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Sustainable Food Packaging: An Integrative Framework

Romina Santi [1,*], Paola Garrone [2], Mattia Iannantuoni [2] and Barbara Del Curto [1,3]

[1] Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Via Luigi Mancinelli 7, 20131 Milan, Italy; barbara.delcurto@polimi.it
[2] Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Via Lambruschini 4b, 20156 Milan, Italy; paola.garrone@polimi.it (P.G.); mattia.iannantuoni@mail.polimi.it (M.I.)
[3] National Interuniversity Consortium of Materials Science and Technology (INSTM), Via G. Giusti 9, 50121 Florence, Italy
* Correspondence: romina.santi@polimi.it

Abstract: The paper proposes a comprehensive and operational definition of Sustainable Food Packaging (SFP). Sustainability is a multifaceted concept, yet most SFP conversations decline it as a mere material substitution issue. The efforts of regulators, packaging producers, food companies, and consumers towards the design and adoption of SFP products are likely to fail without a common understanding of the multiple means by which food packaging contributes to sustainability. Based on an extensive literature review and the contributions of SFP innovation experts, the paper builds a Food Packaging Sustainability Framework (FPSF) that encompasses the three main dimensions of SFP, namely environmental conservation, food safety, and social value, and operationalizes them in terms of objectives and activable levers. The framework can be used as a tool to search and evaluate food packaging products, a conceptual guide for SFP design, and a narrative platform for coordinating supply chain actors, including consumers. The experimental activities applying FPSF gathered the different actors in the supply chain to jointly adopt the integrated model that distributes environmental, social, and economic benefits along the entire production chain.

Keywords: food packaging; sustainability; supply chain; food packaging design

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1. Introduction

In the context of Sustainable Food Packaging (SFP), the lack of a precise and shared definition creates semantic ambiguities and tensions in the design and adoption of new products. A packaging product may be referred to as sustainable in a plurality of instances, for example, if it is made of recycled, recyclable, compostable or bio-based materials, if it conveys information on responsible or safe behavior to consumers, if it eases the access to a given food product for remote communities or disadvantaged citizens, or if it enhances the shelf life of contained food. All these solutions could legitimately be defined as sustainable, yet they create very different benefits for environment, economy, and society [1].

A first critical question with SFP is its distinctively large environmental footprint, which in turn is the combination of a few determinants. The global food packaging (FP) market size is expected to reach USD 456.6 billion by 2027 [2] occupying a leading position within the growing market of packaging [3]. The after-use environmental impact of food packaging is also very large. Not only is FP a major source of solid waste, but the two most preferred materials, i.e., paper (and cardboard) and plastic, are generally designed as single use, which may slow down the diffusion of recycling. Notably, big challenges for the end-of-life FP phases are created by the intertwining of single-use design and plastic characteristics [4,5]. The packaging sector alone creates nearly 150 million tons of plastic in a year, over 95% of which is disposed of in the same year [6]. Global concerns are particularly strong for plastic marine litter and are clearly expressed by the 2030 Agenda

of United Nations that uses floating plastic debris density as an input to its indicator for target 14.1 (i.e., "by 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution"). In addition to ocean pollution, the dispersion of plastic waste in natural environments may bring about soil contamination [7] and blocks in the waterways, which in turn cause flooding and the spread of waterborne diseases that contribute to a significant number of deaths in developing countries each year [8]. Since most debates on single-use packaging products in higher income countries have focused on plastic waste, ad-hoc policies for plastic FP have been introduced e.g., European Union's Directive 2019/904 [9,10].

Aside from its intricate relationship with environmental conservation, FP has multiple pro-social functions, because it determines how supply chain actors and consumers can distribute and handle food products [11,12]. Protection from food safety hazards is the most obvious FP social impact, as made clear by the renewed demand during the COVID-19 pandemic for FP products that protect food from contamination [13]. Food security is a second major FP function, as packaging is necessary to preserve and safely transport food even to the most remote areas [14]. In certain contexts, the availability of packaged food decreases price variability and increases access to nutrients, ultimately decreasing inequalities [15]. Thirdly, FP can be one of the levers to reduce food losses and waste in a world where 1.3 billion tons of food are produced yet not consumed [16–18]. A proper packaging design can imply more efficient food operations and uses, decreasing the volume of wasted products [19]. Finally, FP is also the main interface between consumers and the food supply chain. Its informative and educative power is paramount for spurring consumers to responsible behaviors [20,21].

In summary, FP is a representative example of the multifaceted nature of sustainability. Packaging innovations may be sustainable according to one perspective and not according to others. Synergies and trade-offs arise within the sustainable development agenda [22].

The lack of a comprehensive framework for establishing whether and how FP products achieve sustainability may have far-reaching economic and social implications. Without a definition that encompasses all the main declinations of SFP, practitioners, policymakers, and scholars risk favoring one side above the others, in some cases without being explicit on their own preferences. The claim about the sustainability potential of a packaging solution thus becomes discretionary and potentially misleading. Moreover, overemphasis on one or other sustainability declinations prevents FP supply chain actors from conducting a full evaluation of the effects of a given packaging material, technology, or solution for all their stakeholders. It might even conceal possible negative impacts on dimensions not explicitly considered. On the positive side, the heterogeneous business players that make up the FP and food supply chains can benefit from a shared FP sustainability framework.

The aim of the present paper is the proposition of a clear and comprehensive taxonomy of the multiple sustainability objectives pertaining to FP products to facilitate the design, assessment, and adoption of new sustainable solutions. To answer this call, the research at the origin of this paper has summarized a few heterogeneous streams of literature in a relatively compact framework. Secondly, it has iteratively enriched the resulting framework by engaging FP innovation experts. During three workshops, the experts were asked to verify the interpretative power of the resulting framework and its ease of use, and their feedback was used to obtain a refined version of the framework.

The final Food Packaging Sustainability Framework (FPSF) leans on 3 main declinations of the sustainability concept for FP products, that is, environmental conservation, food safety, and social impact, 11 objectives that capture the desirable impacts of FP within each declination and 30 levers that generalize the possible FP characteristics that enable the achievement of objectives. Therefore, an FP product can be qualified in terms of its sustainability potential when its sustainability declinations, and in greater detail its sustainability objectives, are highlighted along with the activable levers to attain each single objective.

2. Literature Review

Efforts by several organizations have been made to define "sustainable packaging" and to articulate a common understanding within the industry, to provide guidance in decision making as well as in shaping a vision towards a more sustainable packaging system. The aim is to develop a set of principles which could guide decisions [23]. Traditionally packaging is defined sustainable if [24]:

1. it is effective in containing and protecting products throughout the supply chain and by supporting informed and responsible consumption (effectiveness);
2. it uses materials and energy efficiently throughout its life cycle (resource efficiency);
3. its materials are cycled continuously through natural or technical systems (recyclability);
4. it does not pose any risks to human health or ecosystems (safety).

Additionally, ECR Europe/EUROPEN in their Vision of Packaging's Contribution to Sustainable Development state that packaging should also be designed holistically with the product to optimize overall environmental performance, be made from responsibly sourced materials, and meet market criteria for performance, costs, and consumer's expectations. The social function of packaging also includes the ability to grant access to food and provide information to minimize harmful impacts of consumers' choices.

Although many efforts have been made by scholars, business organizations and institutions to define clearly "sustainable food packaging", fragmentation persists.

Different organizations have published definitions and guidelines that could lead to the development of sustainable packaging (not in all cases framed only on the food sector). As can be seen in Table 1, the macro-themes covered and expanded in each publication with clear design directions are varied, often leaving aside issues such as prevention of food losses and social aspects by going more in-depth on environmental strategies.

Table 1. Guidelines and indications for sustainable packaging design.

Guideline Name	Author	Macrothemes
The responsible packaging code of practice [25]	Incpen	The functions of packaging through the supply chain; Honesty in presentation; Convenience in use; Instructions, guidance & information; Legal requirements; Health, safety & consumer protection; Environmental aspects
Packaging sustainability checklist [26]	FDF and INCPEN	Functionality, Re-use, recovery & recycling, Transport
Definition of Sustainable Packaging [27]	Sustainable Packaging Coalition	Is beneficial, safe & healthy for individuals and communities throughout its life cycle; Meets market criteria for performance and cost; Is sourced, manufactured, transported, and recycled using renewable energy; Optimizes the use of renewable or recycled source materials; Is manufactured using clean production technologies and best practices; Is made from materials healthy throughout the life cycle; Is physically designed to optimize materials and energy; Is effectively recovered and utilized in biological and/or industrial closed loop cycles.

Table 1. *Cont.*

Guideline Name	Author	Macrothemes
Sustainable Packaging Guidelines (SPGs) [28]	Australian packaging covenant organisation	Design for recovery; Optimise material efficiency; Design to reduce product waste; Eliminate hazardous materials; Use recycled materials; Use renewable materials; Design to minimise litter; Design for transport efficiency; Design for accessibility; Provide consumer information on environmental sustainability.
Packguide A guide to packaging eco-design [29]	Incpen	Design for minimization; design for re-use, recycling and recovery; design for compostability; communicating with stakeholders.

Instead, it is precisely on environmental aspects, and especially on the issue of recyclability of resources that most of the design guidelines available to date on platforms of various organizations are focused and well detailed. An excerpt can be found in Table 2.

Table 2. Guidelines and indications on packaging design for an efficient recycling.

Guideline Name	Author	Context	Macrothemes
Design4recycling plastics [30]	By allianz d4r and redilo	Swiss	Recyclability (plastic packaging)
Recyclability of plastic packaging [31]	Cotrep	France	Recyclability (plastic packaging)
Recyclability of plastic packaging checklist [32]	Cotrep, elipso, citeo, valorplast	France	Recyclability (plastic packaging)
Reciclabilidade das suas embalagens [33]	Pontoverde	Portugal	Recyclability (domestic and industrial packaging)
Circular packaging desing guidelines [34]	By fh campus Wein, in partnership with circular analitics and packforce austria	Austria, Germany and the Netherlands	Recyclability (plastics, compostable, multilayer, cellulosic, glass, tin plate, aluminum)
Progettare riciclo [35]	Conai	Italy	Recyclability (plastic, cellulosic, alluminium)
Designing for a Circular Economy Guidelines (D4ACE) [36]	CEFLEX	Europe	Recyclability (Flexible plastic packaging)
Circularity by design guideline for fibre-based packaging [37]	4ever green alliance	Europe	Recyclability (fibre-based packaigng)

In these cases, the treatments are contextualized in specific countries, studying recycling infrastructure, and give clear indications that may differ in packaging materials, types, and morphologies.

Different, however, is the state of the scientific literature that tries to give definition and guidance to practitioners around food packaging. In a study by Grönman et al. [38] the macro-lines of action toward food packaging design indicate that packaging must be safe for users and the environment, prevent food losses along the supply chain, and make careful selection of packaging materials. The authors present a methodological diagram of this and distribute the economic, technical, and functional challenges along the product value chain. In this study, the social aspect focuses mainly on usability characteristics. Moreover, Guillard et al. take in consideration the possibility to re-introduce agricultural scraps in developing materials for food packaging and highlights the necessity to tailoring each packaging design to reduce the potential food losses along the supply chain [39]. In a recent study of Dunford, three are the main levers for sustainable food packaging, namely reduce, use biobased/biodegradable materials, recycling/reuse strategies argued through a series of case study [40]. This diversity of approaches was found by Molina-Besch, who instead proposed a prioritization of actions to be carried out for green food packaging development. By comparing different LCA (Life cycle Assessment) studies, it was possible

to see that the first lever for the development of sustainable food packaging is the reduction of possible food losses, next, the management of consumer use phase claims (storage time, cooking) and as third, the material to be used (product-packaging combination [41]. Therefore, the importance of reducing food loss through food packaging design is several times emphasized in the literature, but still set aside from social sustainability.

Starting from this general background, literature from several disciplines has been reviewed (including Innovation Management, Innovation Design, Materials Science and Social Human Sciences Sustainability) to understand various perspectives on sustainability in the food packaging (FP) sector. Papers have been grouped in three clusters: FP environmental impacts, food safety issues related to FP, FP impacts on socio-economic wellbeing.

2.1. Food Packaging and Environmental Sustainability

An accurate design of packaging products is necessary to limit their environmental impacts according to the Circular Economy paradigm. In the application of the reduction, reuse and recycle principles (so called 3Rs), paramount importance is attributed to product design and the choice of materials and energy sources [42]. Decisions made in the design and development phases determine the environmental performances of packaging products over their life cycle [43,44].

FP developers and producers have traditionally tackled two critical questions related to materials, namely the introduction of renewable and recyclable materials and resource efficiency through weight (or mass/volume ratio) reduction [45]. Since the fundamental role of FP is food protection, material selection is obviously a critical step in packaging design. However, packaging design is environmentally sustainable only when the whole packaging system is taken into consideration. When choosing FP materials, many factors should be considered: properties of packaging material, type of food to be packaged, food/package interactions, intended market for the product, desired product life cycle, environmental conditions during storage and distribution, product end use, eventual package disposal and costs [46]. More generally, the "Design for Environment" approach provides organizations with a practical method to minimize environmental impacts by improving product quality and cost efficiency while reducing environmental impacts [47]. Simms and Trott developed a framework for packaging development that leans on the profound and comprehensive evaluation of the needs of all involved parties [48].

As far as the FP end-of-life management is concerned, packaging should provide clear information on how to separate and sort its different fractions [49]. At the same time, FP recycling requires specific care, because recycling into new food packaging may counteract food safety requirements [50], establishing a trade-off with another FP sustainability dimension.

Notably, the influence of FP characteristics on food consumption sustainable behaviors may be even more significant than the impact on packaging waste management [49]. Characteristics such as the lack of clarity about expiry dates and large packaging sizes are major causes of food waste as they lead consumers to fallacious purchase plans, with too large food stocks that tend to expire before being consumed [51]. In greater detail, information presented on packaging to food consumers is an essential input to food waste prevention, in addition to its traditional role for food safety. Food waste entails the dissipation of labor, water, energy, land and other productive inputs, and environment degradation. FP solutions that contribute to reducing food waste conserve resources, mitigate climate change, save nutritious food for commercial distribution or charitable redistribution, and reduce farmers', companies', and households' costs [52]. FP plays a critical role in making food purchases, conservation, and consumption more environmentally friendly. Many food waste problems experienced by consumers descend from packaging characteristics, such as information on food storage, label clarity and cooking advice [53].

2.2. Food Packaging and Food Safety

Food safety is fundamental to all aspects of the food system, and it is essential to prevent and control the advent of potential hazards, such as foodborne pathogens, naturally

occurring toxins, contaminants, such as heavy metals, pesticide residues, veterinary drug residues, and antimicrobial residues, which can cause illness and death [54].

In general terms, product safety refers to the requirement that products must be free of hazards with an acceptable level of risk [55]. FP products contribute to food safety in two ways. First, they protect the contained food from exogenous contaminations. In fact, "the potential for food to become contaminated with chemical substances or microorganisms starts from the moment it is harvested and continues right through until the moment it is eaten" [56]. As a barrier between the food contained inside and the pathogens present outside, FP aims to avoid possible contaminations [57]. Second, packaging itself needs to be produced and assembled with the food in a clean environment, free from possible hazards [56]. Oliveira et al. highlight the importance of a clean process of FP production and assembly, demonstrating that FP materials could slow down the spread of bacteria, even though they would not stop or destroy the bacteria already present in the food [58]. Nonetheless, Carbone et al. show that FP can go beyond the traditional barrier function, because new materials and technologies can avoid food-related bacteria diffusion [59]. Smart packaging technologies are good allies to food safety and quality preservation. Belonging to the wider smart packaging class, "active packaging refers to those technologies intended to interact with the internal gas environment and/or directly with the product, with a beneficial outcome" [60–63], while intelligent packaging monitors the condition of packaged foods to give static or dynamic information about its quality during transport and storage [64–66].

Packaging and labels play a critical role in steering consumers' behavior and guaranteeing food safety at the consumption stage. Information on how to handle, conserve and eat food products prevents the diffusion of foodborne diseases [67]. Expiry dates are the most important piece of information on FP labels for highly perishable products like meat [68,69] or fish [70], but consumers are confused by date coding [71,72]. The misunderstanding of endorsements as "Best before", "Sell by", and "Use by" could cause unsafe consumption of food or generate premature food waste. In addition to traditional labelling, smart labels or 'intelligent indicators can warn consumers about the food product safety [73].

Since consumers may not be aware of or follow storage guidelines, there is scope for improving packaging information on food storage practices [74]. In fact, food storage behavior is particularly guided by the location of food products in the shops (e.g., food taken in the shop freezer will be stored in the freezer at home) [75].

Information structure and strategy should be designed to provoke an impact on consumer sensitivity on food risks, considering that different factors in humans stimulate different risk perceptions [76]. Numerous factors could influence consumers' behavior in this sphere: values, attitudes, knowledge, perceived control and barriers, social norms and socio-demographics [67].

2.3. Food Packaging and Social Impact

Environmental quality targets are set at global, national, and local levels, but less attention is given to the third dimension necessary to achieve sustainable development [77], namely impacts on people and society. According to the 2030 Agenda of the United Nations, the human and social side of sustainability means to eradicate poverty and hunger in all their forms and dimensions, and to ensure that all people can achieve their full potential in dignity, equality, and a healthy environment. The long- and short-term social change, both positive and negative, that a given organization considers because of its actions in a target community is referred to as social impact [78].

A major social impact of FP products is enhanced food security, which, according to the FAO's well-known definition, "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". FP products contribute to enabling diffuse access to safe and nutritious food in a steady way.

On the supply side, FP solutions may contribute to the support of rural communities by enabling small farms to enter food value chains. Around the world, 500 million farms are family businesses that generate about 80% of earth's food [79]. FP labels convey information about the geographical origin and production processes (such as organic farming or local production and processing) and enable consumers to make informed choices and support small local businesses [80]. Fair Trade certifications and marks may enhance the export capacities of producers from developing countries at fair conditions and transparent prices, facilitating the economic and social development of local communities [81,82]. If FP is integrated with targeted communication, it may trigger consumers' responsible purchasing [83,84].

Moreover, new FP technologies, processes and manufacturing practices could enable the development of disadvantaged communities [85]. The production of innovative bio-based materials could decrease the percentage of non-recyclable solid wastes and, simultaneously, create a new source of revenue for small producers [86]. Extending the point of view and thinking in a closed loop supply chain optic [87], the disposal becomes a crucial step of an item's life cycle.

Labels are also relevant to help consumers choose healthy food products [88]. Nowadays, one of the major problems related to human health is malnutrition according to the World Health Organization. Many countries, especially low-and middle-income ones, are affected by a "double burden" due to the coexistence of obesity and undernutrition. Governmental regulations [89] indicate that producers must include in a transparent way the caloric intake (KJ and Kcal) for 100 g of product, the nutritional values and the contained nutrients that may harm some groups of consumers or counteract dietary requirements, such as allergens, high quantities of salt or glucose and the presence of gluten or lactose. Due to the proven inadequacy of such information, especially if addressed to less educated consumers, researchers and regulators proposed the introduction of easily readable and clear labels [90]. The introduction of Front-of-Pack Labels (FoPLs) makes users able to gauge calorie intake and follow a balanced diet [91]. The introduction of colors, emoticons or stars makes the label readable, even for children [92]. FoPLs should be integrated on takeaway meals and on restaurant, school, and company canteen menus [93]. Transparent labelling would encourage both sustainable consumption and sustainable production [94].

FP design could concur to enhance consumers' conduct even beyond the food sector. Physical Activity Equivalent labels provide easy, understandable calorie information and encourage adolescents to reduce their consumption of sugary beverages and to engage in sporting activities [95]. Indeed, the Royal Society for Public Health (RSPH) reports that "53% of people would positively change their behavior after viewing front-of-pack equivalent calorie labelling" [96].

Lastly, FP should be designed to overcome the cognitive and functional limitations of consumers [97]. Information accessibility may be guaranteed to visually impaired people through packaging embossing that reports product details in Braille characters [98]. Elderly consumers may encounter difficulties in opening and reading certain FP products [99].

3. Methodological Issues

The construction of the Food Packaging Sustainability Framework (FPSF) occurred in three steps.

As Section 2 shows, the FP sustainability concept has been investigated from different points of view, studying a wide and fragmented literature across multiple disciplines. The analyzed papers highlighted different themes such as the "sustainable packaging" definition, FP environmental impacts caused by supply chain firms and consumers, FP circularity, FP role in food safety, and opportunities related to smart and active packaging, benefits for given communities or groups of citizens, and the whole society from FP production and use. The literature review resulted in the identification of the three main interpretations of FP sustainability, which in our conceptual framework are labelled as declinations, namely Environmental Conservation, Food Safety, Social Impact (Section 2).

Secondly, the literature review highlighted several FP characteristics that trigger the sustainability impacts. The physical, technological, or informative packaging features that contribute to determining a sustainable FP product have been pinpointed for each of the three declinations. The so-called levers activate different "mechanisms" to generate the impact. In other words, every lever serves a specific environmental, safety or social objective. The overall goals of FP (declinations) are made of more specific objectives, each of which can be achieved thanks to a well-defined cluster of levers. The objectives that make up the sustainability declinations of FP have been defined as mutually orthogonal, that is, efforts have been made to avoid any overlaps in their meaning and definition. Similarly, every lever is assigned univocally to an objective. The "separation" approach is necessary to build a framework that avoids false correlations between the different FP sustainability declinations and objectives and highlights the genuine synergies and trade-offs that exist between the various sides of FP sustainability.

The third step consisted of the empirical validation and enrichment of the theoretical framework through an iterative process that took advantage of the workshops of the Food Sustainability Observatory of Politecnico di Milano.

- A first version of the framework was submitted to be reviewed by over 20 experts from the business and research world (packaging manufacturers, brand owners, retailers, end-of-life consortia, research centers, service, and technology providers) during a first workshop. The participants were presented examples of FP solutions and asked to fill in a checklist of objectives and levers for each of them. The choice of single objectives and levers was debated in a closing session that offered numerous feedbacks on the structure and contents of the framework. The perspectives of participants were also gathered in the form of verbal and written suggestions
- Authors have developed a refined SPSF version thanks to the received feedback and submitted it for corroboration during a second workshop (about 15 experts with a composition similar to the first one). The process was then repeated a third time.

The empirical iterations were aimed at verifying the logical and practical consistency of the framework and at refining and enriching it. The FPSF version that is presented in the fourth section is the result of the three steps and three empirical iterations with experts.

4. Results: The Food Packaging Sustainability Framework

Literature reviews and dialogues with FP experts have confirmed that any taxonomy of sustainable FP products should cover Environmental Conservation, Food Safety and Social Value dimensions. Therefore, the Food Packaging Sustainability Framework (FPSF) leans on these three main declinations. The objectives that translate each declination and the levers that allow the FP product to attain an objective are presented in detail in the remaining part of the Section. Finally, the present section illustrates the integrative framework resulting from the union of the three declinations.

4.1. Environmental Conservation

FP has been found to be sustainable according to the Environmental Conservation declination when it pursues at least one of the following six objectives (without counteracting others): resource efficiency, recyclability of resources, responsible management of packaging end-of-life, responsible food purchasing, responsible food conservation at home, responsible management along the supply chain. Table 3 shows that the objectives of FPSF cover FP's direct effect, namely the per se impacts of food packaging, for example, in terms of materials and energy efficiency and appropriate operations by supply chain players and consumers. They also encompass FP's indirect effect on food sustainability in the form of responsible food purchasing and conservation. Table 3 also highlights the levers behind each objective. An example is summarized for every objective.

Table 3. FPSF: Objectives and levers of the "Environmental Conservation" declination.

Objectives: FP Sustainability Impacts	Levers: FP Characteristics That Enable Impacts	Example
Resource efficiency: Optimized packaging production and transport and use of renewable or recycled resources	• Rationalization of packaging design and mass/volume optimization • Materials from renewable or recycled resources • Energy efficiency in production and transportation	• Product A is an egg packaging that consists of paper pulp, flour, starch, and seeds. After using the eggs, instead of recycling or dispose of the packaging, the user waters it or plants it so that the seeds become green plants.
Recyclability of resources: Design that facilitates FP reuse and materials recycling	• Re-usability of packaging for the same function • Recyclability of materials • Energy efficiency in recycling	• Company A abandons the classic-colored bottle for the transparent PET version. It generates higher-value secondary raw material from recycling.
Responsible management of packaging along the supply chain: Coordination between supply chain actors for proper FP management	• Information on product status and reporting function • Easy handling	• Product B, a collapsible fruit and vegetable crate by Company B ensures product protection and stockability. But the special feature of the product is the integration of transparent walls, so that the product is made visible, optimizing time-consuming controls for logistics.
Responsible management of packaging end-of-life: Simple packaging disassembly and materials sorting	• Information on end-of-life actions • Simple materials separation and collection for recycling • Size and recognizability of materials	• Product C is a packaging introduced as a sustainable alternative to laminated beverage packaging. It allows the plastic liner to be separated, or rather, 'peeled' from its paper cover.
Responsible food purchasing: Environmentally friendly purchasing and consumption through visible labels and readable and understandable information	• Information on food environmental impacts • Readability of product quantity and mode of consumption	• An international foundation with the support of a company advisory board developed a pilot project to offer consumers an eco-score based on LCA analysis on the food packaging they are purchasing.
Responsible food conservation: Environmentally friendly food storage and uses	• Conservation guidelines • Appropriateness to use contexts • Easy handling at home	• Product C is a resealable tab can that replaces the standard stay-on-tab (SOT) opening, allowing consumers to portion out drinks, ensuring longer-lasting freshness.

4.2. Food Safety

FP has been found to be sustainable according to the Food Safety declination when it pursues at least one of the following two objectives (without contrasting the other): safe packaging production and safe behavior with respect to food. The FPSF objectives relate to appropriate design and processes as well as specific choices of materials made by the packaging manufacturer. On the other hand, they enable the responsible management of food for users, preserving its hygienic state. Table 4 summarizes Food Safety objectives and related levers. An example is summarized for every objective.

Table 4. FPSF: Objectives and levers of the "Food Safety" declination.

Objectives: FP Sustainability Impacts	Levers: FP Characteristics That Enable Impacts	Example
Safe packaging production: Compliance of FP production and packaging activities with safety and hygiene standards. FP ability to prevent and control food contamination	• Clean FP production and clean packaging processes • FP physical properties that prevent food contamination • Materials counteracting proliferation of bacteria	• Company C is a leading supplier of aseptic bricks for long-shelf-life milk, juice and other liquid foods and aseptic filling systems.
Safe behavior with respect to food: Maintained food safety during at-home storage and consumption.	• Labels with clear guidelines for conservation and evaluation of product condition • Labels that clarify critical dates • Real-time information labels	• A start-up that has developed the 'conscious label', which prompts the consumer to carry out a sensory exploration (sight, smell, taste) before disposing a product that has exceeded the minimum storage term. Several food industry partners have joined the initiative.

4.3. Social Value

FP is deemed to be sustainable according to the Social Value declination when it pursues at least one of the following three objectives and does not contrast the remaining ones: extended access to food, augmented income, and work empowerment, improved health. Table 5 summarizes Social Value objectives and related levers. An example is summarized for every objective.

Table 5. FPSF: Objectives and levers of the "Social Value" declination.

Objectives: FP Sustainability Impacts	Levers: FP Characteristics That Enable Impacts	Example
Extended access to food: Access to food for segments of the population that would be otherwise excluded	• Easily readable and understandable labels • Shapes and dimensions that simplify packaging delivery and opening	• Company D developed liners on juice bottles that the elderly and others with limited mobility and dexterity can easily remove.
Augmented income and work empowerment: new sources of income and work integration for disadvantaged people and communities. Support for local and small farmers	• Inclusion of disadvantaged communities in the production process • Clear labels on product origin • Clear and visible marks of inclusive practices' certifications • Materials recycled or recovered by disadvantaged people or communities	A start-up intends to change the world 'one bottle at a time'. Proceeds from the bottles go to finance water projects in remote and resource-scarce areas.
Improved health: Consumers' awareness about correct nutrition and active lifestyles	• Easily readable and understandable labels on nutritional properties • Labels that promote active lifestyles and healthy diets	• To improve consumers' eating habits to combat obesity, in the UK has been designed the activity equivalent labelling: a system of labels showing the physical activity required to balance the extra calories taken in by consuming certain types of food.

4.4. The Integrative Framework

Is possible to visualize SFP as an integrated perspective based on the definitions of Tables 3–5. An FP solution is more sustainable than alternative FP products in terms of:

- Environmental Conservation, if it advances towards at least one of the six objectives of Table 3 and does not perform worse in the remaining objectives (relative to alternative FP products).
- Food Safety, if it advances towards at least one of the two objectives of Table 4 and does not perform worse in the other objective (relative to alternative FP products).
- Social Value, if it advances towards at least one of the three objectives of Table 5 and does not perform worse in the remaining objectives (relative to alternative FP products).

Our definition of FP sustainability follows a similar logic.

- FP Sustainability. An FP solution can be defined sustainable if it is sustainable according to at least one of the three declinations and is as sustainable as alternative FP solutions for the remaining declinations.

Figure 1 shows the integrative FPSF, summing up the three declinations, their relative objectives and levers and highlights the dependency of levers from "supply" or "demand" actors. The separation line drawn between objectives crosses the three declinations.

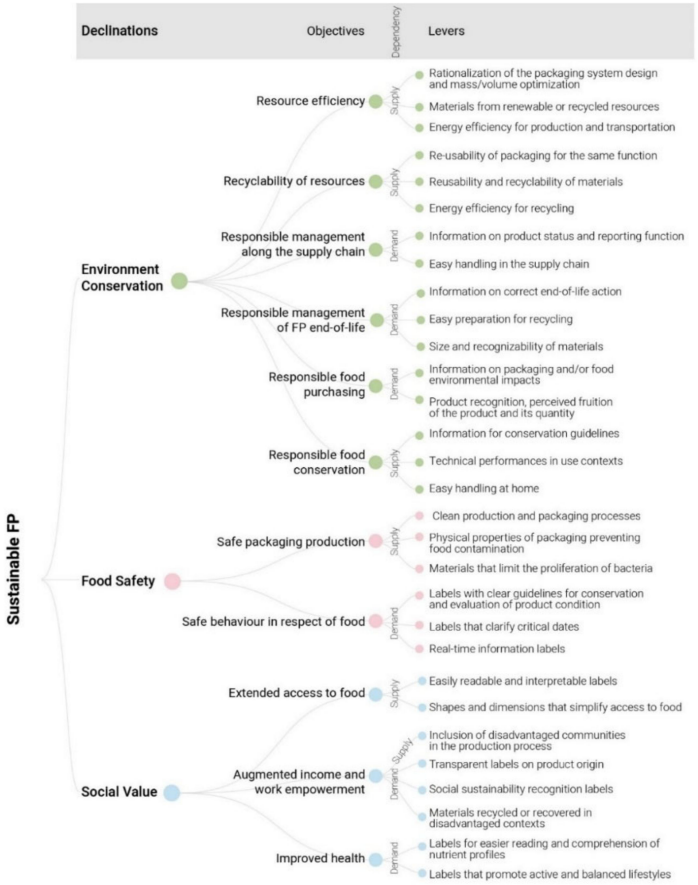

Figure 1. Integrative Food Packaging Sustainability Framework (FPSF), encompassing the three main declinations (Environment Conservation, Food Safety, Social Value), the objectives, the levers.

- Supply: objectives attainable by FP developers and producers and by packagers (actors that design and provide FP solutions) and linked to design and production decisions.
- Demand: objectives attainable by food manufacturers, distributors, or consumers (actors that use FP solutions) and linked primarily to the behavior of food supply chain players and consumers.

5. Discussion

The integrative FPSF shown in Figure 1 attempts to respond to the needs for a clear and comprehensive definition of sustainable FP. The resulting framework works as a conceptual lens to understand innovations in the world of FP. Since the three declinations and their objectives, namely the different interpretations of FP sustainability, are brought to the same level of analysis, it becomes possible to qualify FP products and the positive impacts they generate without ambiguities (Section 4.4).

Researchers and professionals can adopt the FPSF as a tool to collect the necessary information to assess the sustainability potential of an FP solution. To this end, the researcher can collect data on FP characteristics from the owner or producer of the packaging solution, from supply chain players, from experts in materials and end-of-life technologies and from final consumers. Once the framework is populated by data, the presence of levers can be assessed. The presence of levers determines the ability of the FP solution to achieve the related objectives, hence being sustainable according to one of the three declinations (Section 4.4 definitions).

In the different validation workshops (Section 3), the FPSF has been tested using qualitative indicators for the evaluation of FP solutions. Figure 2 shows the skeleton of a designed activity. For the study and comparison of two alternative FP solutions different stakeholder of the supply chain were gathered around a table. They were called to evaluate the solutions using the FPSF objectives and levers, with some tip or example needed by the moderator. After a pilot session it has been noticed that accomplishing a comparison was easier than a single evaluation with qualitative metrics. At the end of the activity, the actors were able to draw up a tri-axial summary graph to discuss around the solutions.

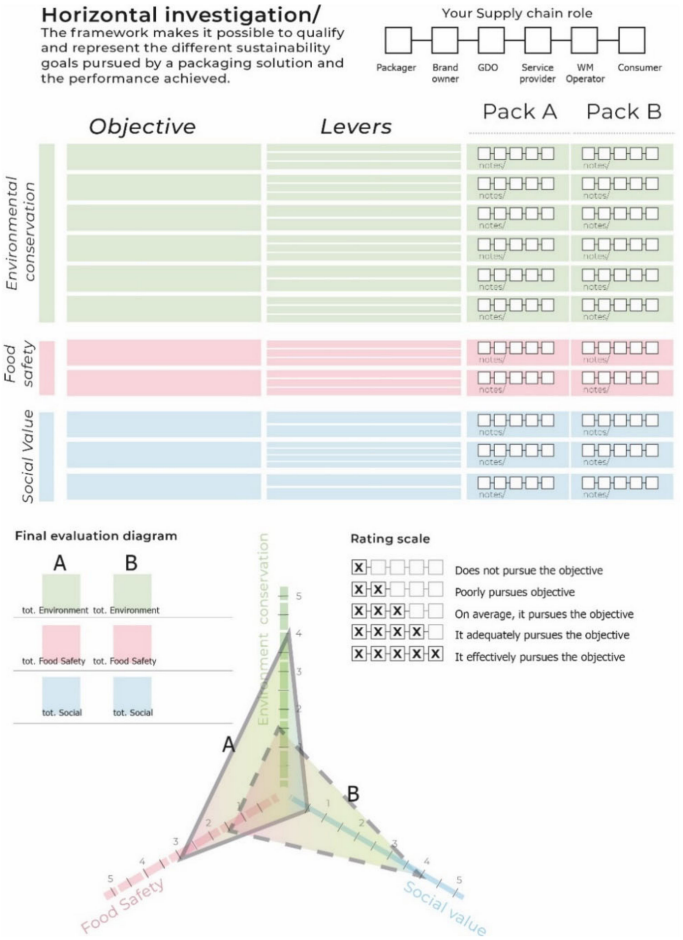

Figure 2. An example of FPSF in its operable structure for comparing FP solutions in a company workshop.

In the shift to quantitative analysis of FP characteristics, an additional workshop has been performed, starting to discuss, and looking for indicators. For using quantitative indicators, normalization and aggregation of dimensions would require having a common unit of impact measurement, a contentious issue in sustainable impact studies.

The tool can be used to identify the food systems, supply chains and policy contexts which foster (or hinder) the sustainability potential of the examined FP solution. The FP industry trajectories can be understood and represented by considering and evaluating several FP products and mapping them against the sustainable objectives. The framework leads to the identification of ambiguities and trade-offs in new sustainable FP concepts. Researchers, actors of the supply chain and communication experts can use the FPSF as a tool to identify the critical FP characteristics that generate sustainability clashes, a first step before redesigning them, wherever possible, also engaging other industry players or building an effective and homogeneous communication with the consumer. They can also direct design and development efforts, working on the most neglected areas of sustainability.

Furthermore, the framework lays the foundations for understanding how the benefits and costs of each sustainability objective are distributed among the actors in the supply chain. The researcher can adopt the tool as a discussion platform to collect the points of view of the packaging manufacturers, brand owners and food manufacturers, distributors, and consumers, actors in waste management services and technologies. This discussion helps to identify the actors to whom the new FP concept may create costs or benefits, and to understand the interdependencies between the choices made by independent players on FP design, production, management, and use. This means putting value chain dynamics at the center of the analysis and developing concrete proposals to align the incentives of the actors toward the introduction of sustainable FP solutions in the market

Moreover, FP designers can adopt the FPSF as a guiding tool because the framework makes explicit the design choices (FP characteristics) that make an FP solution able to pursue a given objective. The design process can implement the framework as a reference to enlarge the considerations on sustainability and to explore the correlation among different characteristics of sustainability. Research is going on to implement the FPSF as a project checklist to verify the inclusion of the most salient elements in the new design for sustainability. The FPSF is a broad lens to understand the diverse sustainable impacts that the FP innovation can have.

6. Conclusions

This work presented the FPSF, a comprehensive framework related to FP sustainability. This final section highlights the limitations of the work and proposes directions for further research.

The absence of qualitative and quantitative scales to evaluate the presence of levers may be an impediment to conducting a practical assessment of FP solutions. The development of the FPSF has engaged FP experts who used the framework as an assessment tool for a set of cases of interest. A preliminary three-degree qualitative scale was used to qualify preliminarily the presence of the levers for each case. The experience and awareness of the involved experts made the assessment possible, yet categorical and quantitative scales should be developed and verified for each of the 30 levers.

A second limitation is related to the coverage of levers. The FP characteristics have been identified through the literature review and redefined and extended thanks to the involved experts' feedback. However, we are aware that a few FP characteristics possibly relevant for sustainability objectives might not yet have been introduced to the FPSF. Attention should be given to the technological, physical, and informative properties of emerging FP concepts to enrich the framework and improve its use as a tool in practice.

A third limitation is related to the lack of an explicit and univocal identification of the actors who, along the FP and food supply chains, own the data on FP characteristics or the costs and benefits of possible solutions which are necessary to apply the FPSF

as an assessment tool or a communication platform. The application of FPSF in a few cases demonstrated the necessity to involve a diverse base of subjects in the gathering of data. The introduction of qualitative and quantitative scales and the identification of the actors to involve for the measurement of levers would greatly enhance the usability of the framework.

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