [69]. Our results are particularly sad given the gap between consumer perception of environmental friendliness and objective assessments of the life-cycle costs of a package [20,70]. This gap could narrow were effective guidance by unmistakable on-pack communication available to support pro-environmental product choices. That it is not in a popular mass market is puzzling.

In the next section we consider potential reasons for the puzzle. We then consider implications for companies and policymakers before outlining avenues for future research.

4.1. Potential Reasons for (Not) Communicating the Environmental Friendliness of Packaging Solutions

The first potential reason behind non-communicating lies in the properties of the product and the practical requirements of its packaging. Wafers are susceptible to water uptake (e.g., loss of crispness), are sensitive to oxidation (e.g., rancidity, unwanted color, and/or taste changes), can take up flavors and suffer structural damage [71–73] while having low water activity and therefore low susceptibility to the growth of pathogenic microorganisms. To extend the shelf life and the overall acceptability of wafers, producers

opt for packaging solutions with high barriers against moisture, oxygen, light, and flavor loss. In many cases, it is difficult to meet all the packaging design requirements using a single material, so producers frequently opt for multilayer flexible food packaging solutions. These are built up of different materials that combine to meet functional requirements for i.e., resealability, barrier protection, strength, and lightweight, along with economic requirements for cost efficiency [74]. The latter also dictates minimal use of materials and often a reduced carbon footprint, both of which are environmental benefits. However, these materials show poor recyclability, a disadvantage heavily discussed as a trade-off among scientists and the public [62]. Therefore, even if a packaging solution is environmentally optimal for the product category, that fact is not easy to communicate.

The second potential reason for the dearth of effective on-pack communication can be found in the role the product plays for consumers and the context in which wafers are consumed. The consumption of confectionary products is often driven by hedonic motives [75], and it still relies on classic impulse triggers. Being reminded of one's responsibility for the waste generated by the package, being beleaguered by details on the environmental impact of the packaging could have a sobering effect on a consumer, perhaps prompting second thoughts that would undermine the sale.

The contradiction between hedonic motives and moral choices is well-known in the literature [76] and most probably not from a perspective appealing to manufacturers of confectionaries. Manufacturers may not want to suppress hedonic impulses with environmental friendly packaging claims or to place moral principles over pleasure [76], because sustainability-linked attributes can affect hedonic properties negatively [77]. However, it is also possible for consumers to derive pleasure from doing something positive for the planet (see the concepts of 'alternative hedonism' [78,79] or 'warm glow' [71]), but this concept is probably difficult (though not impossible) to apply to environmentally friendly packaging of confectionaries. Still, despite extensive academic discourse on the dichotomy between hedonism and morality in consumption practices, we do not know what role these concerns played in the decisions made by the companies. How companies go about meeting both business and ethical obligations becomes a question for further research.

A third way to look at (the lack of) manufacturers' on-pack communication strategies is through the model of ecological responsiveness [80], which names three motives for companies to behave pro-environmentally: to improve competitiveness, to create legitimization, and to fulfill a sense of responsibility to the earth. All three goals can be advanced by environmentally friendly packaging, a straightforward example being the competitive edge gained by saving resources and waste and streamlining logistics [81,82]. However, the development of such packaging entails high production costs, slow time-to-market, technical difficulties, and complex cross-team alignments [14]. Many times, companies lack the business expertise or long-term planning horizon needed to pursue eco-friendly packaging [21]. This is especially true in a product category not under criticism. As it is, businesses are often compelled by law to adopt environmentally friendly packaging initiatives (the legitimization motive) [14,25], but maybe not yet pressing over all product categories.

The fourth potential reason behind scarce on-pack communication is the novelty of the topic. Communicating the environmental friendliness of packaging is just beginning, especially when compared to product related on-pack information (e.g., organic labels or health claims), which have been hotly debated for decades and have evolved from the nonregulatory action policy of a few selected companies to a heavily regulated area [83].

4.2. Implications for Companies and Policymakers

How can scholars, managers, and policymakers use our research and what can be gained from it? This section advances implications aimed at addressing the key issues in relation to environmental packaging management, to stimulate greater attention to this important topic and to expand the scope of discussion.

The tool we have demonstrated provides guidance to companies considering environmentally friendly packaging communication. The attribute–cue matrix summarizes and

visualizes the attribute–cue combinations that manufacturers may use. The matrix can help evaluate the status quo, compare competitive offerings, analyze potential communication directions, and improve existing packaging solutions.

Furthermore, the matrix can be used to improve packaging design: both communication changes and structural design changes can emerge from applying it. While considering packaging redesign, companies need to consider questions such as: How are consumers making sense of the current on-pack communication? Do they want to make a well-founded choice decision prioritizing certain eco-friendly attributes over others? How do consumers make sure that they recognize these attributes from the cues on the packaging across products from different manufacturers? And how can consumer perceptions be aligned with objective environmental impact?

Besides that, our results also indicate that both direct on-pack and implicit communication should be used more often to inform consumers and allow them to choose environmentally friendlier packaging solutions. Companies can use the matrix to identify better ways to provide this information [70] and explicitly signal the package attributes that qualify as environmentally friendly—especially compared to competitors. Using multiple signals of environmental friendliness is supported by cue congruence theory.

This study also provides guidance to policymakers. Our results show that with absent regulation, packaging communications can run the gamut, presenting the consumer with a cacophony of different messages from different producers, each highlighting different attributes with different cues. This more often creates misunderstanding and confusion for the consumer than providing real help in making pro-environmental purchase decisions. As in other markets for eco-friendly products, such as the markets for green electricity or for eco-friendly food, there is a potential positive role for a standardized, easy-to-understand information system, possibly administered by the state. However, the agonizing discourse and stubborn resistance from manufacturers over the nutriscore front-of-pack labeling [84] of food in Germany, France, and other countries [85–88] shows how difficult it is for policymakers to establish such a system. However, with sustainability-related credence attributes gaining more and more importance and consumers being less and less able to judge products with their five senses, accurate and informative labeling becomes a key task for third party actors such as industry associations or the state.

Both policymakers and manufacturers should consider the lack of communication about the end of life of packages. Not only is there almost no on-pack information to help consumers dispose of the package, but even if there were, the collection system in Europe varies from country-to-country and in some countries by region. Perceivable cues on products sold in multiple European countries would have to include regional labeling, which simply is not feasible. Therefore, it appears that action is still needed to reach the recyclability goals of the European Plastic Strategy by 2030 [89] and to ensure that improvements align with the overall goal of sustainability.

4.3. Avenues for Further Research and Limitations

This study is not without limitations and our work hints at multiple avenues for future research. First, we demonstrate a versatile and powerful tool, but do so considering only packaging from one product category in nine countries. Undoubtedly, a larger and more heterogeneous sample would provide a richer understanding of current on-pack communications and might even expand the tool, as applied packaging solutions could differ from the ones found in the category of confectionary products. The validation or further development of the matrix with different sample sets would be beneficial to check for differences across product groups. Therefore, we recommend the attribute–cue matrix be used in the analysis of packaging strategies across product categories and markets, where large differences can be expected due to different consumption factors or packaging solutions.

Second, it would be helpful to understand why companies design packaging solutions the way they do and why they do (not) communicate the way we might think they should.

Do restrictions stemming from technical properties of packaging material and machinery as well as requirements of packaged products largely govern packaging solutions? How do companies position the environmental friendliness of packaging solutions in their marketing strategies? Which stakeholders inside and outside the company are involved in packaging design decisions? How do companies see their potential customers and how do they think customers factor environmental issues of packaging into their buying decisions? These questions call for a qualitative study of decision-making processes involved in packaging design in companies.

Third, let us turn from the supply side to the demand side. Largely absent from the literature are comparative studies of consumer preferences for environmentally friendly packaging across product categories. Do consumers have different preferences regarding pro-environmental attributes of packaging and are they receptive in different ways to cues communicating these attributes depending on the product category and the consumption context? The discourse on the relationship between hedonism and sustainable consumption suggests that environmental impact may be less of a concern for consumers when the product and its consumption are embedded in hedonism.

Another question is which cues are especially credible and effective in communicating pro-environmental attributes. We hypothesize that some attributes would best be communicated by text, others best by nontextual cues. Lastly, it would be helpful to understand how consumers examine a package to determine its environmental friendliness. Observations and eye tracking could be suitable methods to explore this.

Answering these questions would help companies better understand how they can build pro-environmental considerations into their packaging strategies and how they might better help consumers make sound pro-environmental choices. Pursuing these questions would also help policymakers understand where consumer preferences, even if understood well by companies, cannot drive improvements in the overall sustainability of packaging solutions and where, therefore, a positive role for regulation may exist.

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Appendix A

Table A1. Examples of coding rules for the analysis.

Cue	Coding Rule: Coded as Signaling Environmental Friendliness if ...	Example
Color	Packaging was any shade of green	
Label	Recycling code and/or symbol and/or green dot was present	
Image/picture	Nature-related images were present. We excluded any nature-related pictures or graphics that had a direct link to the product and its ingredients, e.g., a cocoa tree	
Haptics/texture	Material was coarse or matte	
Tightly packed	Product was tightly packed (minimum headspace)	
Text	Information on environmental attributes of the packaging was present, e.g., general ecological benefits, appeals for waste treatment or reduction in greenhouse gas emissions	

Table A1. Cont.

Cue	Coding Rule: Coded as Signaling Environmental Friendliness if ...	Example
Weight of the product relative to packaging weight	High product-to-packaging ratio	
Number of packaging levels	No more than one level to open	
Number of packaging waste pieces	Only one waste piece	

Appendix B



Figure A1. Pictures of all collected packages.

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Consumer Complaints about Food Packaging

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8 **Keywords:** Packaging¹, design², consumer³, complaint⁴, dissatisfaction⁵, netnography⁶,
9 communication⁷.

10 Abstract

11 The perceived value of packaging in society is low and consumers frequently have negative
12 associations with packaging. While the current redesign of packaging focuses mainly on enhancing its
13 environmental performance, the consumer's experiences are underrepresented in discussions, although
14 one can find many packaged food product examples, which consumers are dissatisfied with and
15 complain about. This is found worthy of investigation, as it is widely agreed that consumers'
16 perspectives need to be taken into consideration during redesign. To understand why consumers are
17 dissatisfied, over 250 online complaints concerning food packaging were collected. The used
18 methodology leans on Kozinets Netnography (2002), which is described as "... *ethnography on the*
19 *Internet*". Based on the content of the complaints, the online complaints were narrowed down into
20 twelve categories. These categories are understood as opportunities to improve packaging design and
21 better satisfy consumers. Perspectives from European food and packaging law, that touch upon
22 packaging design, related to the investigated complaints, are discussed as orientation in the redesign
23 process. The findings show underlying issues to the predominant negative discourse about packaging
24 in society. In the considered online complaints, one can see various missed design opportunities,
25 fuelling the impression of packaging being unnecessary and leading to its refusal. Food packaging, that
26 implies a higher quality or quantity of products through text-based information, design elements like
27 graphics, certain packaging sizes, windows and sleeves as well as the seemingly excessive use of
28 packaging material are some examples discussed by consumers. Overall, one gets the impression that
29 strict interpretations and a thorough application of consumer protective perspectives from European
30 law onto packaging design, could have avoided a great deal of the issues brought up by international
31 consumers online.

32 1 Introduction

33 Today, stakeholders along the supply chain strive for more sustainable packaging solutions through
34 redesign. This is driven by, for example, environmental problems caused using fossil resources for the
35 production of conventional packaging, as well as poor end-of-life management. ^{1, 2} The packaging's
36 continuous improvement is therefore necessary, *i.a.* to meet self-declared business and politically
37 defined goals, such as higher recycling rates in the European Union for 2025 and 2030. ³

However, the perspective of consumption must not be neglected in this improvement process.⁴ Nowadays, consumers are dissatisfied with packaging (compare results section) and, for example, perceive it as being unnecessary and an environmental burden.⁵ Unpacking small items from huge boxes, broken seals, spillage, multiple waste pieces or packaging layers as well as “everything but easy-to-open” solutions, are just a few examples found, leading consumers to question the benefits and necessity of packaging. Additionally, (misleading) packaging is an up to date discussion *i.a.* relating to current price changes of products and was already found to be an increasingly important issue a decade ago.^{6,7}

From a technical point of view, it is well understood that packaging has different basic functions (e.g. protection, containment, convenience, communication) and attributes (e.g. sustainability) to fulfil.^{8,9} Stakeholders, however, expect multiple (sometimes contradictory) properties, qualitatively and quantitatively from packaged products with different prioritizations of these properties along the supply chain.^{9,10} The protection of the filling good is perceived important along the entire chain, while communication, for example, can be more essential in certain single steps (e.g. purchase decisions or checkout at retail level etc.).⁹ Hence, connected to the functions and their prioritization at each supply chain level, different perspectives exist about what a good packaging solution is or is not. Particularly, at the level of consumption, needs and expectations often diverge from those at professional levels.¹⁰ These expectations can originate from various motives behind purchases (e.g. gift function of confectionery) and can be triggered at the point-of-sale through diverse cues that promise certain attributes.^{9,11}

At the stage of consumption, these expectations include manifold personal values, beliefs and also reflect economic situations of households (e.g. via prices as decisive factor).^{10,12,13} The different expectations are highly understandable from a consumer perspective; however, the described background seems to induce gaps between their expectations and needs from supply chain levels. When these gaps between expectations and actual product properties occur, consumers can feel misled, deceived or, in general, dissatisfied.¹⁴ This might also lead to changes in product purchases or even brand rejections.¹⁵

When approaching the question of packaging design to meet different expectations, one must keep in mind that dissatisfaction about packaging, as well as feeling deceived or misled, can have different characteristics. Looking for example at the term “deceived”, one can find different descriptions in the literature (for example regulatory versus behavioural or objective versus subjective deception).^{14,16,17}

From the viewpoint of dissatisfaction, different theories exist describing *inter alia* the aforementioned gap occurring between expectation and product characteristics. This could also give hints about how to avoid dissatisfaction by understanding the background of what induces dissatisfaction (e.g. such as discussed by Boote (1998): disconfirmation of expectations and attribution theory, equity theory etc.). One can also take a look at the different potential outcomes and complaint behaviour in dissatisfactory situations, for example products not being bought again (exit), people talking about experiences to e.g. family and friends (negative word-of-mouth), contacting third parties or seeking to be heard by companies (voice).^{15,18,19}

In the present work, the term dissatisfaction is used in the following sense: a unified, leading term that is considered as a generalized outcome reported by consumers, respecting for whatever reason they did not rate specific food packaging as appropriate. This includes situations where one might have felt misled or deceived but is not limited to such situations.

The legal side within the European Union protecting the consumers interests is quite clear and, in this work, understood as broadly applicable to improve packaging design. Considering the General Food Law, food products have to be safe and “...the labelling, advertising and presentation of food or feed, including their shape, appearance or packaging, the packaging materials used, the manner in which they are arranged and the setting in which they are displayed, and the information which is made available about them through whatever medium, shall not mislead consumers.”²⁰ Moreover, the Directive 94/62/EC on packaging and packaging waste, defines that “Packaging shall be so manufactured that the packaging volume and weight be limited to the minimum adequate amount to maintain the necessary level of safety, hygiene and acceptance for the packed product and for the consumer.”³

However, consumption reality shows that there must be a gap between these intentions and consumers' experiences. The pressing question is, how to redesign packaging to avoid outcomes of consumers being dissatisfied due to any reason implied by packaging solutions, to enhance *i.a.* the perceived value of the same and proceed with steps towards sustainability (such as sought consumer integration²¹). Furthermore, the above question is found to be valid in situations, where a certain packaging design follows all given legal requirements. Because understood differently than a decade ago by a great share of consumer agencies, that misleading packaging is not an important topic for consumers (p. 39) or even “... that misleading packaging practices do only have one negative consequence for consumers which is their disappointment ...” (p.28)⁷, it is widely regarded as important in scientific literature to engage consumers in packaging design.¹⁰

Although not every experience inducing dissatisfaction about packaging is based on consumers feeling misled, it is worth looking at this issue in particular. In 2012, a European Briefing Paper was published that dealt with the question if specific legislation on misleading packaging was needed. It was therein described that misleading packaging are practices letting consumers think “... there is a greater quantity of the product, than is actually the case, that the product is of a better quality, or that the product possesses certain other characteristics.” (p.12). Specifically, absent or wrongly indicated prices, packaging sizes, wrongful or misleading information through design, and packaging design imitations were mentioned as problematic. Conflicting packaging examples from various member states discussed (Annex II) and it was summarized that packaging solutions have to be evaluated case by case (p.16). Interestingly, it was stated that consumers regularly do not take action against packaging they found inappropriate (p.11). Investigations of “... consumers awareness, attitudes or behavior...” were recommended (p.26).⁷

Next to that, a definition of misleading packaging was given: “...misleading packaging is any kind of product packaging including e.g. packaging size, form or design that notwithstanding a cursory examination deceives or is likely to deceive the average consumer, particularly as to the quantity or the quality, but also other main characteristics of the product and related to the product, taking into account as well comparisons of the product in its current state to previous packaging and to competitors' packaging, and which causes or is likely to cause the average consumer to make a transactional decision that he would not have taken otherwise.” (p.16). Overall, comparisons were drawn reflecting e.g. the Unfair Commercial Practices Directive 2005/29/EC²², the Directive 2006/114/EC Concerning Misleading and Comparative Advertising²³ and the Unit Price Directive 98/6/EC²⁴. The conclusions lead to the suggestions for certain amendments in the directives and the development of *inter alia* shared databases for such packaging cases or more EN-Standards on packaging (p.13, 14).⁷

Since then, one can also find more recent publications that touch upon this topic, for example the Commission Notice from 2021 for Guidance on the interpretation and application of the above mentioned Directive 2005/29/EC from 2021, discussing *i.a.* misleading commercial practices with practical examples, also from the viewpoint of specific product characteristics such as “... *availability, benefits, risks, execution, composition, accessories, after sale customer assistance and complaint handling, method and date of manufacture or provision, delivery, fitness for purpose, usage, quantity, specification, geographical or commercial origin or the results to be expected from its use, or the results and material features of tests or checks carried out on the product; ...*” (Article 6).²⁵

Taking one step back from the above perspectives of misleading packaging and speaking more generally about packaging design, one must admit that the design process is a balancing act between requirements.^{10,26} With these requirements changing along the supply chain, it seems that consumers are at risk of not getting what they wanted to purchase, and producers are struggling to or simply not providing unmistakable, clear messages (idea of “...*transactional decision...*”⁷). These outcomes and underlying messages were found worthy of investigation.

Consumer research in combination with packaging is quite a widespread research topic and publications from the last decade highlight marketing-relevant perspectives of packaging design (e.g.²⁷). However, the profound understanding of packaging (dis)satisfaction, which is discussed as important (e.g.²⁸), seems subordinated in trending packaging redesign which appears to be focussed on design for recycling to enhance sustainability.^{1, 2} This is reflected by the fact that consumer information via cues and attributes is currently not treated at the same level as technically focussed redesign strategies in branch known guidelines about packaging design (e.g.²⁹).

Despite the opportunities for packaging development and research, evidence on food packaging complaints remains scarce in the scientific literature, which may be due to company internal handling of complaints. Exceptions can be found for misleading and deceptive packaging. Germelmann and Held (2014), for example, examined the detection of deceptive packaging by consumers, based on food packaging design. Different packaging designs were compared, analysing consumers' expectations gathered in questionnaires after visual examination and product tasting. Next to text-based information, it was stated that graphics can also be sources of deception.¹⁴ Further, Weinrich et al. (2018) focussed their research on filling heights and the usage of graphics (serving suggestions). Here, the variation of front-of-pack information about product ingredients and the assessment of appropriate filling heights showed the following: firstly, text-based information alongside graphics (*i.e.* serving suggestions) did not significantly change the consumers expectations and, secondly, neither did text-based information about technically necessary filling heights significantly change the perception of overpackaging.³⁰ Similarly in this context, Wilkins et al. (2016) analysed how deceptive packaging, including downsizing and air and slack filling is experienced and managed by consumers. The researchers used pictures of different filling amounts to trigger participants' reactions and showed possible negative outcomes for producers when engaging in practices of filling amount reductions.³¹ Furthermore, digitized analysis methods opened the field for more specific questions on consumer perception, for example, eye-tracking technology. “*Potentially misleading elements*” in combination with this technology were discussed by Clement et al. (2017).³² The opening of packaging as well as related injuries can also be found in studies reporting dissatisfaction about packaging (e.g.³³).

The theoretical contribution of the previous and present research is particularly important, as (packaging) responsible companies are actively reorganizing their strategies and packaging designs all over Europe (compare targets Packaging and Packaging Waste Directive³). In this study, (re-)design is investigated under new perspectives: the combination of consumer research via online complaints

based on dissatisfaction about packaging, allows the prevailing societal discourse to inform the redesign processes. Prospectively, this could avoid negative feedback mechanisms (such as company losses), addressing discussions that *e.g.* deceptive packaging is currently seldomly investigated³¹ and negative experiences with packaging so far do not lead to actions changing the situation⁷.

It is therefore considered important to discuss packaging experiences that finally led to public complaints, based on incorrect impressions about packaging attributes that might have been given or interpreted (compare Wilkins et al. (2016)³¹; Clement et al. (2017)³²). Although it is said hard to measure consumer expectations in this context³¹, one can investigate the complaint behaviour and therefore derive what would have been expected packaging-wise. Because, although dissatisfaction and (often) post-purchase behaviour like complaints stem from negative experiences, they facilitate, on the positive side, opportunities for the sought continuous packaging improvement. While it is clear that not each and every complaint can be understood or backed up from a scientific / technological point of view, taking consumer complaints seriously and understanding why they exist, can help to improve what matters at the stage of purchase and consumption in this controversial packaging debate, between producers needing packaging^{8,9} and (some) consumers not wanting packaging¹⁰. If packaging is seen as a service to a product³⁴ and consumers are dissatisfied through whatever reason, an important aspect must have been overlooked. To understand and consider the context of the publicly-shared consumer complaints, could (admittedly naive, optimistically) even be a chance to improve how people handle packaging (*i.e.* collect, recycle) and support aspirations of sustainability, as this also depends on actions set by consumers (*e.g.* pre-sorting of inseparable materials²⁹).

Against this background, the aim of this work is to answer the following research questions (RQ), set as strategic alignment of the paper:

1. Which packaging related issues can be found behind public complaints about packaged food products?

1.1 Which food products are discussed?

2. Are consumers complaining about the ecological sustainability of food packaging (reflecting the public discourse) or are they complaining about basic packaging functions, *i.e.*, protection, containment, communication and convenience?

2.1 Which (legislative) perspectives can help in packaging redesign to prospectively avoid such complaints?

2 Materials and Methods

To gain deeper insight into packaging-related consumer complaints and to allow redesign discussions, this study overall employed a qualitative perspective, which has previously been used to explore food packaging-related consumer behaviour.^{35, 36}

The data collection and analysis was built on approaches from Kozinets (2002) so-called Netnography, which is described as “...*ethnography on the Internet*...” (p.2). This applied research method is *i.a.* based on the observation of online channels. It involves a researcher identifying, collecting and analysing (“*recontextualizing*”) online communication and is described to start with the formulation of research questions as well as the identification and understanding of these channels and their participants. The methodology is seen as a realistic, unobtrusive, time-efficient and inexpensive research method and allows researchers to gain insights into consumers’ opinions in an inconspicuous

211 manner.³⁷ It was previously used in food packaging research by, for example by Dörnyei and
212 Gyulavári, (2016), who investigated online communication related to labels.³⁸

213 With the internet being a popular viable way to communicate, even more nowadays (about 20 years
214 after Kozinets publication in 2022), one can find endless data about packaging design discussions
215 online. Consumers share pictures, they describe their thoughts and feelings about products and
216 complain about various aspects of packaging solutions. As former discussed by Kozinets (2002), for
217 this work, publicly shared pictures of dissatisfactory food packaging solutions were set as the "...
218 *focused and research question relevant segment ...*", which was found to be "*detailed and descriptively*
219 *rich data*" appropriate for the intended data collection and analysis.³⁷

220 The research into packaging complaints began with an extensive online search (Google) using different
221 keyword combinations (e.g. bad packaging, bad food packaging, bad packaging examples, evil
222 packaging, deceptive packaging, dishonest packaging, unnecessary packaging). The nature of
223 participation was passive: researchers did not participate in online communication, but rather observed
224 the found cases (including comments and pictures). The online postings were understood as
225 intentionally public content and permissions to use the data to identify contextual complaints were not
226 requested. The question if online data is ethically justifiable (as discussed in Kozinets (2002)³⁷) was
227 omitted. None of the accessible data about the individuals posting (like usernames or similar) was used
228 for the recontextualization of the content described via the publicly-shared pictures. Accompanying
229 comments were only used to understand the context of the complaints and thereof derive generalized
230 redesign categories. Microsoft Excel was used to collect the data, combining *i.a.* the links, access dates
231 as well as the corresponding pictures to the discussed products. In total, 21 websites referring to
232 multiple relevant cases of packaging complaints via pictures (single complaints as well as articles with
233 collections of complaints as secondary sources) were identified (compare *Annex A* for a list of the
234 considered websites). The individual cases were saved from the selected sites and served as primary
235 data. The data collection took place between summer and autumn 2021, until a theoretical saturation
236 was reached, as described in Kozinets (2002)³⁷. The final dataset included a total of 250 cases (compare
237 *Annex B* for descriptions of the collected cases) of different pictures.

238 During the analytical phase, collected data was in a first step individually contextualized by six
239 researchers to define the content of single complaints to find a common understanding. One researcher
240 in exchange with two researchers subsequently generated complaint categories based on plausible
241 relations between the described contents (compare *Table 1*). The reporting of the results is generally
242 qualitative due to the nature of the method. The only quantitative part is the description of the cases
243 based on the structure of the *Guidance document describing the food categories in Part E of Annex II*
244 *to Regulation (EC) No 1333/2008 on Food Additives*³⁹ to allow an overview of complaints related to
245 food categories (*Annex B*). For this purpose, one food category (referred to as n. 0) was further added
246 to the pre-existing structure of this *Guidance document*, describing compound foodstuff that is out of
247 the scope of the intentional setup.

248 Overall, the data provides a snapshot of consumer complaints that can be found online and includes
249 more than 250 products allowing the categorization of the underlying issues discussed by consumers.

250 3 Results and Discussion

251 In this work, dissatisfactory experiences with packaging are regarded as avoidable through redesign.
252 The complaints, their possible backgrounds and mitigation measures are the focus of the discussion,
253 which is dealt with in parallel to the results to avoid repetitions and address the categories each after

the other. The reflection of requirements given on a European level that touch upon packaging design, primarily considering the EU Regulation 1169/2011⁴⁰ and the EU Packaging and Packaging waste directive³, are the centre of the comparison of the cases with existing legislative perspectives that give guidance in redesign. These publications are considered as a way to better understand in which directions packaging redesign should go in the analysed online cases. A similar approach was applied in the Briefing Paper on Misleading Packaging from 2012⁷, analysing if certain packaging practices fall foul of specific EU legislation. However, it is not a goal to check the legal compliances of cases but rather induce discussions about complaints and design with existing helpful perspectives that could be applied to better meet consumers' expectations.

3.1 Categorization of Complaints

From the online data, twelve complaint categories were “recontextualized”. Table 1 depicts the complaint categories related to food packaging (RQ 1). Most online complaints (approximately 90%) could be assigned solely to one category, whereas the rest was assigned to a maximum of two categories. The approx. 10% overlap was considered non-essential as no quantitative categorization was aimed at. Furthermore, some cases discussed multiple issues referring to one product.

Table 1. Recontextualized online complaints.

Complaint Category
I. Unclear, hard-to-read or incorrect text-based information about ingredients, manufacturing processes or origins
II. Unclear, hard-to-read or incorrect text-based information about product size or pieces
III. Relabelling
IV. Too much information
V. Unesthetic or uncommon design
VI. Graphics implying certain ingredients, (ingredient) amounts or manufacturing processes
VII. Unclear or beautifying colours and colour schemes
VIII. Hiding or showing specific parts through e.g. windows or sleeves
IX. Closures and sealings
X. Expensive packaging solutions
XI. Packaging sizes, formats or waste amounts versus product sizes
XII. Unnecessary use of packaging or a certain selected packaging material

Next to that, Table 2 offers an overview of the complaint categories per food category (RQ 1.1).

Table 2. Complaint categories in food categories

		Complaint Categories											
		Unclear, hard-to-read or incorrect text-based information about ingredients, manufacturing processes or origins	Unclear, hard-to-read or incorrect text-based information about product size or pieces	Relabelling	Too much information	Unesthetic, uncommon design	Graphics implying certain ingredients or (ingredient) amounts or manufacturing processes	Unclear or beautifying colours and colour schemes	Hiding or showing specific parts through e.g. windows or sleeves	Closures and sealing	Expensive packaging solutions	Packaging size, format or waste amount versus product size	Unnecessary use of packaging or a certain selected packaging material
Product category	0. Compound foodstuff		X				X		X	X		X	X
	1. Dairy products and analogues	X					X		X	X		X	
	2. Fats and oils and fat and oil emulsions	X						X				X	
	3. Edible ices								X			X	
	4. Fruits & vegetables	X	X					X				X	X
	5. Confectionery		X				X		X	X	X	X	
	6. Cereal and cereal products	X	X					X	X			X	X
	7. Bakery wares	X		X		X	X		X			X	
	8. Meat	X					X		X			X	
	9. Fish and fishery products								X			X	
	10. Eggs and egg products											X	X
	11. Sugars, syrups, honey and table-top sweeteners	X											
	12. Salts, spices, soups, sauces, salads and protein products		X			X		X	X	X		X	
	13. Foods intended for particular nutritional uses	X			X	X							
	14. Beverages	X	X		X		X		X	X		X	X
	15. Ready-to-eat savouries and snacks		X			X			X			X	

275 3.2 Outcomes and Mitigation Measures

276 Taking a closer look at the above presented data, one can see that communication via packaging is the
 277 most pressing issue for consumers complaining about packaging (RQ 1). This is represented by
 278 multiple different categories, whether touching upon explicit text-based or graphical information, or
 279 expectations based on specific qualitative or quantitative material use. Other basic packaging functions,
 280 namely protection, containment and convenience, are subordinated topics in the collected cases. Next
 281 to that, in almost all food groups, packaging sustainability is discussed, often as dissatisfaction about
 282 packaging size, format or waste in relation to the product size or amount. Overall, sustainability and
 283 communication are the major concerns of consumers complaining about packaging online (RQ2).
 284 Consumers also criticize the sheer use of packaging, mostly in examples of products with enhanced
 285 convenience levels. They often criticize the packaging as being unnecessary, although one could also
 286 say that the convenience level is the sticking point. In general, the food groups of fruits and vegetables
 287 as well as confectionery make up the largest share of cases (RQ 1.1). This outcome goes hand in hand
 288 with previous literature, where first, fruit packaging is mentioned under the top consumer concerns
 289 (“overpackaging”) ^{10, 41, 42} and, second, confectionery is known for its hedonic and gift function,
 290 influencing packaging design ^{9, 43}.

291 The following section addresses each complaint category in detail, following a thematic structure of
 292 first, mainly text-based, to second, mainly graphic-based and third, material-based complaints with
 293 overlaps between the categories.

294 3.2.1 Text-based complaints

295 Text-based information is an important part of communication and therefore a basic packaging
 296 function. ⁸ It can be discussed in the context of on-pack as well as accompanying information like
 297 advertisements, the latter however, is out of the scope of this work. At the stage of purchase and
 298 consumption, multiple requirements exist for giving information about food products. According to
 299 Regulation (EU) 1169/2011, its purpose is to allow “...consumers to identify and make appropriate use
 300 of a food and to make choices that suit their individual dietary needs.” ⁴⁰ With unclear, hard-to-read or
 301 simply incorrect text-based information, this purpose is hardly attainable. Overall, text-based elements
 302 and their design on packaging can be strong drivers for purchasing decisions speaking about the
 303 analysed cases. They implicate various expectations and were found to have a high potential for
 304 dissatisfaction if unclear, hard-to-read, incorrect or similar.

305 3.2.1.1 Unclear, hard-to-read or incorrect text-based information about ingredients, 306 manufacturing processes or origins

307 In the category of mostly qualitative text-based complaints, it was found that consumers discussed
 308 multiple dissatisfactory scenarios of packaging design they came across. Text-based on-pack
 309 information that should make it clearer for consumers to assess the product characteristics, was shown
 310 to cause dissatisfaction with food packaging. Most often, the following issues were mentioned:

- 311 • hard-to-read ingredients in cases where more valuable ingredients were easier to read than less
- 312 valuable ones,
- 313 • unclear / misleading information about manufacturing methods and origins,
- 314 • unclear / misleading or incorrect information about nutrients or focus groups (e.g. claiming to
- 315 include or be free from certain ingredients, being natural, for kids or similar),

- highlighting favourable nutrient contents that can only be reached by combinations with other products,
- unclear information about percentages of valuable ingredients,
- unclear or misleading product names.

Interestingly, sustainability issues were not found in this context, although environmental claims pose a rising issue discussed *i.a.* on the European level (e.g. Commission Notice 2021²⁵).

Starting with the mentioned cases about hard-to-read information, one can stress that the legibility of text-based information is regulated in (EU) 1169/2011, *inter alia* in terms of font size, colours and contrasts etc. This helps in questions of uncertainty of packaging design, also with objected to accentuations of valuable ingredients (quantitative ingredient declaration). Another issue found online is the unclear information about origins and manufacturing. Both aspects can also be found in 1169/2011 (Article 7), as “... *information shall not be misleading ... as to its ... country of origin or place of provenance, method of manufacture or production;*”.⁴⁰ For text-based statements from the collected sample that deal with complaints about on-pack communication like “free-from ...” or information about specific nutrients, regulation (EC) No 1924/2006 on nutrition and health claims made on foods gives potential guidance. Also focus groups are contextually discussed therein (e.g. kids).⁴⁴

Overall, “*Food information shall be accurate, clear and easy to understand for the consumer ...*”⁴⁰, which was, reflecting the consumers' perspectives, not achieved in the online cases. In the worst case, one could discuss that incorrect information can undermine “... *the protection of consumers' health and the safe use of a food.*”⁴⁰ as it might be the case with unclear information about ingredients. Comparing this information to the perspectives mentioned in⁷, consumers most likely would have taken transactional product choices in the discussed cases if information would have been clear to them. Considering legislative prerequisites, text-based information must be checked thoroughly before bringing a specific product to the market. To respect different perceptions of consumers, one could even trial the clarity of implicit and explicit text-based information, in the sense of how consumers understand the given information via packaging (compare e.g.³⁰). Particularly, the effects of phrases that somehow might indicate that products are made for certain groups, for example more vulnerable ones like children have to be thoroughly evaluated before applied as on-pack communication. Directive 2005/29/EC (Annex I) concerning unfair business-to-consumer commercial practices too touches upon this topic and gives guidance applicable to packaging design.¹¹

3.2.1.2 Unclear, hard-to-read or incorrect text-based information about product size or pieces

Like above, this category deals with complaints about text-based information, but quantity related. In the collected cases, unclear information about packaging- and product sizes was criticized. Declarations of certain product sizes being bigger or smaller than previous or comparable products were frequently objected to. Cases with bigger packaging but less product were also found as online complaints and actions to seemingly hide such changes were criticized. Overall, confusion by any generic statement about size or size changes was visible. Statements about some aspect being (extra) large, medium or small or of a specific size for sharing was shown to dissatisfy consumers, as it does not necessarily meet their expectations. Furthermore, complaints discussing incorrect information about the number of contained pieces were found.

Relating to amounts, giving the net quantity of a food in units of volume (e.g. liquids) or mass is one of the basic mandatory indications that is stated in Regulation (EU) 1169/2011. Some exceptions are

listed in its Annex IX, for example in cases where food products are normally sold by number, given that these are visible or indicated via labelling (Annex IX 1c). However, generally speaking, it is stated that *i.a.* the information about quantity shall not mislead.⁴⁰ Therefore, one can discuss if a verbal description rating sizes of products as being big, large or similar should better be avoided.

The topic of shrinking products (downsizing, “grocery shrink ray”⁷) and changing or not changing the packaging's appearance is an exceptional perspective in this category. It is not only about what is said, but also about what is not clearly communicated. Currently (2022) this topic is becoming more pressing looking at e.g. increasing product prices.⁶ It was already addressed in 2012 and discussed that this practice might not be fully covered by given frameworks and thus could be regarded as a misleading practice (e.g. p. 13, 41, 96).⁷ If product shrinkage is found to be necessary for whatever reason, enlarging the packaging size or adding buzzwords like *big* or *large* to distract from changes is unacceptable. It should rather be clearly indicated. Consumers are found to be more vulnerable in such situations: they do not always check the product's weight and do not expect such price increases.^{7, 45}

3.2.1.3 Relabelling

Another issue found in the context of text-based information is relabelling. In the consumers complaints, it primarily dealt with the relabelling of products to communicate a different shelf-life than seemingly intended in the first place (replacement or over-sticking of label).

Providing correct information via labelling of products is essential in the supply chain (e.g. 178/2022²⁰), e.g. for the traceability in cases of necessary recalls (e.g. Rapid Alert System for Food and Feed⁴⁶). For some scenarios, relabelling can be necessary, for example in cases of imported goods to align with national law.⁴⁷ Regulation (EU) 1169/2011 deals with changing information about food: “ ... *Food business operators, within the businesses under their control, shall not modify the information accompanying a food if such modification would mislead the final consumer or otherwise reduce the level of consumer protection and the possibilities for the final consumer to make informed choices. Food business operators are responsible for any changes they make to food information accompanying a food. ...*”.⁴⁰ Cases of shelf-life relabelled products and communication about these can be found online.⁴⁸

To avoid dissatisfied consumers in cases of necessary relabelling, open communication should help, if one reflects what consumers complained about. Furthermore, as it is generally not forbidden to sell expired products (except for products with a use-by-date) this fact can be communicated at the point of sale.⁴⁹ Instead of (only) relabelling products by e.g. over-sticking labels with new ones that are easily detachable, an explanatory second label that does not hide the previous could at best avoid confusion. Consumers seemed to be irritated in the cases in which they found different shelf-life labelling without explanation.

3.2.2 Text- and graphic-based complaints

Under text- and graphic-based complaints, two categories are discussed. Both deal with consumer complaints that refer to either way of communication and were found to be dissatisfactory packaging practices.

3.2.2.1 Too much information

This category offers one further perspective that packaging design has to apply - the one that too much information can similarly make it hard for consumers to understand product characteristics and to

choose products. Although communication about products is crucial in food packaging (compare above categories and e.g. ⁴⁰), it can also annoy, challenge and even overwhelm consumers. ⁵⁰ The issue of too much information was found online and referred to the food categories of bakery wares and beverages. For example, intendent amusing slogans about ingredients were criticized by consumers.

For packaging design in this context, one has to understand that many consumers base their product choices on very few cues and might ignore others in fast decision-making, e.g. at retail. Often, even the price is the leading decisive criterion. Other decisive criteria are for example nutritional information (“health”) and brand/packaging. ⁵⁰ If additional, optional information (like non-standardized labelling about nutritional properties) is presented, it can disturb the evaluation of more important cues for consumers. ⁵¹ The need and extent of these optional, text- and graphic-based information should be evaluated in its effects on consumers' perception, as it was shown by Hawley et al. (2013) ⁵¹ that many labelling types are (already) hard-to-understand. One could ask, if it brings any measurable benefit to consumers in the decision-making process or if it distracts from the cues that are most often regarded and evaluated.

3.2.2.2 : Unesthetic, uncommon design

Whether packaging is aesthetic or not is a very subjective rating. What one might find appealing or appropriate is unattractive or inappropriate for another person. This category of unesthetic, uncommon design was added as a complaint category to carry out the discussion of what people are design-wise used to and what they claimed to subjectively dislike. The online found cases focussed on uncommon, irritating designs and communication. Examples *inter alia* dealt with the use of widely known non-food packaging formats for food products and vice versa (e.g. personal care products).

Packaging allows the recognition of certain products ⁹, *i.a.* for easy product selection. If designs are out of well-known schemes, one can get attention for products, but also irritate consumers as the analysed data shows. This might probably have worse effects, if non-food products are packaged in food packaging (which was also found in the online complaints but was rated as out of scope of this study). Besides that, such examples are also present in product recalls. ⁵² However, this shows overall that packaging design induces expectations and that design of (food) packaging out of expected schemes can be critical in every-day life. If one reflects the different packaging designs in existing food environments, a basic understanding of what consumers might find (un)common or (un)esthetic for product groups in certain regions, can be derived and might help to avoid irritations. This is also interesting in considering colour schemes (compare complaints about colours in category VII). Reflecting at this point again e.g. Regulation (EU) 1169/2011 ⁴⁰, discussing that also “(b) *the presentation of foods, in particular their shape, appearance or packaging...*” should be “... *accurate, clear and easy to understand ...*”, packaging that is found to be uncommon (therefore not easy to understand) should be rethought.

3.2.3 Graphic-based complaints

Graphics can be seen as part of the basic communication function in packaging design. ⁹ Symbols like pictograms as well as pictures/images can provide multiple information, implicitly and explicitly. ^{9, 11} A unique graphic design via decoration is regarded as important in packaging communication, *i.a.* for a product's identity ⁹ or differentiation ⁵³. The printing of packaging and packaging elements is common for various products at different packaging- (i.e. primary, secondary, tertiary) and supply chain levels. ⁹ A multitude of decoration options like printing processes (e.g. letterpress, flexography, flexo process,

442 gravure, intaglio, offset and digital ink-jet or electrophotography) allows specific design depending on
443 materials, and even product protection (e.g. light protection).^{9, 54}

444 **3.2.3.1 Graphics implying certain ingredients or (ingredient) amounts or manufacturing** 445 **processes**

446 The collected sample that was categorized under graphics that induced dissatisfaction, includes
447 complaints about the disuse of certain depicted ingredients, depicted amounts of used ingredients, the
448 number of depicted pieces, product origins and manufacturing processes. Consumers who were
449 dissatisfied, mostly thought of higher amounts of value ingredients, they expected different product
450 decoration, fillings or toppings (e.g. confectionary and bakery wares) or product shapes, more pieces
451 than actually present or hand-made or national production, where it was neither hand-made nor a
452 produced good from an indicated provenance.

453 In this regard, Regulation (EU) 1169/2011 gives again guidance, as it also deals with the use of graphics
454 on food packaging.⁴⁰ The principle of Quantitative Ingredients Declaration (QUID) sets certain rules
455 for graphics on packaging and defines cases in which ingredients have to be quantified, which meets
456 most of the issues addressed by consumers: "... *The indication of the quantity of an ingredient or*
457 *category of ingredients used in the manufacture or preparation of a food shall be required where the*
458 *ingredient or category of ingredients concerned: ... (b) is emphasised on the labelling in words, pictures*
459 *or graphics;*". QUID applies *inter alia* "(ii) where pictorial representation is used to emphasise
460 selectively one or more ingredients...;" or "... (iii) where an ingredient is emphasised by an image
461 evoking its origin ...". Exceptions exist for cases like serving suggestions, representations of all food
462 ingredients and preparation instructions.⁵⁵ Although QUID in relation to packaging design is probably
463 not a general rule for the use of graphics, but rather a rule for the declarations if one uses graphics, it
464 can help the consumer to better understand the composition of the food product and be properly
465 informed about value ingredients. To avoid dissatisfaction, one could apply trials with different designs
466 before marketing. The evaluation of certain packaging designs, similarly to Germelmann and Held
467 (2014)¹⁴ who studied different tea packages, can show if a mismatch between expectations and product
468 characteristics exists. If this is the case, the exchange of the causal cues seems appropriate.

469 **3.2.4 Complaints about graphics and material use**

470 The following two categories deal with complaints that were related to both, graphical as well as
471 structural elements of material use. The blurred visual impression of products through mostly coloured
472 packaging material and the use of packaging elements like windows or sleeves is in focus. Both can be
473 seen as aspects in the sense of the communication function, but are also related to product protection
474 (e.g. protecting from light through the use of colours or opaque packaging and giving on the other hand
475 insight to a product's appearance).^{9, 54} Furthermore, the perceived ecological sustainability was
476 discussed online in the collected cases.

477 **3.2.4.1 Unclear or beautifying colours and colour schemes**

478 Complaints in this category dealt mainly with packaging intensifying the colours of products (film
479 wrap) and confusing or alike colour schemes for different products of the same brands or in between
480 brands, against the consumers' intuitions or expectations. Interestingly, complaints about ecological
481 sustainability in the context of colour use were not found in the online sources.

482 Addressing consumer issues with colours, packaging designers should have in mind what people
483 associate with certain colours and that it is a way to distinguish between products and product groups

as well as to evaluate quality criteria. While black for example, might suggest elegance and higher prices, white is seen as a colour for “reasonably priced” products.⁵³ Next to that, colour also transports information about e.g. the quality and freshness of meat or the ripening of fruits and vegetables^{8,9}. Even specific taste expectations are related to colours.⁵⁶ In packaging design, one must further consider that the expectations for product properties based on colours can vary between regions. Ampuero and Vila (2006)⁵³ for example discussed that “patriotic products” were associated with the colour red of the national flag (Spain) in their study. Even studies about colours in packaging design, dealing with issues of global acceptability of products can be found.⁵⁷ Also Germelmann and Held (2014) used different colour schemes in their evaluation of tea packaging to trial the detection of deceptive packaging.¹⁴

If it comes to packaging that gives unclear information by colours about e.g. the usage (like product group specific packaging colours), the food products properties (e.g. freshness) or if it beautifies / intensifies the products' very own colour, consumers can get irritated and dissatisfied. If products are hard to distinguish from others or if used colours distort the selection at the point-of-sale in ways like covering quality related criteria, consumers can have hard times making informed choices. This goes against the goal of providing food information, if one reflects on one hand the discussed perspectives from Regulation (EU) 1169/2011⁴⁰ and the definition of misleading packaging⁷ on the other hand.

3.2.4.2 Hiding or showing specific parts through e.g. windows or sleeves

The use of packaging elements like windows and sleeves has different functions in food packaging and was a cause for dissatisfaction found online. Whereas windows mostly provide sight of the actual product's appearance, sleeves can be used for labelling purposes, to decorate areas, stabilize specific packaging types like thin-walled cups or even combine multiple consumption units (e.g. dairy). With the use of sleeves, the access to and visibility of areas behind potentially is restricted and might need interaction by e.g. opening or removal.

These circumstances were part of multiple complaints about e.g. cardboard boxes with and without trays, cups, trays with cardboard or plastic sleeves as well as partly transparent flexible film packaging. Dissatisfaction about the actual product amount or the overall ratio of value ingredients were in most cases the addressed issues, also in combination with the amount of packaging material used. Hidden levels of filling heights with windows on the lower part of the packaging solution or sleeves or labels on the upper part were frequently found. Specific sizes of outer packaging combined with a partial sight to the product but hollow structures or unused space in inner levels, invisible until consumption, were found too. The presentation of value ingredients (e.g. in toppings on various products) through transparent areas like windows was a source of dissatisfaction, if the rest of the product did not look alike.

Taking away the consumers' possibility to analyse e.g. filling amount versus packaging size besides obligatory weight information makes it hardly possible to decide at the point-of-sale if product-to-packaging ratios are found appropriate or not. Although some requirements might induce the need for hollow spaces or certain headspace in packaging (e.g. mechanically, chemically protect products⁹, several products were criticized that seemingly took advantage of this argument and parallel placed products in visible areas behind windows or hid empty rooms behind sleeves or labels. As this overall increases the use of packaging material, the ecological sustainability in the light of material efficiency can be and also was questioned. It is clear that hiding or showing of specific product parts induces certain expectations about its composition. If these are not met after unpacking, dissatisfaction is likely, and redesign should be considered. One can come back to the General Food Law²⁰, reflecting that “...

*the ... presentation of food ..., including their ... packaging, the packaging materials used, the manner in which they are arranged and the setting in which they are displayed, ... shall not mislead consumers.”. Qualitative aspects like the presentation of certain, maybe decisive or value ingredients should therefore not show specific parts if the rest of the product contains less of the same ingredients. Furthermore, hollow packaging parts and or unused spaces should be avoided if these are not intended for protective needs. If the product's properties induce such necessities, this fact should be clearly communicated to avoid expectations of higher product quantities. Overall, the efficiency of solutions, where windows and sleeves potentially hide unused packaging space should be analysed in detail to meet 94/62/EC ³, Annex II, saying that “... *packaging volume and weight be limited to the minimum adequate amount to maintain ... safety, hygiene and acceptance for the packed product and for the consumer.”.**

3.2.5 Complaints about material use

This section contains four categories of complaints that could be connected to qualitative and quantitative issues of material use. The complaints deal one more time with the basic function of communication, as well as the functions of protection, containment and convenience. In the online collected cases, discussions concerning the ecological sustainability of the products were frequently found as well.

3.2.5.1 Closures and sealing

In the online complaints, different issues with closures and sealings were discussed. Mostly these referred to detached seals or reclosures and unpractical or hard-to-open solutions. More detailed, the cases dealt with detached seals from plastic films on metal trays, detached seals in single tea bags and flow-packs, detached reclosure in pouches, hard-to-open rigid lids on boxes and shrink film to secure screwcaps, spillage through opening and incorrectly attached spouts on beverage cartons. Hence, in the collected cases the proper containment of the products and secondly, product protection were not met, which was linked to spillage and potential hygienic problems. Packaging intended for reclosure that was not further reclosable, was related to convenience (e.g. “*apportionment function*”, “*convenience of use*” ⁸) and similarly to product protection (e.g. dry, powdery products that could not be reclosed, probably taking up water). Hard-to-open packaging solutions, on one hand hindering the safe opening for the operating person (e.g. the need of knives), and on the other hand, causing spillage during apportionment, were found as well.

The (effective) closure of packaging solutions is an important factor providing product protection, proper containment, convenience and, by avoiding food waste, supporting sustainability. ⁸ Reflecting Robertson (2012) ⁹ the closure and sealing function have different main goals: effective seals, opening and resealing as well as tamper evidence. Furthermore, four types of closures are distinguished: “*Closure to retain internal pressure*”, “*contain and protect contents*”, “*maintain vacuum inside container*” and “*to secure contents inside container*”. Next to this perspective, various sealing types and sealing techniques exist. ⁹

In this category, dissatisfaction and redesign are related to the material selection as well as applied closures and sealing systems. To ensure the enduring functioning of closures and sealing, packaging testing like shock testing, vibration testing, compression testing and atmospheric testing (e.g. temperature, humidity) can be run to understand the impacts of handling along the supply chain. ⁵⁸ If these shortcomings had been detected at an earlier stage, a great number of the cases collected online could have been prevented probably. Furthermore, packaging that was found to be hard-to-open by

consumers could have been avoided too. For example, peel tests, tear growth tests and tests about sealed-seam strength can be applied to detect the mentioned situations.⁵⁹ Caner, Pascall (2010)³³ investigated aspects of this category, as they analysed the openability of ten packaging types and even the related risks for injuries. Legal perspectives about closure and sealings could be looked at from the perspective of safe food²⁰: Ineffective seals can pose multiple hygienic risks.

3.2.5.2 Expensive packaging solutions

In this category dealing with expensive packaging solutions, consumers were dissatisfied with available identical food products, when the price per kilogram product showed big differences between packaging solutions (e.g. rectangular versus irregularly-shaped boxes). The price per kilogram product was in one solution less than half the price of a comparable second one.

Overall, the costs of packaging are a part of everyday purchases of *i.a.* fast moving consumer goods and include for example the material costs, cost for handling and labour, storage, disposal, reuse and other positions. While it is easy to understand that certain packaging solutions can be more costly than others, e.g. if they involve enhanced packaging technology or induce for example higher disposal costs, also the use of specific formats is a matter of costs, reflecting less efficient transportation.^{10, 60} The material choice that goes hand in hand with protection, the types and sizes of the containments, the packaging elements allowing convenience and the design for communication purposes, are all part of these costs.^{8, 10, 60} Comparing available products in retail, the packaging costs, for example, in limited editions or products with gift functions can be higher than in comparable products with conventional packaging solutions.^{9, 36} The higher costs can be incurred at any step in the supply chain, whenever efficiency or effectiveness is impaired in an aspect (e.g. transportation reflecting stacking, folding etc.).^{10, 60}

To avoid dissatisfaction about costs, communication seems to be key. The advantages of the more expensive packaging solution have to be clearly communicated. If not, consumers cannot see the point in paying higher product prices per kilogram of the same product with packaging variations, as the data shows. The willingness to pay for visible benefits is higher if consumers are properly informed, for example in the context of morality and ecological benefits of products.^{9, 61} Reusability of packaging could be such a benefit, reflecting that this behaviour is generally given for some packaging solutions: Caner and Pascal (2010)³³ for example, analysed *inter alia* convenience functions (specifically opening) of different packaging solutions. Consumers were asked if they had reused packaging after emptying the main product, depending on the packaging types. The reuse of plastic and glass bottles/jars was reported by approximately 22 and 37% of the study's participants.³³

3.2.5.3 Packaging size, format or waste amount versus product size

This category mostly describes complaints about situations in which consumers found that the packaging solutions were inefficient and wasteful compared to the contained product. On one hand, people were dissatisfied about perceived overpackaging/wasteful packaging in the light of environmental problems and secondly, they felt tricked by slack filling/ half-full packages. Many examples criticized had large packaging solutions as outer layers, often with inner layers that used very little of the possible space provided (likewise to category VIII dealing with specifically showing or hiding product characteristics). Furthermore, single packaged units of products were discussed by consumers.

Packaging sizes and formats vary depending on products and producing companies. While packaging has to be effective, it is also necessary to be efficient e.g. minimal material use. The latter can be

evaluated through the ratio between product and packaging, that describes their weight relation.¹⁰ Although science agrees that there is an optimal point of packaging between material use and product protection (product waste) (compare e.g. “The Innventia AB Model”), the food environment in retail offers manifold products within food categories with seemingly lavish or efficient packaging solutions.¹¹ Referring to the consumer’s impression about wasteful packaging and looking at slack filling, the European Briefing Paper, 2012⁷ discusses it as misleading if non-functional.

However, whether the considered cases are ecologically unsustainable, depends on multiple aspects, potentially including aspects overseen by consumers. Life cycle assessment (LCA) is a broadly accepted approach to analyse such cases.¹⁰ Next to that, shelf-life and stress tests can help to determine how much packaging material is necessary to provide e.g. barrier needs for product protection^{8,9}, dealing with the question of adequate amounts of packaging material (Annex II of Directive 94/62/EC³). Touching upon this topic, one can add that it can currently be found online that in public consultations of the initiative on “*Reducing packaging waste – review of rules*”, Article 9 of 94/62/EC³ (Essential requirements) is asked to prospectively include the issue of overpackaging.⁶² The issue of dissatisfaction with sizes and waste amounts is also pressing in e-commerce, looking at the cases. That frustration free e-commerce packaging is worked out, was already reported in 2012.¹⁰

Concerning the complaints about wasteful packaging in combination with small product amounts, like in multipacks, the question of realistic consumption/portion sizes can give guidance to avoid absurdly small units and unnecessary packaging waste. In many settings, consumers probably eat more than one cheese slice (e.g. 25 g each) and multiple instead of single cookies (e.g. 7 g each) at once. While smaller consumption units allow on one side the prevention of food waste⁶³, the packaging waste amounts can be higher¹¹.

3.2.5.4 Unnecessary use of packaging or a certain selected packaging material

Food packaging is frequently discussed under the perspective of environmental sustainability and consumers have the opinion that for many product categories, packaging, mostly plastic packaging, is unnecessary^{9, 10}. In online complaints about specific products, this impression was strong in certain categories, mostly fruits and vegetables. It very often dealt with flexible film wraps, partly in combination with expanded trays (e.g. expanded polystyrene). Furthermore, the unpacking of foods like fruits and vegetables from natural protective layers like peels or shells and repacking it into non-biodegradable counterparts / conventional plastic packaging was criticized multiple times (e.g. coconuts, citrus fruits etc.), this was also true for eggs. Prepared products with higher convenience levels like pre-cut pieces and their need for more sophisticated packaging were often discussed and likewise reasons for consumers being dissatisfied. Next to that, the wrapping of single fruits and vegetables that can on one hand easily be sold in bulk due to their relatively small sizes and, furthermore, amounts that do not match realistic consumption behaviour, were a basis for complaints (e.g. single potatoes, single berries etc.). Furthermore, one could find criticism referring to specific material selections, like the use of polystyrene (PS) trays.

In the mentioned cases, avoidance of higher convenience levels as well as informative messages can be discussed as options to bridge the gap between expectation and technological needs of products. Single initiatives in retail already try to follow such educational strategies and one can partly find messages about the packaging itself on the products.¹¹ Overall, this is a category where consumption patterns (like avoidance) could make a difference, probably at most concerning high-convenience products that might use elaborate packaging solutions, resource intensive production and different packaging waste amounts compared to alternative products that are neither pre-cut, nor peeled, boiled

658 or differently prepared. However, one can find that the sales of convenience products rose over the last
659 years and this product type is said to be trending.^{10, 64} Redesign in some of the cases in this category
660 is hard to reach, as technically, pre-cuts etc. need protective packaging, for example, against
661 unfavourable colour changes.⁹

662 3.3 Overall impression and future steps

663 Collecting and analysing the complaints about packaging that consumers shared online, a deepened
664 understanding of packaging practices that dissatisfy consumers could be developed. Its inclusion in
665 redesign processes seems important to improve the situation. Comparing the issues that consumers
666 mentioned against packaging perspectives from selected European law, one can sum up that a multitude
667 of rules exist that designers could have applied differently to better satisfy consumers. One can even
668 state provokingly, that most of the issues would not have arisen if packaging was designed according
669 to the strictest possible interpretations of these rules. Some discussed perspectives certainly leave room
670 for interpretation (for example, how much is an adequate use of material), but designers could just
671 adhere to the most truthful way of presenting their products via packaging, as, in the long term,
672 repercussions can be expected³¹, except perhaps from the most loyal consumers that might stay
673 although dissatisfied.¹⁵

674 The seeming play with consumers' expectations based on packaging design undermines the goals of
675 optimizing packaging for sustainability, as neglecting packaging is one visible outcome parallel to/ or
676 of the found packaging practices. If it is not repercussions on consumption patterns at purchase like
677 brand rejections, the impression of packaging being unnecessary already has its effects on sustainable
678 consumption, for example, if it is left out according to consumers' wishes enlarging for some products
679 the food waste problem in supply chains, if providing non-regional, non-seasonal products⁶³. As far
680 as science (via e.g. LCA) can evaluate the sustainability of products at this point, it is ecologically
681 beneficial for many product to package them versus leaving them unpackaged.⁶³

682 Regarding limitations, one has to mention that the data collection only provides a snapshot of online
683 complaints, and that the available data is expanding on a daily basis. Furthermore, recitations of
684 pictures on various websites, starting e.g. from a single post in social media, were not tracked down to
685 their original sources. The picture of the specific case was the starting point for the recontextualization
686 of the complaint. The accompanying text, if available, might have changed from website to website.
687 Overall, the recontextualization of the data is a potential source of interpretation bias, as it is related to
688 the researchers' interpretation. Whether or not one can "trust" the pictures is also a question that could
689 be discussed. The analysis might have included cases that were "set up".

690 Considering the comparison with perspectives from European food or packaging law, one gets the
691 impression that these, before marketing the products, could actually have prevented most of the found
692 complaints. What is true from a theoretical approach, is practically not the case, as it must be mentioned
693 that the national origin of the complaints goes beyond Europe. It was not a goal to detect the actual
694 area where the product was marketed (or if it was legally correct). This means that various other
695 legislative perspectives were probably relevant for specific cases. However, consumers were
696 dissatisfied independent of existing law, which implies the need to redesign the mentioned solutions in
697 any case. Furthermore, these selected documents are obviously not all possible (EU) publications one
698 could compare the sample with, but in doing so, all issues found could be addressed and discussed.

699 Redesign is often mentioned as a potential future step to improve the situation of the overall negative
700 perception of packaging and specifically the found complaints. It is highly recommended for packaging

designers, for the sake of progress to a more sustainable consumption, not to exploit / take advantage of possible different interpretations of existing legislative perspectives on packaging design. Moreover, marketing and product development must work together closely, avoiding solely marketing-driven designs. Reflecting the complaints, consumers are sensitive to various packaging practices that are experienced as dissatisfactory, even if these practices meet legal requirements. Packaging designers who, similarly, like consumers, seek a more sustainable future of products, should take these experiences into consideration and avoid these to the best of their knowledge (and respect sustainability impacts of packaging solutions). Very often, inefficiency was objected to and similarly seen in the researchers' evaluation of the complaints. There is (still) a need to catch up on design improvements for ecological sustainability and, in many cases, implicit and explicit communication. To further allow an overview of cases which are found inappropriate by consumers, the idea of a shared database⁷ could help to keep packaging designers updated with the most recent concerns of consumers and packaging design that did not meet their expectations. This would bring clarification in a topic that seems currently neglected in the technical-centred debate about packaging redesign. It is considered beneficial, if social sciences and humanities find their place in this discussion, as the consumers' wishes, and consumption patterns have already shown to have enough weight to change packaging design (such as the preference for paper or unpackaged goods with potentially conflicting food waste occurrence). Currently, however, this perspective seems not to be used for actually improving packaging design for sustainability, but rather heating the conflict in which producers and consumers think to know it better.

4 Conclusion

As food packaging is a driver for, on one hand, purchase decisions and, on the other hand, a hot topic in sustainability, its design must be examined from various perspectives. Redesign is a pressing issue for food producers and retailers, and is in the middle of its realization, reflecting time-bound recycling goals in the European Union. Up to now, consumers seem to be dissatisfied with packaging and their experiences and expectations should have a place in the redesign process, as it is part of their daily consumption. The collection of consumer complaints about packaging and their categorization into twelve areas of potential redesign foci, allowed the development of a deepened understanding about what consumers dislike about food packaging today and therefore prospectively could be improved. Fruit and vegetable packaging as well as confectionary packaging were often found in discussions about dissatisfactory packaging. The aspect of packaging sizes, formats and waste versus product amounts and sizes was an issue represented in almost all product groups. European law related to food and packaging offers manifold perspectives that, provocatively said, could have avoided the discussed, negative experiences with packaging, if applied in their strictest possible interpretation to packaging design. Further steps to improve the situation around dissatisfactory packaging could incorporate existing ideas, *i.a.* to establish a centralized European database for complaints about the packaging⁷ of (food) products to respect consumers wishes and include these, to the best of the packaging designer knowledge about sustainability, into the design process. Further studies would be required to prospectively investigate how packaging designs were developed in the first place and how negative consumer feedback has or has not influenced these designs.

5 Conflict of Interest

The authors are members of the COST Action Circul-a-bility.

6 Author Contributions

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856 [Umschau/pdfs/pdf_2018/07_2018/EU07_2018_WuF Weinrich Englisch.pdf](https://www.ernaehrungs-umschau.de/fileadmin/Ernaehrungs-Umschau/pdfs/pdf_2018/07_2018/EU07_2018_WuF_Weinrich_Englisch.pdf)
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Annex A – Considered websites (alphabetically) which contained complaints about dissatisfactory packaging

1. www.boredpanda.com
2. www.dailydoseoflol.com
3. www.demilked.com
4. www.fishki.net
5. www.gwp.co.uk
6. www.instagram.com
7. www.interestingengineering.com
8. www.ipackdesign.com
9. www.knowyourmeme.com
10. www.packhelp.com
11. www.piqueen.com
12. www.pleated-jeans.com
13. www.reddit.com
14. www.skaties.lv
15. www.sudzibas.lv
16. www.twitter.com
17. www.unifiedmanufacturing.com
18. www.utopia.de

19. www.videvestis.lv
20. www.voolas.com
21. www.watson.de

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975 **Annex B - Products addressed in complaints, assigned to food categories based on ³**

Food category	Products and frequency in sample
0. Compound foodstuffs (Added category describing compound meals at different convenience levels)	Sum = 21 • Moussaka (1) • Pizza (9) • Rolls (2) • Wraps (4) • Pasta (1) • Cheese with breadsticks (1) • Sandwich (2) • Hot Dog (1)
1. Dairy products and analogues <i>(1.1 Unflavoured pasteurised and unflavoured sterilised (including UHT) milk, 1.2 Unflavoured fermented milk products, including natural unflavoured buttermilk (excluding sterilised buttermilk) non-heat-treated after fermentation, 1.3 unflavoured fermented milk products, heat-treated after fermentation, 1.4 flavoured fermented milk products including heat-treated products, 1.5 dehydrated milk as defined by Directive 2001/114/EC, 1.6 cream and cream powder, 1.7 cheese and cheese products, 1.8 Dairy analogues, including beverage whiteners, 1.9 edible caseinates)</i>	Sum = 16 • Yogurt and yogurt drinks (4) • Cheese and cheese products (9) • Curd desserts (2) • Beverage whitener (1)
2. Fats and oils and fat and oil emulsions <i>(2.1 Fats and oils essentially free from water, 2.2 Fat and oil emulsions mainly of water-in-oil type, 2.3 Vegetable oil pan spray)</i>	Sum = 3 • Vegetable oil (1) • Butter (2)
3. Edible Ices	Sum = 3 • Edible Ices (3)

4. Fruits & Vegetables (4.1 Unprocessed fruits and vegetables, 4.2 Processed fruits and vegetables)	Sum = 59 • Fennel (1) • Strawberry (4) • Apple (4) • Banana (5) • Citrus fruits (9) • Potato (5) • Coconut (4) • Melon (3) • Carrot (2) • Pear (1) • Tomato (2) • Garlic (3) • Onion (2) • Mixed fruits and vegetables (2) • Mango (1) • Beet (1) • Salad (1) • Cauliflower and broccoli (3) • Aubergine (1) • Plantain (1) • Apricot (1) • Avocado (1) • Cucumber (1) • Corn (1)
5. Confectionery (5.1 Cocoa and chocolate products as covered by Directive 2000/36/EC, 5.2 Other confectionery including breath freshening micro-sweets, 5.3 Chewing gum, 5.4 Decorations, coatings and fillings, except fruit-based fillings covered by category 4.2.4)	Sum = 44 • Dragon beard candy (1) • Jelly babies and beans (6) • Chocolate and pralines (12) • Chocolate coated nuts (1) • Lokum (2) • Chocolate Lentils (5) • Hard candy (3) • Chewing gum (3) • Soft candy (2) • Nougat (1) • Mint thins (3) • Cocoa powder (1) • Spread (3) • Pastille (1)
6. Cereal and Cereal Products (6.1 Whole, broken, or flaked grain, 6.2 Flours and other milled products and starches, 6.3 Breakfast cereals, 6.4 Pasta, 6.5 Noodles, 6.6 Batters, 6.7 Pre-cooked or processed cereals)	Sum = 13 • Breakfast cereals (8) • Pasta (3) • Rice (2)
7. Bakery wares (7.1 Bread and rolls, 7.2 Fine bakery wares)	Sum = 26 • Cookie (10) • Cereal bar (2) • Pastry (1) • Bread (4) • Cake and sweet rolls (8) • Donut (1)

8. Meat <i>(8.1 Fresh meat, excluding meat preparations as defined by Regulation (EC) No 853/2004, 8.2 Meat preparations as defined by Regulation (EC) No 853/2004, 8.3 Meat Products)</i>	Sum = 12 • Fresh meat (3) • Meat roast (2) • Sausage (4) • Pate (1) • Jerky (1) • Cold cuts (1)
9. Fish and fishery products <i>(9.1 Unprocessed fish and fisheries products, 9.2 Processed fish and fishery products including molluscs and crustaceans, 9.3 Fish roe)</i>	Sum = 5 • Shrimp (2) • Salmon (3)
10. Eggs and egg products <i>(10.1 Unprocessed eggs, 10.2 Processed eggs and egg products)</i>	Sum = 5 • Cooked eggs (4) • Raw eggs (1)
11. Sugars, syrups, honey and table-top sweeteners <i>(11.1 Sugars and syrups as defined by Directive 2001/111/EC, 11.2 Other sugars and syrups, 11.3 Honey as defined in Directive 2001/110/EC, 11.4 Table-top sweeteners)</i>	Sum = 1 • Sugar (1)
12. Salts, spices, soups, sauces, salads and protein products <i>(12.1 Salt and salt substitutes, 12.2 Herbs, spices, seasonings, 12.3 Vinegars and diluted acetic acid (diluted with water to 4-30 % by volume), 12.4 Mustard, 12.5 Soups and broths, 12.6 Sauces, 12.7 Salads and savoury based sandwich spreads, 12.8 Yeast and yeast products, 12.9 Protein products, excluding products covered in category 1.8)</i>	Sum = 10 • Soup (2) • Herbs and Spices (4) • Salad (1) • Spread (2) • Mustard (1)
13. Foods intended for particular nutritional uses as defined by Directive 2009/39/EC <i>(13.1 Foods for infants and young children, 13.2 Dietary foods for special medical purposes defined in Directive 1999/21/EC (excluding products from food category 13.1.5), 13.3 Dietary foods for weight control diets intended to replace total daily food intake or an individual meal (the whole or part of the total daily diet), 13.4 Foods suitable for people intolerant to gluten as defined by Commission Regulation (EC) No 41/2009)</i>	Sum = 2 • Cookie (1) • Shake (1)
14. Beverages <i>(14.1 Non-alcoholic beverages, 14.2 Alcoholic beverages, including alcohol-free and low-alcohol counterparts)</i>	Sum = 20 • Tea (4) • Juice (6) • Wine (1) • Soft drink (3) • Coffee (1) • Water (1) • Powdered drinks (3)

	• Beer (1)
15. Ready-to-eat savouries and snacks <i>(15.1 Potato-, cereal-, flour-, or starch-based snacks, 15.2 Processed nuts)</i>	Sum = 10 • Chips (5) • Popcorn (1) • Nuts (3) • Cracker (1)