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Sustainable food packaging: An updated definition following a holistic approach

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Food packaging solutions need to be redesigned to be more sustainable, but determining which solution is 'more optimal' is a very difficult task when considering the entire food product value chain. Previous papers paved the way toward a sustainable food packaging definition, but it is far from being commonly accepted or well usable in the broad food systems domain, which further results in uninformed choices for sustainable food packaging made by all stakeholders in the value chain: producers, distributors, practitioners and consumers. Therefore, this work aims first at giving a state-of-the-art overview of sustainable food packaging terms (38 similar terms were identified and grouped into four clusters: Sustainable, Circular, Bio and Other sustainable packaging) and definitions using systematic (narrative) review analysis and 'controlled expert opinion feedback' methodology. Second, it aims to offer an updated definition for sustainable food packaging, which is also specific to food packaging and be simple, coherent, easily understandable, and communicable to everybody. The applied holistic approach intends to include all aspects of the food-packaging unit, to consider food safety and packaging functionality, while taking into account different disciplines and challenges related to food packaging along the supply chain. Being a balancing act, a sustainable food packaging may not be a perfect solution, but contextual, suboptimal and in need of constant validation.

KEYWORDS

food, packaging, definition, sustainable, holistic, eco-friendly packaging, circular, challenges

1. Introduction

Food packaging solutions are widely recognized to produce multiple advantages within the whole food supply chain and related stakeholders, but the present consumption rate of materials, linear production and consumption models used for packaging, and their littering make the current situation no longer bearable. The current packaging solutions for food need to be redesigned in a more sustainable way (Herbes et al., 2020; Testa et al., 2020). Without a doubt, the environmental problems caused by (fossil fuel-based plastic and high resource intensive materials) packaging need to be tackled by launching new solutions, focusing on refuse, reuse, replace, reduce as well as recycle such materials (see e.g.: Papargyropoulou et al., 2014; Knauf, 2015; Van Ewijk and Stegemann, 2016). The concept of packaging sustainability—in accordance with the Brundtland Report (Keeble, 1988), is defined as a 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'—has been one of the most highly discussed topics for some time (Nordin and Selke, 2010; Boz et al., 2020; Ketelsen et al., 2020), and has been an emerging area of interest for scholars and practitioners around the world (Ketelsen et al., 2020; Vila-Lopez and Küster-Boluda, 2020; Wandosell et al., 2021).

Previous papers paved the way toward a sustainable food packaging definition (Wikström et al., 2019; Camilleri, 2020; Morseletto, 2020), but it is far from being commonly accepted or well usable in the broad food systems domain. Companies (such as Coca-Cola, McDonald's, Tesco), organizations [such as Sustainable Packaging Alliance (SPA) and Sustainable Packaging Coalition (SPC)] and academic researchers with different academic backgrounds (economic, material sciences, environmental management, etc.) have formulated various definitions, which are not fully aligned (Pauer et al., 2019). The lack of agreement is leading to confusion not only among consumers, who already struggle with identifying sustainable packaging solutions at the point of sale (Boz et al., 2020; Acuti et al., 2022), but presumably also among legislators and other supply chain members (Trubetskaya et al., 2022). Lack of a widely accepted definition (or use of strict versus vague definitions) may lead to major inconsistencies, even to misleading consumers, greenwashing or fraud. When there is no clear understanding of what a sustainable food packaging is, consumers can make wrong choices even with the best of their intentions, from a sustainable point of view (information asymmetry; Akerlof, 1970). This for example may lead to preferring the less sustainable packaging at the expense of the more sustainable one, which then may even disappear from the market. This becomes even more complicated in situations where organizational changes are needed, as for example in tackling solutions linked to re-use of packaging.

This intrinsic controversy that characterizes food products complicates the definition of sustainability in the packaging field. Current definitions on sustainability of packaging solutions are often associated with only waste reduction and pollution prevention. For example, the current EU strategies toward the circular economy deliver a sustainability definition based on packaging waste reduction and support it by the implementation of several tools and requirements (European Commission, 2015, 2019, 2020). This approach may not capture the complexity that food packaging has. Food packaging must serve some critical basic functions, but developing such packages nowadays is more of a balancing act between costs and benefits to reach an equilibrium (e.g., less packaging or more food waste). For example, it has to protect the food from external influences (physical, chemical and biological) throughout the supply chain (including many stages such as point of purchase, use at home and post-use), maintain its safety and quality during the given shelf life, refrain from releasing harmful substances into the food, respond to the highest safety standards, which are set by regulatory agencies (Begley et al., 2005), provide visual product quality cues and other relevant information important for consumers' trust and ultimately reduce food waste and loss. All of these aspects are of critical importance. Furthermore, the requirements for packaging may be different for the same product in different supply chains (e.g.: kept at ambient, cold, or frozen storage), causing increased complexities.

Food packaging has a special place in the plastic packaging debate since 40% of the plastic produced, namely PE, PP, PET and PS, is being used in food packaging applications (Plastics Europe, 2021), and the use of plastic in this domain is seen by consumers as a problem larger than climate change (Otto et al., 2021). Selecting the right packaging method, material and tailoring properties according to the needs of the food product (fit-for-purpose packaging as reported by Verghese et al., 2015) is a critical aspect, since every product has its own characteristics, thereby having product-specific requirements. All those factors add complications when striving for sustainable harmonization and obviously cause a new set of challenges at the end of life of the particular packaging material (Bauer et al., 2021).

Hence, harmonization is required to ensure uniform strategies when defining packaging sustainability and packaged food supply systems, across all actors. Furthermore, clear communication to and from policymakers is needed—especially in industry sectors where producers are overburdened by cost, legislation, and strict but sometimes overwhelmingly skewed compliance requirements. A commonly agreed holistic definition of sustainable food packaging would show how sustainability can be assessed for food products, would accelerate progress, alleviate the discourse, and would assist in the establishment of effective collaborations among stakeholders. In addition, this agreement will also reduce greenwashing by avoiding the fashionable effects of certain terms relating to sustainability, used wrongly or rightly, making more complex the consumer's choice in the end and the work of industrials really invested in reducing the environmental impact.

Therefore, the aims of this article are (1) to clarify the currently used terms and definitions for sustainable food packaging, (2) to identify critical issues which are relevant to the topic, and (3) to offer an updated and holistic consensus definition for sustainable food packaging. This work was carried out by a vast group of researchers engaged in different disciplines of food packaging and with diverse research backgrounds, therefore, this new definition intends to consider the entire value chain, which extends from raw material resources all the way to post consumer processing of the packaging material. Contrary to previous definitions, this definition aims to be specific to food packaging and be simple yet coherent, holistic and harmonic, easily understandable, and communicable to everybody. Moreover, this article is written with the undisguised goal of starting an international dialog on this very impactful and dynamic subject.

2. Methodology

2.1. Analysis framework

The analysis framework consisted of three steps. Firstly, a systematic (narrative) review analysis was performed using Web of Science. Articles in a 20 years' time range (2002 to July 2022) were

extracted to create a knowledge database. The search string was composed of the following keywords and fields: 'Topic: Food'; 'All fields: Packaging'; Abstract: 'sustainability', 'sustainable', 'environmental', 'circular', 'green', 'eco-friendly' or 'eco friendly'. Boolean operators "AND" and "OR" were used to combine the three defined research fields and keywords. If needed, additional articles were also employed for analysis to further clarify some of the concepts. The descriptive results of the literature search are described in Section 2.2.

In the second phase, relevant articles were qualitatively analyzed to review the terminology, to identify critical issues and to create an updated definition for sustainable packaging. Thirdly, a technique similar to Delphi (structured communication with qualitative analyzing approach) was used in two rounds to complete the initial review of the terminology, to refine the list of critical issues and to finalize the new definition. Similar methodologies are often used in many areas of science to find a consensus of a group of experts'opinion with controlled opinion feedback (Dalkey and Helmer, 1963; Hasson and Keeney, 2011; Niederberger and Spranger, 2020), and it serves an important basis for evaluating previous results and often useful when opinions from an expert group are presumably more accurate than those from unstructured groups (Niederberger and Spranger, 2020), especially in a field where incomplete knowledge is evident (Giannarou and Zervas, 2014). First, a small panel of experts (a group of 5 experts; without anonymity) was selected based on interdisciplinarity and expertise in the field of sustainable packaging. During a series of online meetings all experts presented their views, then responses were collected, conflicting viewpoints were identified, analyzed and discussed until consensus was reached. The group's views were analyzed qualitatively, and the initial text was modified accordingly. In the second round a larger panel was constructed (a group of 20 experts including the previous experts) to collect different views in written form. Again, viewpoints were identified, analyzed and discussed until consensus was reached.

As a result, a review of terminology arranged based on agreed relevance (Table 1; discussed in Section 3.1), a review of challenges (Table 2; discussed in Section 3.2) and the new definition (discussed in Section 4) for sustainable packaging were established.

2.2. General search results

The search with the keyword 'food' as a topic narrowed down the search to 854,551 references, while 'packaging' limited the search to 121,981 references. After applying the 'sustainability' keyword (or a synonym such as 'sustainable', 'environmental', 'circular', 'green', 'eco-friendly' or 'eco friendly') the article search resulted in a database of 3,850 references.

In general, results show that the food packaging community at large, which includes researchers, practitioners, industry and marketing experts, has been increasingly focused on finding sustainable packaging solutions for food products. This is well reflected in Figure 1, where the number of publications related to 'sustainable food packaging' have exponentially grown in the past 20 years with a steep increase in the years between 2019 and 2022. The trend can be assumed to continue in the near future, which makes the aim of this article especially relevant.

Results also show limited integration between disciplines, or connections between consumers, materials and food (see Figure 2). The lack of multidisciplinary research can also be a reason for missing clear definitions in the food packaging topic. For example, a large number of articles are related to technical (material) fields, such as antimicrobial substances to increase product shelf life. While other articles use more general terms and focus on consumer related issues without material related terms. Moreover, the absence of terms related to end of life also indicates the need for a more integrated (holistic) approach in this field, which can be completed first in a definition that can be easily understood by everyone.

3. Results

3.1. Previously used terms and definitions of sustainable packaging

Different terms used in previous research for sustainable packaging were reviewed (see Table 1, which summarizes the 38 different packaging terms related to the concept of sustainable packaging). All these terms highlight the (reduction of) impact that packaging has on the environment or society (Ilgin and Gupta, 2010; Prakash and Pathak, 2017; Nguyen et al., 2020; Zeng and Durif, 2020). The used terms have been summarized in four clusters: *'Sustainable packaging'*, *'Circular packaging'*, '*Bio packaging*' and *'Other sustainable'*.

3.1.1. Sustainable packaging

Packaging solutions in this category include the Triple Bottom Line (TBL) approach based on economic, social, and environmental impacts (Jain and Hudnurkar, 2022) and their integration into the life cycle of the packaging material—from cradle to grave—throughout each stage of the supply chain. Terms like environmentally friendly and green packaging are often used as synonyms for sustainable packaging, therefore those were also put in this category; however, these are not necessarily synonyms. When describing sustainable packaging, authors either used their own definitions or the definitions by the Sustainable Packaging Coalition (2005, 2009) or the Sustainable Packaging Alliance (2004). These definitions offer a valuable starting point, but have also been criticized earlier in literature (Grönman et al., 2013). It is also noted that sustainable packaging always comes with an environmental impact, therefore 'more' and 'less' sustainable packaging would be a more appropriate term (Boz et al., 2020), or the concept of 'sustainable packaging' should be deconstructed, because this absolute value is rather utopic. Moreover, these terms do not refer, at least directly, to the potential of reducing food waste, although this may be sometimes the case, and are mostly focused on avoiding unnecessary packaging, overpackaging or single-use plastics, thus reducing the direct environmental consequences of the use of the materials.

3.1.2. Circular packaging

Packages in this category are designed according to the principles of the circular economy. Recyclable, recycled, reusable and zero waste are often considered as similar terms, and so grouped together. Circular packaging can be seen as one way toward sustainability due to the reduction in new resources entering the system. It can be regarded as a subcategory of sustainable

TABLE 1 Review of terminology used for sustainable packaging solutions.

Terms	Definitions/characterizations	Source
Sustainable packaging (9)		
Sustainable packaging	By using the word 'sustainable' the concept of sustainability is applied to the field of packaging production (product/package systems). It includes insertion of the goals of sustainable development (economic, social and environment) into the life cycle of packaging, from cradle to grave, throughout each stage of the supply chain. As a result, sustainable packaging is perceived as safe, healthy, market-efficient, and cost-effective, which is obtained, produced, transported, and recycled via sources of renewable energy, as well as with the use of renewable or recyclable materials; it also utilizes clean production technologies and best practices; is designed to optimize the materials and energy used, and can be effectively recovered and reused in numerous production cycles.	Orzan et al. (2018); Grönman et al. (2013); Magnier and Schoormans (2015); Boz et al. (2020); Martinho et al. (2015); Nordin and Selke (2010)
Environmentally friendly packaging; Eco-friendly packaging; Ecologically responsible packaging; Ecologically conscious packaging; Pro-environmental packaging; Ecologically packaged products; Eco-design(ed) packaging	These terms are all related to a packaging innovation strategy, which contributes to the United Nations (UN) Sustainable Development Goals (SDGs) and accomplishes a balance of ecological, social, and economic development. It causes less environmental harm than traditional packaging, makes efficient use of materials, leads to less solid waste, and reduces food losses and waste. It is usually constructed according to life cycle assessment (LCA), features multiple sustainable attributes, and evokes explicitly or implicitly consumers' eco-friendliness.	Nguyen et al. (2020); Prakash et al. (2019); Prakash and Pathak (2017); Scott and Vigar-Ellis (2014); Ketelsen et al. (2020); Koenig-Lewis et al. (2014); Yokokawa et al. (2018); Zeng et al. (2021); Zeng et al. (2020); Zeng and Durif (2020); Magnier and Crié (2015)
Green packaging	Green packaging clearly highlights its impact on waste and pollution, uses ecological materials, or manufacturing techniques which avoid potentially toxic constituents for human health and the environment.	Wandosell et al. (2021); Ahmed and Varshney (2011)
Circular packaging (14)		
Circular packaging; Zero waste packaging	Circular packaging is designed according to the principles of the circular economy (recycled content, reusability, design for disassembly, and recyclability) to preserve the natural resources, optimize their use, and minimize the negative impact on the environment. Zero waste packaging is specifically focused on the material flow, with no waste. However, often confused for zero landfill. In this case also, at end of life the packages are reused, repaired, or redistributed within the system.	Testa et al. (2020); Jäger and Piscicelli (2021); Song et al. (2015)
Recyclable packaging	Recyclable packaging is made of materials that can be re-introduced within the circle with the help of disposal, collection, sorting, and reprocessing with mechanical or chemical methods. Efficiency or economics are not included in this definition, nor if recycling is down-cycling.	Muranko et al. (2021), Wang et al. (2021)
Recycled packaging; Post-consumer recycled content packaging; Ocean plastic packaging; Beach plastic packaging;	Recycled packaging is made of recycled materials (e.g.: post-consumer recycled content or ocean plastic) subsequently saving the need to use new, virgin material.	Van Sluisveld and Worrell (2013); Magnier et al. (2019)
Reusable packaging; Closed-loop packaging; Returnable packaging; Multi-way packaging; Non-disposable packaging; Durable packaging; Refillable packaging	Reusable packaging is a waste management strategy and combines forward distribution operations with reverse logistics, which involves an operation (handling, storage, and transport) by which products or components are used again for the same purpose for which they were conceived. This saves the need to use new material.	Muranko et al., 2021; Accorsi et al., 2020; Van Sluisveld and Worrell, 2013; Vöröskői et al. (2020); Dubiel, 1996; Böröcz, 2023
Bio packaging (10)		
Bio-based packaging; Plant based packaging; Biomaterial based packaging; Bioplastic packaging; Biopolymer packaging; Biopackaging	Bio-packaging refers to materials which are either bio-based, from renewable raw materials originating from biological resources (such as agricultural or marine sources: microbial resources like microbial cellulose, polyhydroxyalkanoates, polysaccharides, proteins, lipids, and/or resins), or bio-degradable or have both properties. It includes bio-based packaging which may not be recyclable or biodegradable, or fossil fuel-based yet biodegradable.	Gontard and Guilbert (1994); Lomartire et al. (2022); Reichert et al. (2020); Cutter (2006); Santhosh et al. (2021); Cruz et al. (2022)
Bio-degradable packaging; Oxo-degradable packaging	Biodegradable packaging describes alternative end-of-life scenarios for packaging materials where its breakdown occurs via industrial or home-composting. Fossil fuel-based packaging that is bio-degradable can also be in this definition.	Reichert et al. (2020); Ivonkovic et al. (2017); Allison et al. (2021); Cruz et al. (2022); Zaborowska et al. (2021)

(Continued)

TABLE 1 (Continued)

Terms	Definitions/characterizations	Source
Compostable packaging	Compostable packaging refers to materials which break down and degrade in the environment, but consists of only organic elements that degrade in the environment without leaving any toxic residue. All compostable materials are biodegradable, but not all biodegradable materials are compostable.	Reichert et al. (2020); Allison et al. (2021)
Edible packaging (films, coatings)	Edible packaging is a wrapping or coating that is an integral part of the (food) product, fully degradable and can be eaten with the product.	Petkoska et al. (2021); Janjarasskul and Krochta (2010); Kadzińska et al. (2019); Cutter (2006)
Other sustainable packaging (5)		
(Eco) Refill packaging	Refill packaging prolongs the lifetime of (parent) packaging through a second more lightweight and flexible packaging (but also considered as a supplementary one-way product).	Van Sluisveld and Worrell (2013)
Non-excessive packaging	Non-excessive packaging refers to a packaging redesign, where abundant components are removed without compromising other packaging functions, quality, and esthetics.	Van Sluisveld and Worrell (2013)
Lightweight packaging; Downgauging packaging	Lightweight packaging decreases the external dimensions of packaging, while maintaining similar inner dimensions, while offering the same or an enhanced packaging strength [e.g.: reducing the average thickness of the original material; replacing original material for a more lightweight alternative (composite)].	Van Sluisveld and Worrell (2013)
Innovative packaging	This includes novel materials in mono- or multilayers while decreasing the environmental pressure by considering a broad range of sustainability issues (e.g.: waste prevention, efficient use of resources, process optimization, recycle, reuse). Innovative packaging is more of a design and holistic approach.	Reichert et al. (2020); Vanderroost et al. (2014)

The order of the terms was established based on relevance. The number of identified synonyms are in parentheses. The number of references used in the table depended on the number of identified synonyms for the same term and on the accuracy of the definition in the literature.

TABLE 2 Review of challenges for sustainable packaging solutions.

1	The protection of food products takes center stage
2	The food product-package is one inseparable unit
3	For food packaging both direct and indirect sustainability effects must be considered
4	Food packaging is a resource, not litter
5	Avoidance of food packaging is not always the best option
6	Sustainable food packaging development, in practice, is a balancing act
7	Multidisciplinary approach is needed to create sustainable food packaging solutions
8	Not all food packaging innovation is sustainable
9	Context (local) is key to food packaging sustainability
10	Regulatory landscape of sustainable food packaging is not fully comprehensive
11	Consumer knowledge and awareness on sustainable food packaging is limited
12	Food packaging is an information source on both product and packaging sustainability

The order of the challenges was established based on relevance.

packaging, however the concept shifts the focus more to the life-cycle (resource cycles) and to the end of life of the material (Testa et al., 2020), in spite of the fact that avoidance should be the highest priority in the decision tree. Re-introducing a material to avoid the use of virgin resources may at times be costly, or very difficult to be proven safe (Nerín et al., 2022; Tsochatzis et al., 2022). Reusing, mechanical or chemical recycling are all within the circular packaging definition, and the origin of the material (e.g.: from renewable sources, fossil fuel) or the amount of resources (energy, raw materials, etc) are not included in the definitions. Their end of life can also be quite varying, for example, in the case of compostable materials, their conditions for compostability may vary from simple household composting to complex industrial composting. Similarly, recycling can be chemical, mechanical, and may result in a downgrade of the material. Furthermore, in this category of terms, there is no reference to the specific functions (i.e., protection) that the packaging material may impart to the food.

3.1.3. Bio packaging

This is a diverse and slightly ill-defined category, since packages in this category can also be those labeled "compostable," "bio-degradable," "oxo-degradable," or "bio-based." These packages are highlighting the origin of the packaging material and/or its ability to degrade. The materials can be made from renewable sources (e.g.: second generation feedstocks), or are in some cases fossil-based. Plastic material made from bio-based material may not necessarily be bio-degradable. This broad group of packaging could be regarded as a subcategory of sustainable packaging, however, one must consider the material's origin, and especially in the case of displacement of food crops with biomass waste or residues, e.g., unavoidable agricultural or forestry wastes as well as their potential degradability at end of life alternative (Cruz et al., 2022). Moreover, such terms are a big source of confusion not only among consumers, therefore could lead to an environmental risk in the long term.

3.1.4. Other sustainable packaging

Packages in this category fulfill certain aspects of sustainability (Lewis et al., 2007, 2010; Santi et al., 2022), which looks at broader solutions for sustainable packaging, leading to effective, efficient, cyclic and safe practices. For example, refills, innovative and lightweight packages indicate solutions which bring significant improvements to current practices, and to some extent also are easily demonstrating to the end user (i.e., consumer) the improved function; for example, they lead to minimizing food waste, decrease plastic littering, or improving waste sorting are indicated in the definitions. These can be also considered as a subcategory of sustainable packaging.

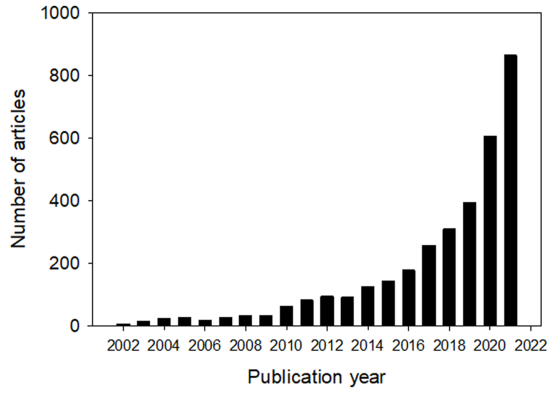

FIGURE 1
Number of publications on sustainable food packaging between 2002 and July 2022.

Based on the numerous (38) expressions collected, one can conclude that, unfortunately, literature uses too many terms, of which many are very similar (see synonyms such as 'Environmentally friendly', 'Eco-friendly', 'Ecologically responsible', 'Ecologically conscious', 'Pro-environmental', 'Eco-designed). In many cases the definitions are superficial and cannot be used outside of the context they belong to. The definitions treat the three pillars of sustainability (natural, human, and economic capital; Hansmann et al., 2012) unequally, and the environment gets the most focus. Moreover, there is little emphasis on the role (responsibility) that the actors (i.e., consumers, managers) may play, and, more importantly, these terms do not relate the packaging together with the product, which in food is a grave simplification. The use of technical terms also may present communication challenges, as this may hinder the public (mostly consumers, but also journalists and managers) to understand, evaluate and make appropriate practical decisions. Hence, the current definitions of sustainable packaging are too complex and cannot be communicated well because consumers and other stakeholders do not have enough abilities (will) to process this information (Dörnyei et al., 2017). All these factors can lead to the so-called problem of 'information overload', or worse, to misleading communication of sustainable packaging (greenwashing).

3.2. Challenges and reasons for updating sustainable food packaging

A review of the literature also brings up some of the important challenges in relation to re-defining the concept of food packaging sustainability (see Table 2).

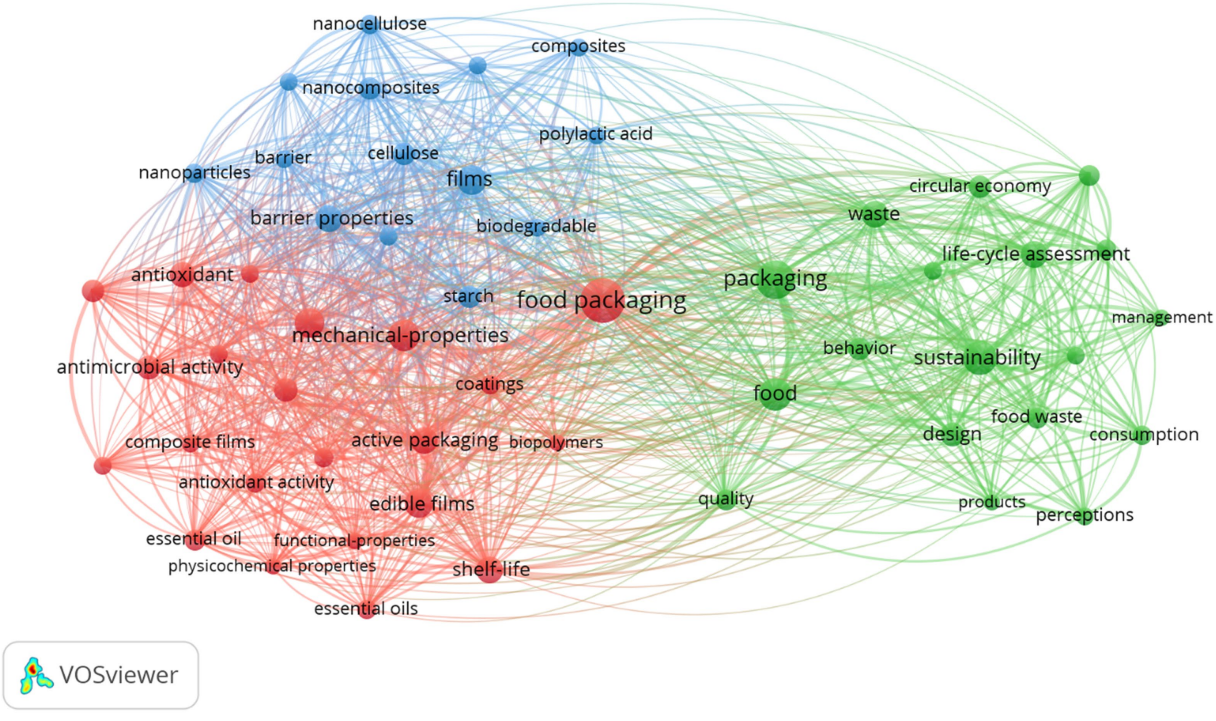

FIGURE 2
Co-occurrence analysis of the most relevant papers in literature. Size of the nodes represent more frequently used terms. Different colors represent different clusters. The minimum number of terms is 10, at least 30 times occurring /terms.

3.2.1. The protection of food products takes center stage

Packaging exists because of the product. This is especially true for food products, where packaging can be regarded as an added service (Löfgren, 2005; Löfgren et al., 2008). Therefore, the packaging solution needs to ensure, first and foremost, without compromises, the quality and safety of the food it contains (Han et al., 2018). However, this sometimes includes over-packing with the use of unnecessary long shelf life (often forced by retailers) instead of optimal shelf life or 'just necessary packaging' (Coffigniez et al., 2021). Food packaging and shelf life extension is a balance between the packaging and waste. Longest shelf life sometimes is not necessary, especially in areas where logistic and technological infrastructure make it possible to consume food in a much shorter time or if products are on average sold much before the expiration date. When long distances are instead critical to provide consumers with healthy and affordable choices (i.e., remote locations) long shelf life is critical to avoiding food waste. This means that the materials have a verifiable means to ensure – among others – no chemical components in amounts that can endanger the health of the consumers should migrate from the environment (and from the packaging material) into the food, or release micro/nanoplastics in the environment. Such a product centered approach of packaging is very unique to the food packaging field and significantly complicates the adoption and validation of universal sustainable packaging solutions.

3.2.2. The food product-package is one inseparable unit

To evaluate and measure the sustainability of packaged food products, the product and (and not necessarily only the primary) container should be regarded as a unit with a common environmental footprint, and the material should not be evaluated alone itself, nor the food (Meherishi et al., 2021). In particular, for food, it should be emphasized that primary packaging prevents food waste, which is a very important aspect of the environmental footprint (Dilkes-Hoffman et al., 2018; Molina-Besch et al., 2019). Food waste contributes to a significant amount of the total greenhouse gas emissions of the food, and once it is processed, all resources used are part of the final balance. The package is only a portion of the entire footprint (Crippa et al., 2021). Hence, no sustainable solutions can be found where the quality and shelf life of the product are compromised.

3.2.3. For food packaging both direct and indirect sustainability effects must be considered

Environmental impacts related to food packaging could be the result of direct (refer to the impacts caused during production, consumption, and disposal) or indirect (refer to the impacts generated by the industries that supply the final production point) effects on the environment (Lindh et al., 2016). While the negative direct effects of packages are usually considered in sustainability evaluations, the positive or negative indirect effects that packaging could provide through food product protection, supply chain, or sorting and end of life are not always included. In case of packaged food products, the two environmental effects need to be considered together (de Koeijer et al., 2017) as including indirect effects may show very different overall environmental impact, depending on the food-packaging system (Williams and Wikström, 2011; Wikström et al., 2016).

3.2.4. Food packaging is a resource, not litter

Packaging is a people-made novel entity (Persson et al., 2022), and it will always have a negative environmental cost; it is not possible to have packaging materials with no impact on the environment. All packaging material has an environmental footprint (Morgan et al., 2022), and there is a cost associated with the resources used, even when recycled or reused. In the case of food products, it is important to quantitatively measure the environmental footprint of the food, from cradle to grave, including the packaging material with its own life-cycle (if circular). Furthermore, the added value the package can offer needs to be taken into consideration, together with any littering or recovering efforts (consumer behavior is very important in the late stages of the life cycle), as well as any reduction in food waste. Food packaging then should be considered as an additional, valuable resource integral part of the food product, and can no longer be considered of low value, ending up in litter or waste.

3.2.5. Avoidance of food packaging is not always the best option

As with many resources employed in the food system, complete avoidance of the packaging use should be the preferred solution, but only if this does not have a detrimental effect on the safety and quality of the product or on minimizing food waste (Beitzen-Heineke et al., 2017; Williams et al., 2020). In particular, minimizing food waste needs to be the primary goal. On average, packaging is estimated to account for only 10% of the total energy inputs for one person's weekly consumption of food, while it plays a critical role in ensuring that the other 90% of energy inputs to the supply chain are not wasted (Verghese et al., 2015). Instead, a critical hierarchy needs to be established, and it has to be related to an overall decrease of the footprint, as quantified for example using a life cycle assessment (LCA), which takes into consideration all resources, as well as the end of life and food waste (Nguyen et al., 2020), and a social life cycle assessment (SLCA), which is aimed at evaluating social and socioeconomic aspects of product-packaging units (Jørgensen, 2013).

3.2.6. Sustainable food packaging development, in practice, is a balancing act

A well designed package needs to fulfill basic important functions, such as protection, storage, loading and transport, marketing, sale, promotion and communication, and impart trust of the food to the consumer, a 'guarantee' of its quality and consistency (Molina-Besch et al., 2019; Ketelsen et al., 2020); all of this while also satisfying any sustainability requirements originating from the entire life of the product-package unit, including, but not limited to, logistics, production, engineering, material sources, end of life functions such as sorting, composting or recycling (Lindh et al., 2016; Wandosell et al., 2021). A sustainable packaging can be achieved by operating on three different levels: (1) at the level of raw materials (through the use of recycled raw materials, renewable resources or deriving from the revaluation of industrial processing waste); (2) at the production level (through more energy efficient processes); and (3) at the level of eco-design (through the reduction of thicknesses and weights; the realization of mono materials, fully recyclable structures in alternative to heterogeneous, multi material packaging, which are harder to sort; the realization of biodegradable and/or compostable packaging, in alternative to fossil fuel-based materials). In order to provide sustainable packaging with satisfying performance suitable for food

applications, it is fundamental to implement appropriate innovative functionalization strategies; among these, the use of nanotechnologies, blending and/or filling technologies, the development of active packaging, the realization of high performance active and passive coatings and layers orientation. The combination of multiple requirements and sustainability implementation possibilities makes sustainable packaging development an extremely difficult balancing act which is hard to measure. As a consequence, in practice, sustainability in packaging development is still limited (de Koeijer et al., 2017).

3.2.7. Multidisciplinary approach is needed to create sustainable food packaging solutions

Packaging sustainability is defined and measured differently depending on the discipline (Jiménez-Guerrero et al., 2015; Martinho et al., 2015; Han et al., 2018; Herbes et al., 2020; Zeng and Durif, 2020; Wandosell et al., 2021; Zeng et al., 2021). For example, from the materials engineering perspective packaging sustainability means balancing resource use while optimizing the properties of the packaging source material (e.g.: ease in processability, low energy consumption, or less use of chemicals in production or end of life). In this case sustainability is mostly measured by LCA (Steenis et al., 2018). The process is not easy, especially if data input is poor (Radonjič, 2019), but at least with LCA it is possible to give an exact answer between scenarios. On the other hand, from a marketing perspective, packaging is an essential tool to communicate and influence consumers (Dörnyei and Lunardo, 2021), deliver information, and aid in decision making. In this case the effectiveness of a package is mostly measured by consumers' willingness to buy, and sustainability is only applied with designs that facilitate sales goals. Companies have clear ambitions with regard to improving food packaging sustainability; but not at the expense of product's market potential. However, as far apart as the two disciplines are at the current time, they must work together to find optimal sustainable packaging solutions for food products.

3.2.8. Not all food packaging innovation is sustainable

When developing innovative sustainable food packaging solutions, challenges of technological nature, concerning materials and processes, can be encountered. For example, in an attempt to replace fossil-fuel-based plastics, the use of renewable materials in bio-plastics is steadily growing (Cruz et al., 2022; Rosenboom et al., 2022; Shlush and Davidovich-Pinhas, 2022). Although the use of bio-plastic is associated with positive consumer perception (Herbes et al., 2018), these materials may not be necessarily compostable, biodegradable, recyclable, or may be a challenge to sort depending on the economies of scale in the various municipalities. In addition, some technological properties of these materials are still not fully satisfactory, hindering their large market uptake. Among these, raw material variability, a too narrow processing window, inherent brittleness, poor barrier properties, scarce impact and thermal resistance. As for the processes, a fundamental requirement for the implementation of innovative sustainable packaging solutions on a large scale is industrial feasibility. In general, non-invasive innovations compared to conventional technologies (e.g., redesigning packaging by reducing thickness and weight) are excellent options for improving current practices and are generally welcomed and accepted by all stakeholders. On the other hand, more invasive innovations (for example the use of new materials or "niche" technological innovations, not compatible with conventional manufacturing processes or machin-ability) often raise a number of additional problems along the value chain, will rarely meet industrial acceptance and may create confusion and slow down acceptance and implementation (Morone and Imbert, 2020).

3.2.9. Context (local) is key to food packaging sustainability

Determining the sustainability of the food packaging solution by omitting the context in which the solution exists can lead to incorrect evaluations. The context, i.e., country of origin, consumption region and supply chains, specific product features, and user (consumer) habits, plays a major role in determining packaging sustainability (Lindh et al., 2016). For example, an LCA analysis of packaging for olive oil demonstrated that while glass bottles are preferable for local distribution, tinplate cans are more sustainable for long-distance distribution (Guiso et al., 2016). Therefore, including more context-specific factors into sustainable packaging evaluations will lead to more sustainable and transparent solutions, toward true harmonization of sustainable packaging in the marketplace.

3.2.10. Regulatory landscape of sustainable food packaging is not fully comprehensive

Sustainable packaging is not yet properly defined by law, current regulations are not comprehensive and often misleading to some extent, which makes it a challenge to design truly sustainable packaging solutions. Similarly, unnecessary packaging is also an ill-defined concept. Labeling regulations are also limited: uses of claims (symbol, color) which falsely convey that the package is more sustainable than the alternative in the market can be misleading and lead to greenwashing (Boz et al., 2020). It is then clear the need for a shared regulatory framework, which constitutes a guideline for the sustainable design of packaging and is supported by consumer engagement, through a more transparent communication (Dörnyei et al., 2022).

3.2.11. Consumer knowledge and awareness on sustainable food packaging is limited

Recent studies highlight that consumers show increasing concern about sustainability issues, and sustainability affected food consumption is becoming a genuine driver of choice (Trivium Packaging, 2022). It is critical therefore that consumers are provided with information on the sustainability of the food package, and that there are clear instructions also on how to dispose of the food package at the post consumer phase. Indeed, the consumer is mindful of the environment but is often poorly informed about specific issues, for example, the degree of sustainability of the various materials and the context in which they are used. Consumers are often not able to distinguish between industrial composting and household (home-) composting, in addition, there is no real control (composition, rest of plastic fragments, etc) on the compost made at home, which may result in more littering. Recent evidence also shows that the sustainability rating of European consumers and scientific LCAs currently are misaligned (Otto et al., 2021). Moreover, complexity in use of terms (as already described above) also hinders consumer understanding of truly sustainable packaging choices. Consumer knowledge about packaging sustainability needs to be improved to prevent and avoid greenwashing at consumer but also at industry level.

3.2.12. Food packaging is an information source on both product and packaging sustainability

As one of the main contacts in the consumer journey, the package itself has increasingly become an effective way to communicate with consumers and other stakeholders about sustainability (Wyrwa and Barska, 2017). Consumers use multiple attributes and cues, such as packaging design (Otto et al., 2021), verbal attributes (e.g., text labels, logos and other cues), symbolic and text-based cues (Dinh et al., 2022) to evaluate the sustainability of the food product (such as product composition or shelf-life) and its packaging (such as showing garbage sorting instructions; Magnier and Crié, 2015). This dual task can sometimes confuse users if not sufficiently explicit.

4. Updated and holistic definition for sustainable food packaging

The search for sustainable packaging solutions is constantly evolving. Thanks to innovation in the food packaging field, technological advances, and impact assessment methodologies, a fixed definition of packaging sustainability is logically not possible. However, results provided in this work suggest that there are some major aspects that contribute to a sustainability definition for food packaging. A definition that includes all these aspects while giving space to future innovation is required (Santi et al., 2022). Therefore, a holistic definition of 'sustainable food packaging' is proposed here to be used by the broader food packaging community, in both scientific and mainstream publications.

Sustainable food packaging is an optimized, measured (quantified) and validated solution, which takes into consideration the balance of social, economic, ecological and safe implementations of the circular value chain, based on the entire history (life cycle) of the food product-package unit.

While the holistic definition was created specifically for the food domain, it can be also applied to other areas with minor changes. The definition offered takes into consideration the balance of the lowest possible use of resources (e.g.: rational use of ecologically available resources, avoidance of unnecessary overconsumption) and at the same time all direct and indirect environmental impacts. It includes all aspects of the food-packaging unit, as well as all stakeholders and actors needs along the supply chain, while being efficient, effective, cyclic and safe (Lewis et al., 2007, 2010). Furthermore, it should be produced from renewable sources, preferably using land and water resources that do not displace food and feed. This holistic perspective is key to the ability to take into consideration food safety and packaging functionality into the equation, including consumers, who play a key role in ensuring that the intended design is implemented.

The analysis of definitions also shows the necessity to broaden and deepen the aspects of measurement and metrics of sustainable packaging and to open a new debate in future publications. Measurement is an important step of the current definition, however exact measures that would be associated with this new definition is not offered here. There are a plethora of metrics to assess packaging sustainability (e.g.: LCA, Ellen McArthur Circularity index), and the landscape is dynamic, often new metrics emerge. Although the measurement of sustainability is still not a fully harmonized practice and often under debate, it should be made a priority to have systems in place that allow comparisons between solutions as they become available. It is then clear that there is a need to come up not only with a common definition, but a 'standard' to evaluate sustainability in this field. This would reduce the number of vague, confusing, or even misleading claims, and align common metrics for what sustainability is really about. As there are already problems with the ESG reporting skewing by the companies due to vague framework and assessment, the terminology and research must include strictly measured data with well defined goals, metrics and research framework.

It is then not only important to choose the appropriate material, and to design the appropriate packaging solution, but also awareness, education, and communication to the end users are required to ensure that the package solution ends up being treated and used the way it is intended. Compostability, recyclability, reuse rates for food packaging will continue to be limited if the practical implementation challenges (such as infrastructure) are not overcome, and unless the entire community does not resort to harmonized policies that reduce these practical challenges. In the case of food packaging, a consumer centered approach is key to ensure that the material does not end up as litter or landfill.

Being a balancing act, a sustainable food package solution may not be perfect, but contextual, suboptimal and in need of constant validation. It is important to note that food product designers, food scientists and food packaging practitioners have in common the social responsibility to find the best solution, even when it is not necessarily easy, affordable or convenient, and when it may require organizational changes, as we strive to reach global sustainability goals.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KRD and MC: conceptualization and methodology. KRD: writing—original draft preparation. KRD, IU-U, VK, RW, and MC: writing—review and editing. KRD, IU-U, VK, RW, LI, IK, GC, PC, MCF, MKP, EA, BM, VF, AA, SY, FP, MD, LJ, VC, and MC: editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Accorsi, R., Baruffaldi, G., and Manzini, R. (2020). A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry. *Sustain. Prod. Consum.* 24, 48–61. doi: 10.1016/j.spc.2020.06.014

Acuti, D., Pizzetti, M., and Dolnicar, S. (2022). When sustainability backfires: a review on the unintended negative side-effects of product and service sustainability on consumer behavior. *Psychol. Mark.* 39, 1933–1945. doi: 10.1002/mar.21709

Ahmed, J., and Varshney, S. K. (2011). Polylactides—chemistry, properties and green packaging technology: a review. *Int. J. Food Prop.* 14, 37–58. doi: 10.1080/10942910903125284

Akerlof, G. A. (1970). The market for "lemons": quality uncertainty and the market mechanism. *Q. J. Econ.* 84, 488–500. doi: 10.2307/1879431

Allison, A. L., Lorencatto, F., Michie, S., and Miodownik, M. (2021). Barriers and enablers to buying biodegradable and compostable plastic packaging. *Sustainability* 13:1463. doi: 10.3390/su13031463

Bauer, A. S., Tacker, M., Uysal-Unalan, I., Cruz, R. M., Varzakas, T., and Krauter, V. (2021). Recyclability and redesign challenges in multilayer flexible food Packaging—a review. *Foods* 10:2702. doi: 10.3390/foods10112702

Begley, T., Castle, L., Feigenbaum, A., Franz, R., Hinrichs, K., Lickly, T., et al. (2005). Evaluation of migration models that might be used in support of regulations for food-contact plastics. *Food Addit. Contam.* 22, 73–90. doi: 10.1080/02652030400028035

Beitzen-Heineke, E. F., Balta-Ozkan, N., and Reefke, H. (2017). The prospects of zero-packaging grocery stores to improve the social and environmental impacts of the food supply chain. *J. Clean. Prod.* 140, 1528–1541. doi: 10.1016/j.jclepro.2016.09.227

Böröcz, P. (2023). Decision on single-use and reusable food packaging: searching for the optimal solution using a fuzzy mathematical approach. *J. Sci. Food Agric.* 103, 1042–1048. doi: 10.1002/jsfa.11745

Boz, Z., Korhonen, V., and Koelsch Sand, C. (2020). Consumer considerations for the implementation of sustainable packaging: a review. *Sustainability* 12:2192. doi: 10.3390/su12062192

Camilleri, M. A. (2020). European environment policy for the circular economy: implications for business and industry stakeholders. *Sustain. Dev.* 28, 1804–1812. doi: 10.1002/sd.2113

Coffigniez, F., Matar, C., Gaucel, S., Gontard, N., Guilbert, S., and Guillard, V. (2021). The use of modeling tools to better evaluate the packaging benefice on our environment. *Front. Sustain. Food Syst.* 5:634038. doi: 10.3389/fsufs.2021.634038

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., and Leip, A. J. N. F. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food* 2, 198–209. doi: 10.1038/s43016-021-00225-9

Cruz, R. M. S., Krauter, V., Krauter, S., Agriopoulou, S., Weinrich, R., Herbes, C., et al. (2022). Bioplastics for food Packaging: environmental impact, trends and regulatory aspects. *Foods* 11:3087. doi: 10.3390/foods11193087

Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Sci.* 74, 131–142. doi: 10.1016/j.meatsci.2006.04.023

Dalkey, N., and Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Manag. Sci.* 9, 458–467. doi: 10.1287/mnsc.9.3.458

de Koeijer, B., Wever, R., and Henseler, J. (2017). Realizing product-packaging combinations in circular systems: shaping the research agenda. *Packag. Technol. Sci.* 30, 443–460. doi: 10.1002/pts.2219

Dilkes-Hoffman, L. S., Lane, J. L., Grant, T., Pratt, S., Lant, P. A., and Laycock, B. (2018). Environmental impact of biodegradable food packaging when considering food waste. *J. Clean. Prod.* 180, 325–334.

Dinh, M. T. T., Su, D. N., Tran, K. T., Luu, T. T., Duong, T. H., and Johnson, L. W. (2022). Eco-designed retail packaging: the empirical conceptualization and measurement. *J. Clean. Prod.* 379:134717. doi: 10.1016/j.jclepro.2022.134717

Dörnyei, K. R., Bauer, A. S., Krauter, V., and Herbes, C. (2022). (not) communicating the environmental friendliness of food Packaging to consumers—an attribute-and Cue-based concept and its application. *Foods* 11:1371. doi: 10.3390/foods11091371

Dörnyei, K. R., Krystallis, A., and Chrysochou, P. (2017). The impact of product assortment size and attribute quantity on information searches. *J. Consum. Mark.* 34, 191–201. doi: 10.1108/JCM-10-2015-1594

Dörnyei, K. R., and Lunardo, R. (2021). When limited edition packages backfire: the role of emotional value, typicality and need for uniqueness. *J. Bus. Res.* 137, 233–243. doi: 10.1016/j.jbusres.2021.08.037

Dubiel, M. (1996). Costing structures of reusable packaging systems. *Packag. Technol. Sci.* 9, 237–254. doi: 10.1002/pts.2770090502

European Commission. (2015). Closing the loop—an EU action plan for the circular economy. Available at: https://www.eea.europa.eu/policy-documents/com-2015-0614-final

European Commission. (2019). Directive on single-use plastics. Available at: https://environment.ec.europa.eu/topics/plastics/single-use-plastics_en.

European Commission. (2020). *A new circular economy action plan for a cleaner and more competitive Europe*. European Commission: Brussels, Belgium, 1–20.

Giannarou, L., and Zervas, E. (2014). Using Delphi technique to build consensus in practice. *IJBSAM* 9, 65–82.

Gontard, N., and Guilbert, S. (1994). "Bio-packaging: technology and properties of edible and/or biodegradable material of agricultural origin" in *Food packaging and preservation* (Boston, MA: Springer), 159–181.

Grönman, K., Soukka, R., Järvi-Kääriäinen, T., Katajajuuri, J. M., Kuisma, M., Koivupuro, H. K., et al. (2013). Framework for sustainable food packaging design. *Packag. Technol. Sci.* 26, 187–200. doi: 10.1002/pts.1971

Guiso, A., Parenti, A., Masella, P., Guerrini, L., Baldi, F., and Spugnoli, P. (2016). Environmental impact assessment of three packages for high-quality extra-virgin olive oil. *J. Agric. Eng.* 47, 191–196. doi: 10.4081/jae.2016.515

Han, J. W., Ruiz-Garcia, L., Qian, J. P., and Yang, X. T. (2018). Food packaging: a comprehensive review and future trends. *Compr. Rev. Food Sci. Food Saf.* 17, 860–877. doi: 10.1111/1541-4337.12343

Hansmann, R., Mieg, H. A., and Frischknecht, P. (2012). Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability. *Int. J. Sustain. Dev. World Ecol.* 19, 451–459. doi: 10.1080/13504509.2012.696220

Hasson, F., and Keeney, S. (2011). Enhancing rigour in the Delphi technique research. *Technol. Forecast. Soc. Chang.* 78, 1695–1704. doi: 10.1016/j.techfore.2011.04.005

Herbes, C., Beuthner, C., and Ramme, I. (2018). Consumer attitudes towards biobased packaging–a cross-cultural comparative study. *J. Clean. Prod.* 194, 203–218. doi: 10.1016/j.jclepro.2018.05.106

Herbes, C., Beuthner, C., and Ramme, I. (2020). How green is your packaging—a comparative international study of cues consumers use to recognize environmentally friendly packaging. *Int. J. Consum. Stud.* 44, 258–271. doi: 10.1111/ijcs.12560

Ilgin, M. A., and Gupta, S. M. (2010). Environmentally conscious manufacturing and product recovery (ECMPRO): a review of the state of the art. *J. Environ. Manag.* 91, 563–591. doi: 10.1016/j.jenvman.2009.09.037

Ivonkovic, A., Zeljko, K., Talic, S., and Lasic, M. (2017). Biodegradable packaging in the food industry. *J. Food Saf. Food Qual* 68, 26–38. doi: 10.2376/0003-925X-68-26

Jäger, J. K., and Piscicelli, L. (2021). Collaborations for circular food packaging: the set-up and partner selection process. *Sustain. Prod. Consum.* 26, 733–740. doi: 10.1016/j.spc.2020.12.025

Jain, P., and Hudnurkar, M. (2022). Sustainable packaging in the FMCG industry. *Clean. Responsible Consum.* 7:100075. doi: 10.1016/j.clrc.2022.100075

Janjarasskul, T., and Krochta, J. M. (2010). Edible packaging materials. *Annu. Rev. Food Sci. Technol.* 1, 415–448. doi: 10.1146/annurev.food.080708.100836

Jiménez-Guerrero, J. F., Gázquez-Abad, J. C., and Ceballos-Santamaría, G. (2015). Innovation in eco-packaging in private labels. *Innovations* 17, 81–90. doi: 10.1080/14479338.2015.1011055

Jørgensen, A. (2013). Social LCA—a way ahead? *Int. J. Life Cycle Assess.* 18, 296–299. doi: 10.1007/s11367-012-0517-5

Kadzińska, J., Janowicz, M., Kalisz, S., Bryś, J., and Lenart, A. (2019). An overview of fruit and vegetable edible packaging materials. *Packag. Technol. Sci.* 32, 483–495. doi: 10.1002/pts.2440

Keeble, B. R. (1988). The Brundtland report:'our common future'. *Med. War* 4, 17–25. doi: 10.1080/07488008808408783

Ketelsen, M., Janssen, M., and Hamm, U. (2020). Consumers' response to environmentally-friendly food packaging-a systematic review. *J. Clean. Prod.* 254:120123. doi: 10.1016/j.jclepro.2020.120123

Knauf, M. (2015). Waste hierarchy revisited—an evaluation of waste wood recycling in the context of EU energy policy and the European market. *Forest Policy Econ.* 54, 58–60. doi: 10.1016/j.forpol.2014.12.003

Koenig-Lewis, N., Palmer, A., Dermody, J., and Urbye, A. (2014). Consumers' evaluations of ecological packaging–rational and emotional approaches. *J. Environ. Psychol.* 37, 94–105. doi: 10.1016/j.jenvp.2013.11.009

Lewis, H., Fitzpatrick, L., Verghese, K., Sonneveld, K., Jordon, R., and Alliance, S. P. (2007). *Sustainable packaging redefined*. Melbourne, Australia: Sustainable Packaging Alliance.

Lewis, H., Verghese, K., and Fitzpatrick, L. (2010). Evaluating the sustainability impacts of packaging: the plastic carry bag dilemma. *Packaging Technology and Science: An International Journal* 23, 145–160. doi: 10.1002/pts.886

Lindh, H., Williams, H., Olsson, A., and Wikström, F. (2016). Elucidating the indirect contributions of packaging to sustainable development: a terminology of packaging functions and features. *Packag. Technol. Sci.* 29, 225–246. doi: 10.1002/pts.2197

Löfgren, M. (2005). Winning at the first and second moments of truth: an exploratory study. *Manag Service Qual.* 15, 102–115. doi: 10.1108/09604520510575290

Löfgren, M., Witell, L., and Gustafsson, A. (2008). Customer satisfaction in the first and second moments of truth. *J. Prod. Brand Manag.* 17, 463–474. doi: 10.1108/10610420810916362

Lomartire, S., Marques, J. C., and Gonçalves, A. M. (2022). An overview of the alternative use of seaweeds to produce safe and sustainable bio-Packaging. *Appl. Sci.* 12:3123. doi: 10.3390/app12063123

Magnier, L., and Crié, D. (2015). Communicating packaging eco-friendliness: an exploration of consumers' perceptions of eco-designed packaging. *Int. J. Retail Distrib. Manag.* 43, 350–366. doi: 10.1108/IJRDM-04-2014-0048

Magnier, L., Mugge, R., and Schoormans, J. (2019). Turning ocean garbage into products–Consumers' evaluations of products made of recycled ocean plastic. *J. Clean. Prod.* 215, 84–98.

Magnier, L., and Schoormans, J. (2015). Consumer reactions to sustainable packaging: the interplay of visual appearance, verbal claim and environmental concern. *J. Environ. Psychol.* 44, 53–62. doi: 10.1016/j.jenvp.2015.09.005

Martinho, G., Pires, A., Portela, G., and Fonseca, M. (2015). Factors affecting consumers' choices concerning sustainable packaging during product purchase and recycling. *Resour. Conserv. Recycl.* 103, 58–68. doi: 10.1016/j.resconrec.2015.07.012

Meherishi, L., Narayana, S. A., and Ranjani, K. S. (2021). Integrated product and packaging decisions with secondary packaging returns and protective packaging management. *Eur. J. Oper. Res.* 292, 930–952. doi: 10.1016/j.ejor.2020.11.022

Morgan, D. R., Styles, D., and Lane, E. T. (2022). Packaging choice and coordinated distribution logistics to reduce the environmental footprint of small-scale beer value chains. *J. Environ. Manag.* 307:114591. doi: 10.1016/j.jenvman.2022.114591

Morone, P., and Imbert, E. (2020). Food waste and social acceptance of a circular bioeconomy: the role of stakeholders. *Curr. Opin. Green Sustain. Chem.* 23, 55–60. doi: 10.1016/j.cogsc.2020.02.006

Molina-Besch, K., Wikström, F., and Williams, H. (2019). The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture?. *Int. J. Life Cycle Assess.* 24, 37–50.

Morseletto, P. (2020). Targets for a circular economy. *Resour. Conserv. Recycl.* 153:104553. doi: 10.1016/j.resconrec.2019.104553

Muranko, Ż., Tassell, C., Zeeuw van der Laan, A., and Aurisicchio, M. (2021). Characterisation and environmental value proposition of reuse models for fast-moving consumer goods: reusable packaging and products. *Sustainability* 13:2609. doi: 10.3390/su13052609

Nerín, C., Bourdoux, S., Faust, B., Gude, T., Lesueur, C., Simat, T., et al. (2022). Guidance in selecting analytical techniques for identification and quantification of non-intentionally added substances (NIAS) in food contact materials (FCMS). *Food Addit. Contam. A* 39, 620–643. doi: 10.1080/19440049.2021.2012599

Nguyen, A. T., Parker, L., Brennan, L., and Lockrey, S. (2020). A consumer definition of eco-friendly packaging. *J. Clean. Prod.* 252:119792. doi: 10.1016/j.jclepro.2019.119792

Niederberger, M., and Spranger, J. (2020). Delphi technique in health sciences: a map. *Front. Public Health* 8:457. doi: 10.3389/fpubh.2020.00457

Nordin, N., and Selke, S. (2010). Social aspect of sustainable packaging. *Packag. Technol. Sci.* 23, 317–326. doi: 10.1002/pts.899

Orzan, G., Cruceru, A. F., Bălăceanu, C. T., and Chivu, R. G. (2018). Consumers' behavior concerning sustainable packaging: an exploratory study on Romanian consumers. *Sustainability* 10:1787. doi: 10.3390/su10061787

Otto, S., Strenger, M., Maier-Nöth, A., and Schmid, M. (2021). Food packaging and sustainability–consumer perception vs. correlated scientific facts: a review. *J. Clean. Prod.* 298:126733. doi: 10.1016/j.jclepro.2021.126733

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., and Bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *J. Clean. Prod.* 76, 106–115. doi: 10.1016/j.jclepro.2014.04.020

Pauer, E., Wohner, B., Heinrich, V., and Tacker, M. (2019). Assessing the environmental sustainability of food packaging: an extended life cycle assessment including packaging-related food losses and waste and circularity assessment. *Sustainability* 11:925. doi: 10.3390/su11030925

Persson, L., Carney Almroth, B. M., Collins, C. D., Cornell, S., de Wit, C. A., Diamond, M. L., et al. (2022). Outside the safe operating space of the planetary boundary for novel entities. *Environ. Sci. Technol.* 56, 1510–1521. doi: 10.1021/acs.est.1c04158

Petkoska, A. T., Daniloski, D., D'Cunha, N. M., Naumovski, N., and Broach, A. T. (2021). Edible packaging: sustainable solutions and novel trends in food packaging. *Food Res. Int.* 140:109981. doi: 10.1016/j.foodres.2020.109981

Plastics Europe, E. P. R. O. (2021). *Plastics—The facts 2021*. An Analysis of European Plastics Production, Demand and Waste Data. Available from: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2021/.

Prakash, G., Choudhary, S., Kumar, A., Garza-Reyes, J. A., Khan, S. A. R., and Panda, T. K. (2019). Do altruistic and egoistic values influence consumers' attitudes and purchase intentions towards eco-friendly packaged products? An empirical investigation. *J. Retail. Consum. Serv.* 50, 163–169. doi: 10.1016/j.jretconser.2019.05.011

Prakash, G., and Pathak, P. (2017). Intention to buy eco-friendly packaged products among young consumers of India: a study on developing nation. *J. Clean. Prod.* 141, 385–393. doi: 10.1016/j.jclepro.2016.09.116

Radonjič, G. (2019). "Packaging sustainability and greenwashing" in *Conference proceedings of the 1st conference on circular Packaging, Slovenia, Ljubljana*, 13–21.

Reichert, C. L., Bugnicourt, E., Coltelli, M. B., Cinelli, P., Lazzeri, A., Canesi, I., et al. (2020). Bio-based packaging: materials, modifications, industrial applications and sustainability. *Polymers* 12:1558. doi: 10.3390/polym12071558

Rosenboom, J. G., Langer, R., and Traverso, G. (2022). Bioplastics for a circular economy. *Nat. Rev. Mater.* 7, 117–137. doi: 10.1038/s41578-021-00407-8

Santhosh, R., Nath, D., and Sarkar, P. (2021). Novel food packaging materials including plant-based byproducts: a review. *Trends Food Sci. Technol.* 118, 471–489. doi: 10.1016/j.tifs.2021.10.013

Santi, R., Garrone, P., Iannantuoni, M., and Del Curto, B. (2022). Sustainable food Packaging: an integrative framework. *Sustainability* 14:8045. doi: 10.3390/su14138045

Scott, L., and Vigar-Ellis, D. (2014). Consumer understanding, perceptions and behaviours with regard to environmentally friendly packaging in a developing nation. *Int. J. Consum. Stud.* 38, 642–649. doi: 10.1111/ijcs.12136

Shlush, E., and Davidovich-Pinhas, M. (2022). Bioplastics for food packaging. *Trends Food Sci. Technol.* 125, 66–80. doi: 10.1016/j.tifs.2022.04.026

Song, Q., Li, J., and Zeng, X. (2015). Minimizing the increasing solid waste through zero waste strategy. *J. Clean. Prod.* 104, 199–210. doi: 10.1016/j.jclepro.2014.08.027

Steenis, N. D., van der Lans, I. A., van Herpen, E., and van Trijp, H. C. (2018). Effects of sustainable design strategies on consumer preferences for redesigned packaging. *J. Clean. Prod.* 205, 854–865. doi: 10.1016/j.jclepro.2018.09.137

Sustainable Packaging Alliance (2004). Defining sustainable packaging. Available at: http://www.sustainablepack.org/.

Sustainable Packaging Coalition (2005). Definition of sustainable packaging. Available at: http://www.sustainablepackaging.org/.

Sustainable Packaging Coalition (2009). Sustainable packaging indicators and metrics framework. Available at: http://www.sustainablepackaging.org/Uploads/Resources/spc_indicator_metrics_framework.pdf.

Testa, F., Iovino, R., and Iraldo, F. (2020). The circular economy and consumer behaviour: the mediating role of information seeking in buying circular packaging. *Bus. Strateg. Environ.* 29, 3435–3448. doi: 10.1002/bse.2587

Trivium Packaging (2022). Global buying green report. Available at: https://www.triviumpackaging.com/media/kwkpgrfb/2022buyinggreenreport.pdf

Trubetskaya, A., Scholten, P. B. V., and Corredig, M. (2022). Changes towards more sustainable food packaging legislation and practices. A survey of policy makers and stakeholders in Europe. Food Packaging and shelf. *Life* 32:100856. doi: 10.1016/j.fpsl.2022.100856

Tsochatzis, E. D., Lopes, J. A., and Corredig, M. (2022). Chemical testing of mechanically recycled polyethylene terephthalate for food packaging in the European Union. *Resour. Conserv. Recycl.* 179:106096. doi: 10.1016/j.resconrec.2021.106096

Van Ewijk, S., and Stegemann, J. A. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *J. Clean. Prod.* 132, 122–128. doi: 10.1016/j.jclepro.2014.11.051

Van Sluisveld, M. A., and Worrell, E. (2013). The paradox of packaging optimization–a characterization of packaging source reduction in the Netherlands. *Resour. Conserv. Recycl.* 73, 133–142. doi: 10.1016/j.resconrec.2013.01.016

Vanderroost, M., Ragaert, P., Devlieghere, F., and De Meulenaer, B. (2014). Intelligent food packaging: the next generation. *Trends Food Sci. Technol.* 39, 47–62. doi: 10.1016/j.tifs.2014.06.009

Verghese, K., Lewis, H., Lockrey, S., and Williams, H. (2015). Packaging's role in minimizing food loss and waste across the supply chain. *Packag. Technol. Sci.* 28, 603–620. doi: 10.1002/pts.2127

Vila-Lopez, N., and Küster-Boluda, I. (2020). A bibliometric analysis on packaging research: towards sustainable and healthy packages. *Br. Food J.* 123, 684–701. doi: 10.1108/BFJ-03-2020-0245

Vöröskői, K., Földesi, P., Kóczy, L. T., and Böröcz, P. (2020). Fuzzy approach for the decision on disposable or returnable packaging. *Sustainability* 12:7304. doi: 10.3390/su12187304

Wandosell, G., Parra-Meroño, M. C., Alcayde, A., and Baños, R. (2021). Green packaging from consumer and business perspectives. *Sustainability* 13:1356. doi: 10.3390/su13031356

Wang, Q., Zhang, W., Tseng, C. P. M. L., Sun, Y., and Zhang, Y. (2021). Intention in use recyclable express packaging in consumers' behavior: an empirical study. *Resour. Conserv. Recycl.* 164:105115. doi: 10.1016/j.resconrec.2020.105115

Wikström, F., Verghese, K., Auras, R., Olsson, A., Williams, H., Wever, R., et al. (2019). Packaging strategies that save food: a research agenda for 2030. *J. Ind. Ecol.* 23, 532–540. doi: 10.1111/jiec.12769

Wikström, F., Williams, H., and Venkatesh, G. (2016). The influence of packaging attributes on recycling and food waste behaviour–an environmental comparison of two packaging alternatives. *J. Clean. Prod.* 137, 895–902. doi: 10.1016/j.jclepro.2016.07.097

Williams, H., Lindström, A., Trischler, J., Wikström, F., and Rowe, Z. (2020). Avoiding food becoming waste in households–the role of packaging in consumers' practices across different food categories. *J. Clean. Prod.* 265:121775. doi: 10.1016/j.jclepro.2020.121775

Williams, H., and Wikström, F. (2011). Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. *J. Clean. Prod.* 19, 43–48. doi: 10.1016/j.jclepro.2010.08.008

Wyrwa, J., and Barska, A. (2017). Packaging as a source of information about food products. *Procedia Eng.* 182, 770–779. doi: 10.1016/j.proeng.2017.03.199

Yokokawa, N., Kikuchi-Uehara, E., Sugiyama, H., and Hirao, M. (2018). Framework for analyzing the effects of packaging on food loss reduction by considering consumer behavior. *J. Clean. Prod.* 174, 26–34. doi: 10.1016/j.jclepro.2017.10.242

Zaborowska, M., Bernat, K., Pszczółkowski, B., Wojnowska-Baryła, I., and Kulikowska, D. (2021). Anaerobic degradability of commercially available bio-based and oxo-degradable packaging materials in the context of their end of life in the waste management strategy. *Sustainability* 13:6818. doi: 10.3390/su13126818

Zeng, T., Deschenes, J., and Durif, F. (2020). Eco-design packaging: an epistemological analysis and transformative research agenda. *J. Clean. Prod.* 276:123361. doi: 10.1016/j.jclepro.2020.123361

Zeng, T., and Durif, F. (2020). The impact of eco-design packaging on food waste avoidance: a conceptual framework. *J. Promot. Manag.* 26, 768–790. doi: 10.1080/10496491.2020.1729320

Zeng, T., Durif, F., and Robinot, E. (2021). Can eco-design packaging reduce consumer food waste? An experimental study. *Technol. Forecast. Soc. Chang.* 162:120342. doi: 10.1016/j.techfore.2020.120342