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The Contribution of Sustainable Packaging to the Circular Food Supply Chain

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ABSTRACT

As food supply chains pursue sustainability, numerous questions arise from their agents, focusing on the role of reverse logistics in sustainable packaging design and its effective contribution to waste reduction and the conservation of natural resources. With the goal of developing a new multi-criteria decision-making framework, this article examines how several multi-criteria decision-making approaches can be used to facilitate the selection of sustainable product-package designs. Using a case study, the multi-criteria decision-making method analyses package design, helping decision-makers to determine and minimize the percentage of food losses at each step of the supply chain. Furthermore, the design of both the product and its packaging must encompass the entire life cycle, including materials sourcing, production, transportation, use and disposal. Achieving sustainability requires a collaborative effort among all supply chain agents, from producers to consumers. Consequently, this study aims to explore the challenges and opportunities of attaining sustainable product and packaging design in the food supply chain, emphasizing the need for a long-term, collaborative approach to sustainability. This study concludes that sustainable packaging is highly relevant in the circular food supply chain due to its direct contributions to reducing food waste, conserving resources, mitigating carbon emissions, and meeting consumer preferences for eco-friendly products. Given the consideration of relevant criteria, the multicriteria method appears to be suitable for analysing food supply chains, thanks to its systematic approach in managing the application of sustainable packaging throughout the entire process, including the production, processing, distribution, and consumption of food products.

1 | Introduction

The adoption of sustainable packaging is being promoted, and it is expected to grow in supply chains and markets at a rate of around 7% from 2021 to 2026. According to EMF [1], only 14% of plastic packaging used globally in diverse supply chains is collected for recycling. Increasing the recycling rate will contribute to achieving complete circularity of packaging materials. The global value for bioplastics supply chain and markets, including biodegradable and compostable plastics, is expected to reach approximately 2.6 million metric tons by 2023, reducing the environmental impact of packaging [2].

Estimates from Quicke [3] indicate that the transition to a net-zero emissions environment by 2050 will create new industries worth $10.3 trillion for the global economy. Considering the relevance of several factors, as enumerated by Chiffoleau and Dourian [4], including environmental impact, health implications, supply chain density, consumer awareness, and certification standards, the sustainability analysis of food supply chains deserves close attention (Figure 1). Therefore, for Sarkis [5], sustainability has become a long-term objective, which requires the implementation of food packaging solutions using circular supply chains (https://www.edrawmax.com/).

Sustainable packaging plays a crucial role in the circular supply chain. According to a study of WEF [6], the incorporation of circular economy principles is expected to increase profits for supply chain managers. Furthermore, the packaging industry is transitioning from the linear take-make-use-dispose approach

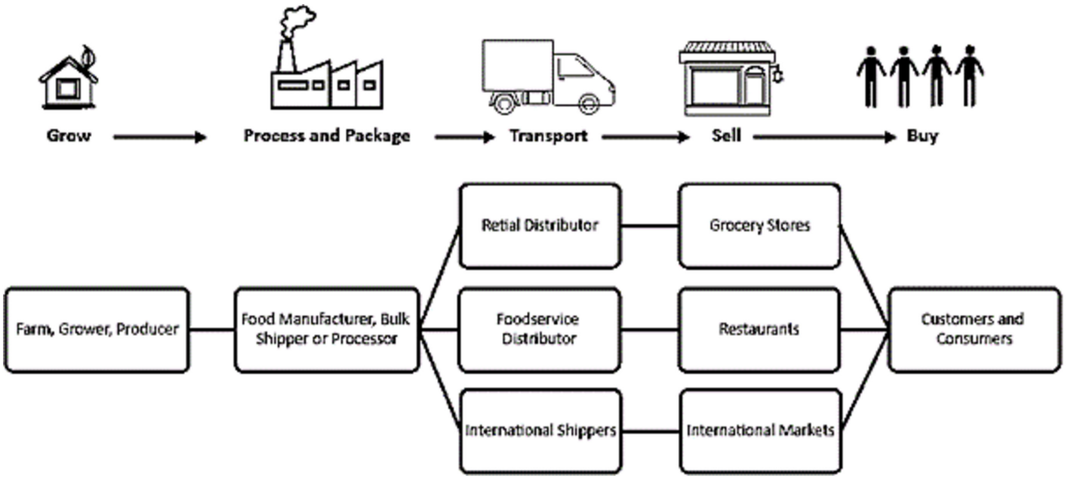

FIGURE 1 | The food supply chain.

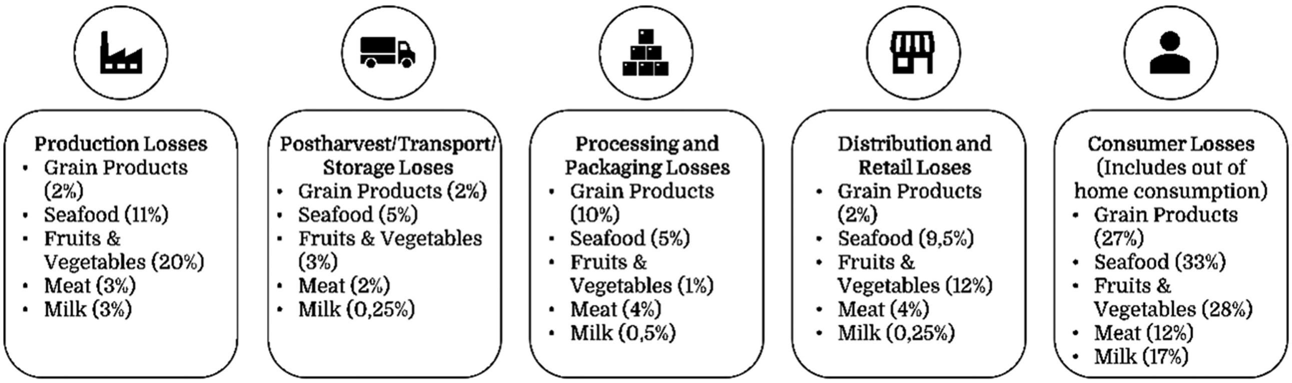

FIGURE 2 | Food losses at each step in the supply chain (S. [10]).

to more sustainable circular practices. For supply chain agents committed to achieving 100% sustainable packaging in the near future, Brennan et al. [7] emphasize the need for prioritizing low-carbon footprint packaging. Moreover, lifecycle assessment (LCA) tools can aid in measuring the environmental impact of their packaging choices.

Govindan [8] indicates that the implementation of a sustainability methodology (including sustainable packaging) in the food supply chain implies ensuring food quality and safety for customers through improved sustainable product design and reduced food waste. Previously, Parthiban, Zubar, and Katakar [9] argued that by integrating performance metrics from the sustainable packaging concept, multi-criteria approaches introduce a product lifecycle perspective to mitigate the external impacts of the food supply chain and minimize shipping distances, all while maintaining the objective of achieving consumer satisfaction.

The circular food supply chain has gained significant attention in production management [10]. Consequently, there is a growing emphasis on reducing its environmental impact. Schmidt, Foerstl, and Schaltenbrand [11] argue that sustainable supply chain management (SSCM), particularly when applied to sustainable packaging, can effectively address environmental and economic challenges. By adopting SSCM principles, businesses can define transparent strategies that improve the long-term economic performance of their supply chain.

Specifically, using parameters such as life cycle assessment (LCA), material input index (MIX), recyclable index, and composability index, the sustainability of packaging in the food supply chain can be enhanced. As a result of these measures, supply chain agents can identify opportunities to reduce the environmental impact of their products and improve their overall sustainability performance [12].

Following this line of thought, García-Arca and Carlos Prado [13] introduced a three-level foundation approach for sustainable packaging design. This approach encompasses product protection, transport packaging, and tertiary packaging. In contrast, traditional packaging relies on non-renewable resources, has limited recyclability, and contributes significantly to food waste across the supply chain [14]. As a result, the global economy suffers losses of approximately US$1 trillion annually. Wikström et al. [15] further highlight that these economic losses are primarily associated with traditional packaging and the post-harvest logistics processes in agricultural production, which include transportation, storage, and distribution of agricultural products (Figure 2).

Considering all the referred aspects, this paper aims to substantiate the extension of the significance of sustainable packaging in the context of circularizing the food supply chain. Concurrently, and taking into account the relevant perspectives, the study will evaluate the multi-criteria approach as a methodology adequate for choosing between sustainable package designs.

Apart from the introductory section, which establishes a framework and discusses the significance of sustainable packaging, the paper incorporates a comprehensive literature review that references various approaches to sustainable packaging and the food supply chain. Additionally, the methodology section outlines the utilization of multicriteria sustainable packaging parameters and agents to enhance the circularity of food supply chains. Moreover, the paper includes a case analysis section, which presents multiple examples illustrating how sustainable packaging plays a vital role in creating circular food supply chains.

2 | Literature Review

According to Li et al. [16] sustainable packaging in the food supply chain and markets constitutes a fundamental aspect, considering its contribution to mitigate waste generation and greenhouse gas emissions. Thus, Kasza et al. [17] argue that companies should adopt sustainable packaging and other sustainable practices, with the aim of reducing food waste, minimizing impacts, and extending the product life cycle to promote circularity of the food supply chain [18].

Some authors argue that definitions of SSCM should emphasize the value of sustainability in food supply chains [19]. This is particularly relevant when considering sustainable packaging practices. The food supply chain plays a crucial role in the logistics of any agent, encompassing transportation and distribution processes from production to the end consumer. Manzini and Accorsi [20] further advocate for the incorporation of specific principles and practices that integrate sustainable packaging concepts to ensure the efficiency of the food supply chain.

Although focused on environmental concerns and ensuring the optimal use of natural resources [21], Cucchiella et al. [22] argue that the quantification of the value of sustainable packaging can contribute to assessing its relevance to economic development. Equally, Agyabeng-Mensah et al. [23] and Pour et al. [24] support that sustainable supply chain policies and practices that maximize profit should also intrinsically contribute to economic and social well-being as a whole, actively maintaining and enhancing the environment.

Sustainability supply chain management (SSCM) is the practice of integrating environmental, social and economic considerations into the management of supply chains to ensure the sustainability of the entire system. It involves managing the entire life cycle of products and services, from the sourcing of raw materials to the disposal of waste (Figure 3).

Elkington [26] demonstrated the positive impact on profitability and brand reputation of adopting sustainable practices. Sabuj, Islam, and Hossain [27] considered that the application of the integrated and extended SSCM, which includes sustainable packaging, has increased the adoption of sustainability due to growing concerns about social and environmental impacts of business operations [28].

For instance, SSCM implies the implementation of sustainable procurement and packaging practices, involving the selection of suppliers that meet environmental and social standards. This integrated vision of the supply chain also contemplates the reduction of food waste by implementing sustainable practices at production and packaging levels, such as the use of renewable energy and the adoption of circular supply chain principles [29].

Another crucial aspect, as mentioned by Rezaei et al. [30], is sustainable packaging, which entails selecting materials and packaging designs that minimize environmental impact (Table 1). According to Accorsi et al. [31], sustainable packaging should entail recycling or reusing packages to minimize waste generated throughout the food supply chain.

In contrast to Meherishi, Narayana, and Ranjani [31], who focus on a particular method to segment sustainable packaging approaches, other authors considered a set of parameters for this purpose. One of these authors is Vendries [33], who used LCA to evaluate the environmental impact of various packaging designs, end-of-life scenarios, and materials used in food packaging.

Another line of research in this area concerns the quantity of specific materials present in food packaging. Klemeš and Bučko [37] undertook a study in which they employed material intensity indicators (MII) to quantify and assess the potential for reducing the amount of material incorporated into a product or service. Similarly, Peters and Samarasinghe [38] employed the

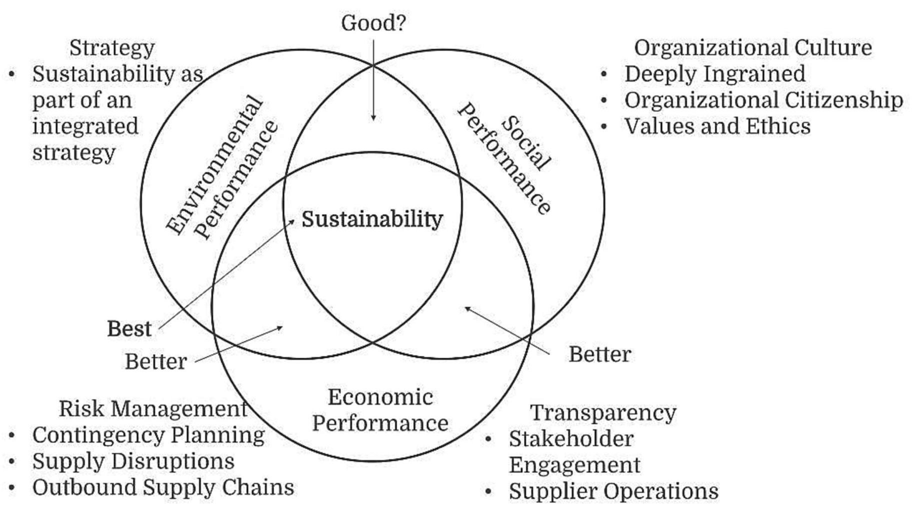

FIGURE 3 | Sustainable supply chain management [25].

TABLE 1 | Packaging according each level in SSCM [32].

Packaging level	Packaging type
Primary level	Containers, trays, bottles, carton, paper, kiosk
Secondary level	Containers, pallets, cardboard boxes, crates, shrink wrap and film, trays, RTI, metal cages
Tertiary level	Carrier, containers, pallets, crates RTI, cages

TABLE 2 | Recyclability index approaches.

Authors	Methodology	Key findings	Limitations
Herrmann, Rhein, and Sträter [34]	A mixed-method approach, combining a discrete choice experiment (DCE) and qualitative free-text analysis. The DCE assessed consumers' willingness-to-pay for various food packaging options, while the qualitative analysis explored the reasons behind their choices.	a. Consumers are willing to pay extra for recyclable, compostable, or recycled food packaging. b. Willingness-to-pay is influenced by consumers' perceptions of packaging sustainability. c. Willingness-to-pay varies depending on the type of product. d. Access to recycling or composting facilities affects consumers' willingness to pay for sustainable packaging.	a. Findings may not apply to other countries since it was conducted in Italy. b. Only examined a limited range of food packaging options. c. Other factors like product price and packaging convenience were not considered in assessing consumers' willingness-to-pay.
Geueke, Groh, and Muncke [35]	A systematic review to examine the chemical safety of recycled food packaging. The authors conducted a comprehensive search in various databases and consulted experts to find relevant studies.	a. Recycling can lead to higher levels of potentially hazardous chemicals in food packaging. b. The levels of these chemicals depend on the material, recycling process, and prior use of the packaging. c. To mitigate chemical exposure risks, using high-quality materials, improving recycling processes, and avoiding hazardous chemicals are essential measures.	a. It focused solely on peer-reviewed journal literature. b. Economic and environmental impacts of recycled food packaging were not assessed. c. It did not provide policy or practice recommendations.
Pauer et al. [36]	A life cycle assessment (LCA) to evaluate the environmental sustainability of three types of food packaging: paper, plastic, and metal. The assessment spanned 50 years and covered various impacts like climate change, acidification, eutrophication, and land use.	a. Food packaging's environmental impact varies based on material, design, and end-of-life disposal. b. Paper packaging has the lowest impact, followed by plastic and metal. c. To decrease environmental impact, using recycled materials, lightweighting packaging, and enhancing recyclability are effective measures.	a. Only conducted for a single product, so the findings may not be generalizable to other products. b. Did not consider the social and economic impacts of food packaging. c. Did not consider the impact of food waste on the environmental impacts of food packaging.

recyclability index (RI) to quantify the recyclability of food waste practices. Three other relevant approaches can be identified in the Table 2. With a different nature and complexity from the recyclability index, the composability index has been studied as a metric that quantifies the ease of composting the material, the availability of composting facilities, and the demand for compost.

Baek, Park, and Kang [39] defend that the concept of sustainable packaging involves the definition of packaging materials and designs that minimize and, where possible, improve the environmental impact of the packaging throughout its supply chain. Jadoon et al. [21] agree that sustainable packaging implies the use of recyclable or biodegradable materials and the design of packaging that makes it easy to recycle or reuse.

In this context, Koch [40] found that consumers are willing to pay more for food products that are packaged in a sustainable way, and businesses are increasingly recognizing the need to improve their organizational efficiency and reduce food waste. Not surprisingly, for Pauer et al. [36], these indicators already suggest that we can overcome the challenges of limited availability of recyclable or biodegradable materials, as well as promoting best practices and educating consumers and businesses about the benefits of sustainable packaging.

Paul et al. [41] consider a set of dimensions commonly applied in multicriteria analysis in food supply chains, which were examined by the following authors: Refsgaard et al. [42] analysed the environmental impact by studying factors such as greenhouse gas emissions. Rodrigues [43] examined the economic viability through statistics related to production costs and price stability. Closs, Speier, and Meacham [44] examined trade practices and working conditions to evaluate the social equity dimension. Nayak and Jespersen [45] prioritized the weight of food safety within the multi-criteria decision-making (MCDM) structure, focusing on factors like nutritional content and food safety standards. Lastly, Gobel et al. [46] interpreted processes for minimizing waste and optimizing resource utilization to quantify the resource efficiency of a food supply chain (Figure 4).

The food packaging industry has a significant impact on sustainability, as it plays a critical role in reducing food waste and minimizing environmental impact. The use of sustainable packaging materials, such as recyclable or biodegradable materials, can help to reduce the environmental impact of the food packaging industry. However, for Herbes, Cebeci, and Dekker [48], there is a growing recognition among businesses in the food packaging industry of the importance of sustainability and the need to adopt more sustainable practices. Though Pauer et al. [36] alert for some challenges associated with sustainable packaging, such as the limited availability of sustainable materials and the need for more education and awareness among consumers and businesses about sustainable packaging options.

Consumer factors indeed play a crucial role in driving the adoption of sustainable packaging, thereby facilitating the transition to a circular food supply chain. According to Jerzyk [49], consumers are more inclined to choose products with sustainable packaging due to factors such as increased access to information, heightened awareness of environmental issues (A. J. [50]), and the influence of brand reputation, which fosters customer loyalty [51].

Furthermore, as suggested by Fiksel [52], regulatory requirements serve as a motivating force for businesses to embrace sustainable packaging practices to ensure compliance with legal mandates. On the other hand, Matthews, Moran, and Jaiswal [53] highlight that cost-effective sustainable packaging solutions, which do not significantly raise product prices, encourage participation in the circular economy by promoting the recycling and reuse of products and packaging.

3 | Materials and Methods

This article follows, first, a qualitative literature review explained by Rezaei et al. [30]. The main objective of this review is to understand the criteria for selection and the best approach for analysing a food supply chain. The chosen methodology should be a systematic approach to managing the application of sustainable packaging throughout the entire process, including production, processing, distribution, and consumption of food products.

The ultimate goal is to ensure that decision-making within the supply chain considers sustainability without compromising product quality and the overall aim of food supply chains. This approach should offer benefits through efficient and integrated decision-making, leading to improved speed and quality. According to Van der Vorst, Van Donk, and van Nunen [54], these decisions are closely connected with alternative solutions.

Rezaei et al. [30] conducted a study in which they identified the key processes and agents involved in food supply chains. They evaluated their performance and developed strategies not only to enhance sustainable packaging but also to integrate efficiency and quality parameters. With that purpose, they selected criteria

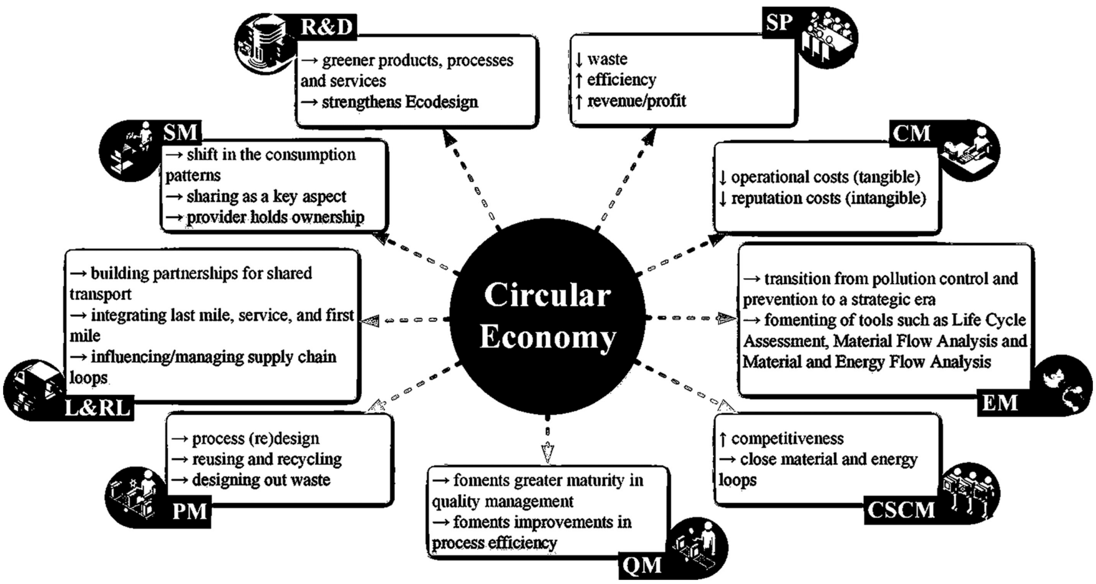

FIGURE 4 | Circular supply chain to sustainable business management [47].

and the best approach for analysing food supply chains across all stages of the food supply chain.

Therefore, Davis et al. [55] indicate that the first step in the study involves identifying all the processes that are part of the food supply chain. These processes encompass various stages, including production, processing, packaging, transportation, distribution, and retailing. To achieve this objective effectively, the authors propose conceptualizing the mapping of both physical and information flows within the supply chain (Figure 5) (https://www.eea.europa.eu/publications/designing-safe-and-sustainable-products-1).

The primary goal of this theoretical construction is to establish a SSCM framework and gain insights into how external factors impact the economic performance of the food supply chain, as highlighted by Carter et al. [10], who insist that the structure should allow for validating the impact of sustainable packaging principles in the food packaging supply chain.

The MCDM approach, particularly the analytical hierarchy process (AHP), can be utilized to choose the optimal package design, considering the preferences of all supply chain agents. Additionally, Huang, Keisler, and Linkov [57] assert that this approach facilitates risk evaluation, which is relevant to circular supply chain strategies. In this regard, it helps in identifying vulnerabilities, assessing the robustness of packaging alternatives, and promoting contingency plans to mitigate risks.

In the context of multiple MCDM methods, the best worst method (BWM), as employed by Rezaei et al. [30] in the selection of a sustainable product-package design, appears to require less comparison data while yielding more consistent outcomes (Figure 6). On the other hand, the outcomes obtained through the BWM should be compared with those achieved using the simple additive weighting (SAW) method. Darvazeh et al. [58] applied the SAW method to determine the optimal number of suppliers, considering a set of leagile (lean and agile) and environmentally sustainable criteria. This approach involves assigning weights to each criterion and evaluating each alternative based on these assigned weights.

Additionally, AHP is used to construct a hierarchical structure of criteria and sub-criteria, assigning weights to them based on their relative importance. Tirkolaee, Farhangi, and Hosseini [59] identified a set of criteria that considered relevant and then organized these criteria into a hierarchy, with recyclability at the top and end-of-life options at the bottom. They assigned weights to the criteria, assigning the highest weight to recyclability, followed by environmental impact, food safety, materials used, production process, and end-of-life options [60, 61]. Then, they used the weights to evaluate different packaging options.

On the contrary, the SAW method yields intriguing outcomes in the context of the food supply chain perspective. This is because it permits the calculation of scores for each supply chain agent, such as suppliers, based on their performance with respect to each criterion and the assigned weights of these criteria. The process involves multiplying the normalized scores for each criterion by its corresponding weight and then summing up the results across all criteria. As a result, Wati [62] employs a combination of AHP and SAW scores, utilizing an aggregation method, typically a weighted average, to determine a final score for each supplier.

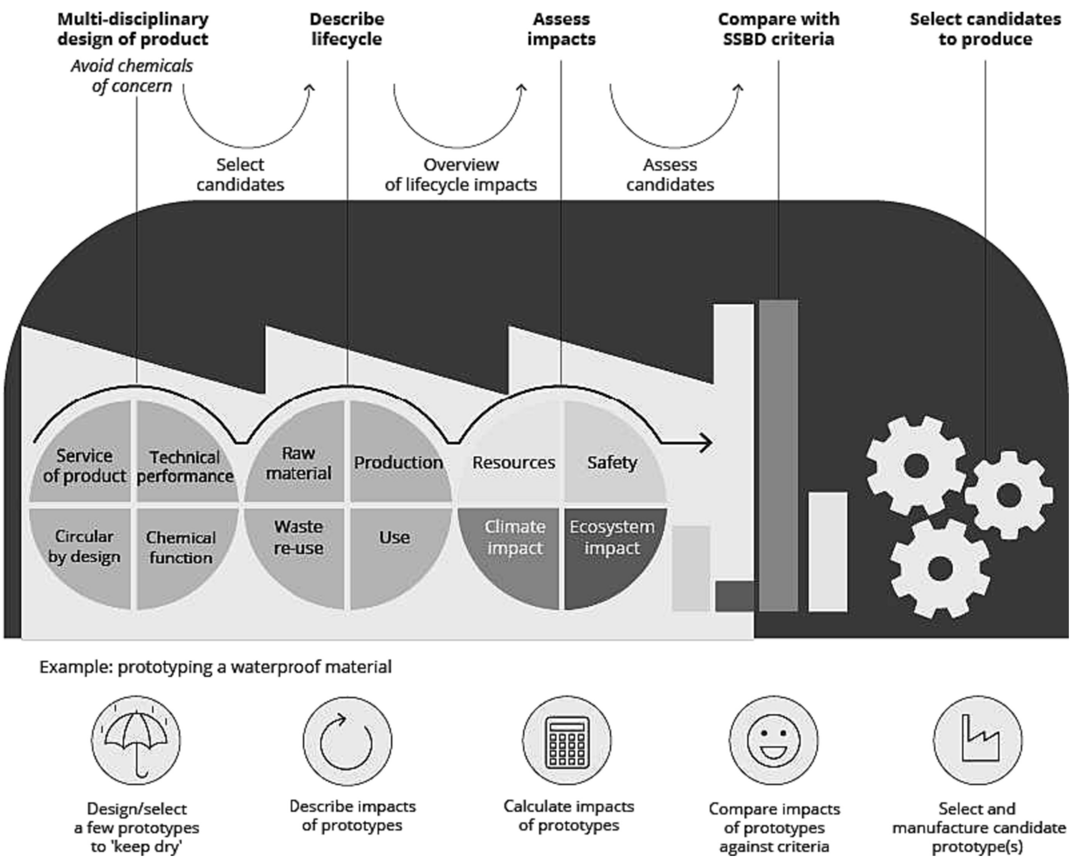

FIGURE 5 | Implementing safe and sustainable by design approaches.

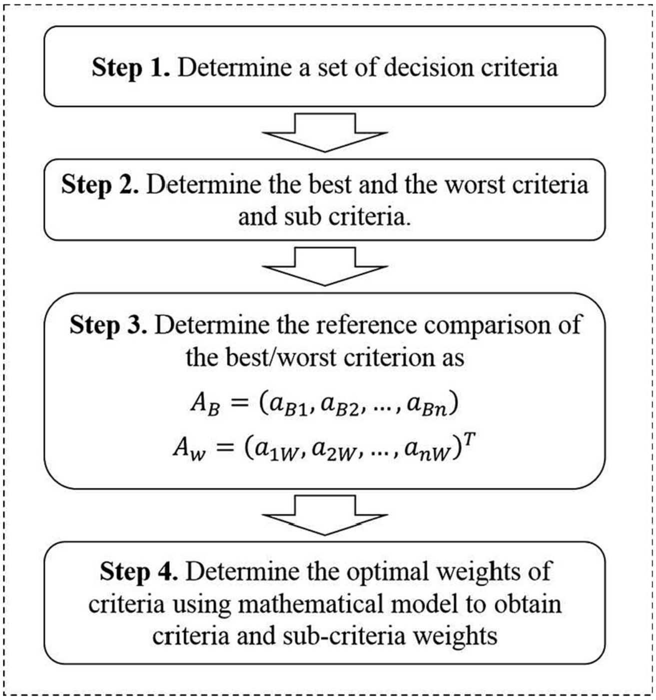

FIGURE 6 | Flowchart for the best-worst method [56].

TABLE 3 | Different MCDM frameworks.

Authors	Criteria	Weights	Ranking
Goel and Goswami [60]	Recyclability, environmental impact, food safety, materials used, production process, end-of-life options	Recyclability = 0.3, environmental impact = 0.2, food safety = 0.15, materials used = 0.1, production process = 0.1, end-of-life options = 0.15	Paper packaging, plastic packaging, metal packaging, glass packaging
Tirkolaee, Farhangi, and Hosseini [59]	Recyclability, environmental impact, food safety, materials used, production process, end-of-life options	Recyclability = 0.3, environmental impact = 0.25, food safety = 0.15, materials used = 0.1, production process = 0.05, end-of-life options = 0.15	Paper packaging, plastic packaging, metal packaging, glass packaging
Goswami and Agrawal [61]	Recyclability, environmental impact, food safety, materials used, production process, end-of-life options	Recyclability = 0.3, environmental impact = 0.2, food safety = 0.15, materials used = 0.1, production process = 0.1, end-of-life options = 0.15	Paper packaging, plastic packaging, metal packaging, glass packaging

Several papers have employed multicriteria analysis formulas to evaluate the sustainability of food packaging. One such study conducted by Molina-Besch and Pålsson [63] employed an MCDM formula to identify barriers to the adoption of sustainable packaging practices within the food supply chain. Additionally, Afif and De Boer [64] utilized a MCDM formula in their research to assess the influence of consumer sustainability concerns on the adoption of sustainable packaging practices. Thus, there is the possibility of formalizing a conceptual score to analyse the impact of sustainable packaging in the food supply chain:

$$S = \alpha_R R + \beta_E IEI + \gamma_F SFS + \delta_M M + \epsilon_P P + \zeta_{EoL} EoL \quad (1)$$

S: sustainability score; α_R: weight of recyclability; $\beta_E I$: weight of environmental impact; $\gamma_F S$: weight of food safety; δ_M: weight of materials; ϵ_P: weight of production process; ζ_{EoL}: weight of end-of-life options; R: recyclability; EI: environmental impact; FS: food safety; M: materials; P: production process; EoL: end-of-life options.

Specific situations contribute to different MCDM frameworks. For example, Tirkolaee, Farhangi, and Hosseini [59] placed more weight on recyclability because they were interested in quantifying the environmental impact of packaging. On the other hand, Goswami and Agrawal [61] assigned greater importance to food safety because they specifically focused on the safety of packaging for human consumption (Table 3).

4 | Results and Discussion

Recognizing the massive amount of packaging waste as one of the major sources of pollution, Murtas et al. [65] state that leading companies are rethinking all levels of their supply chains to assess opportunities for achieving competitive advantages through a focus on strategic sustainable product-packaging. Sarkar et al. [66] also examined the role of sustainable packaging in the circular economy, arguing that sustainable packaging reduces waste, conserves resources, and creates a more sustainable supply chain. In order to assess how sustainable packaging is being applied, the following case studies were analysed (Table 4).

Companies should choose sustainable products and materials for their designs and incorporate more sustainable methods for consumers. This involves transitioning from a linear supply chain to a circular supply chain. One of the companies demonstrating commitment to sustainable packaging practices is *Heinz*. According to Heinz [70] and HeinzUK [71], the company set a goal in 2015 to make 100% of its packaging recyclable, reusable, or compostable by 2025. As of 2021, 98% of *Heinz*'s packaging was recyclable, reusable, or compostable. Rezaei et al. [30] evaluated the sustainability of alternative package designs intended for commercial use, such as in restaurants or commercial uses for three brands (*Heinz Tomato Ketchup, Heinz Mayonnaise, Heinz Beans* using a multiple criteria life cycle approach, considering environmental impact, economic feasibility, and social performance (Figure A1). The scores were assigned based on the performance of each package design across these criteria, without taking into account the machine materials in the life cycle approach.

Scores and rankings are specific to the criteria and methodology used, and they may not necessarily reflect the overall preference of consumers or food supply chain agents. Nevertheless, the following figure provide valuable insights into the sustainability of different packaging options. These insights can inform decision-making processes aimed at improving product packaging sustainability. According to the results of this case analysis, the alternative package designs for *Heinz Tomato Ketchup* received scores ranging from 4.68 to 6.71 (Figure 7). It demonstrates a significant economic perspective's contribution to the final score, with the SOM (contactless Sauce-O-Mat unit applicable with 2.5L, 5L, 6L Heinz Tomato Ketchup and BBQ sauces) design dominating over the others. (The social performance of SOM has a relative score of over 8, as reported by Rezaei et al. [30]).

The diagram of the product *Heinz Mayonnaise* presents a similar diagram to the product *Heinz Tomato Ketchup* but the alternative package designs received scores ranging from 5.08 to 6.83 (Figure 8). Therefore, the fact that the highest-scoring design is SOM seems to confirm its superiority in terms of the sustainability parameter.

SOM is a high-quality sauce dispensing solution with qualities of cleanliness, durability, and visual impact. Therefore, its perceived overall score is high due to its ability to avoid raw and packaging material waste and provide package functionality, given its refilling capability. Another quality of SOM is its compliance with environmental regulations.

The pattern shown in Figure 9 reflects the different nature of the products being packaged (beans vs. mayonnaise). Thus, the alternative package designs for *Heinz Beans* are different from the ones considered in Figure 8, with scores ranging from 5.38 to 7.80. This confirms the close relationship between the final score and the economic score and demonstrates a dominance of the metal can packaging over the others.

TABLE 4 | Alternative sustainable packaging case studies.

Case study	Approach	Focus	Strengths	Weaknesses
Tripathi and Tiwari [67]	Qualitative research	Consumer behaviour	a. Insights into how consumers perceive sustainable packaging b. Used to identify opportunities for improvement	a. Subjective b. Not generalizable
R. V. Kumar et al. [68]	Case study	Sustainable packaging from a supply chain perspective	a. Challenges and opportunities of sustainable packaging in the supply chain b. Identify opportunities for improvement	a. Specific to the case study company b. Not generalizable
OECD [69]	Life Cycle Assessment (LCA)	Environmental impact of biscuit wrappers	a. Assessment of the environmental impact of biscuit wrappers b. Compare different packaging options	a. Can be complex and time-consuming b. Requires accurate data

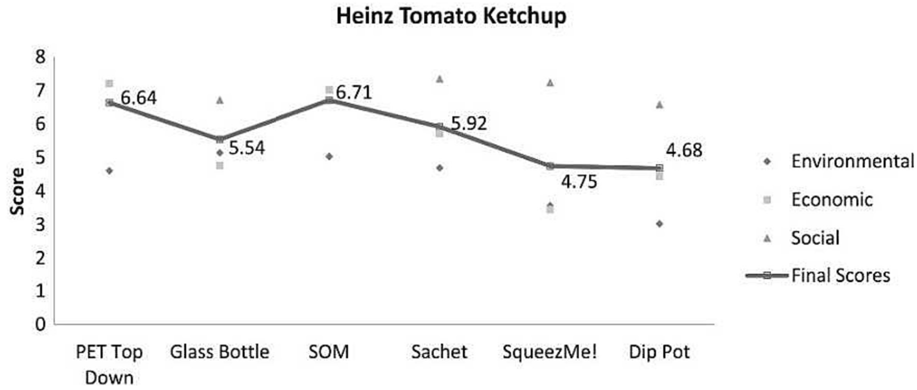

FIGURE 7 | Scores for alternative package designs [30].

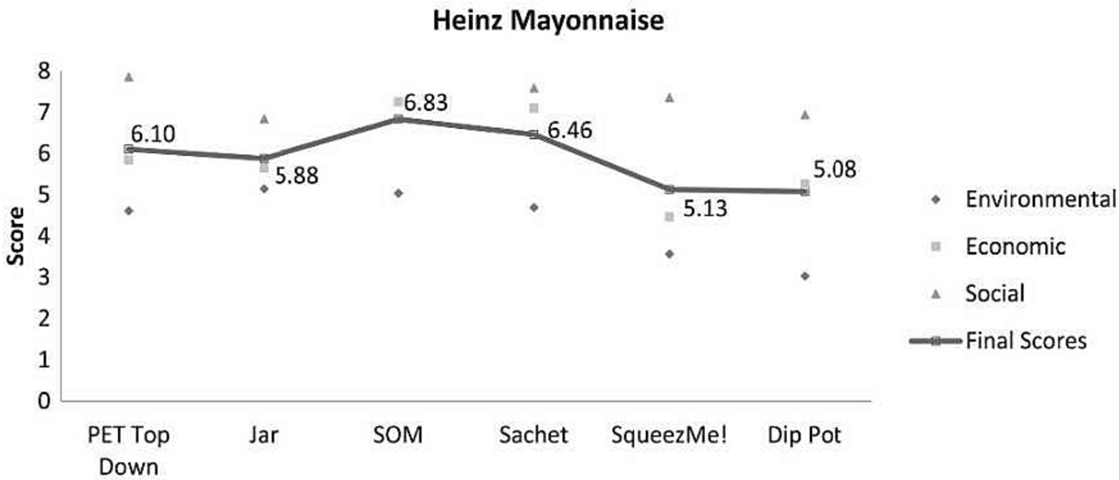

FIGURE 8 | Scores for alternative package designs [30].

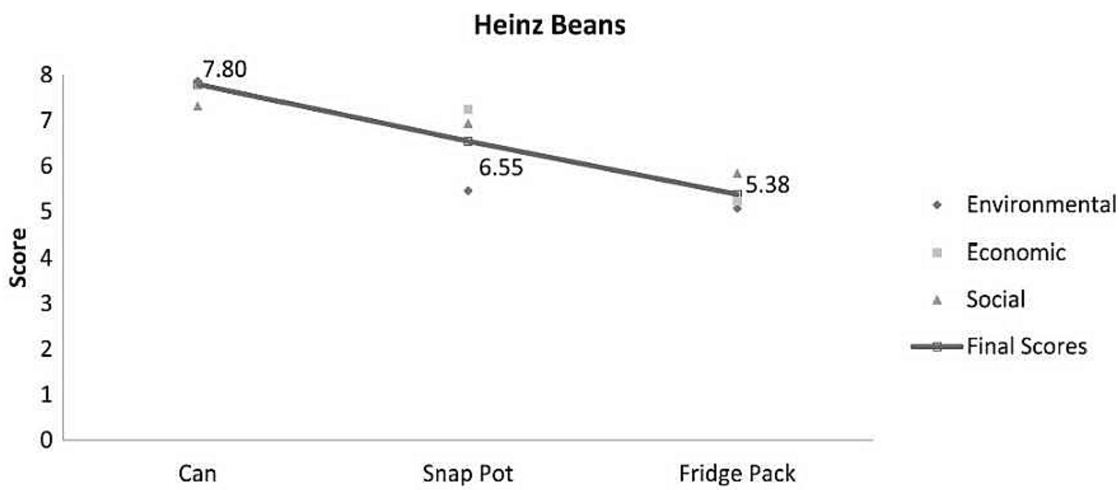

FIGURE 9 | Scores for alternative package designs [30].

Considering the evidence taken from the case analysis, the four-step process for transitioning from a linear supply chain to a circular chain proposed by V. Kumar et al. [72] deserves to be evaluated. It is a process that integrates materials, processes, and agents of the supply chain with the objective of making it sustainable (Figure 10). Therefore, it seems to follow Singh [73] with the definition of the process of reducing waste in all supply chain stages, improving resource efficiency, especially in the early stages of the supply chain. Although, as Ekins [74] claimed, it requires a shift in the value proposition of the materials and services reused. The transition process is approached by Pigosso et al. [75] who described the first step, which consists of redesigning the product to ensure its recyclability or reutilization at the end of its primary lifecycle. This takes into account the materials used in production, the design of the product, and its disassembly or recycling.

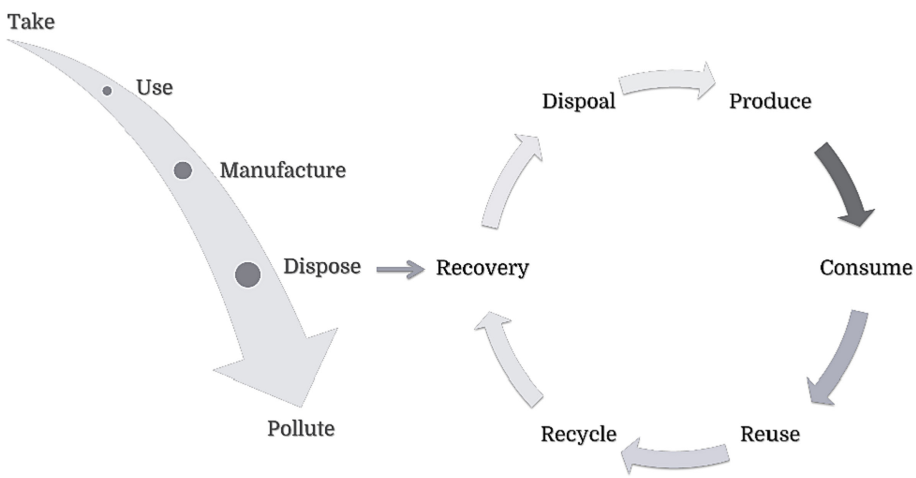

FIGURE 10 | Transition from linear supply chain to circular chain (V. [72]).

According to Van Ravenswaay et al. [76], the next step is to implement reverse logistics, facilitating the return and reuse of products and materials. This requires a system for collecting and processing used products, establishing partnerships with other supply chain agents. The third step that could have been enunciated by Lacy et al. [77] is that to use circular business models to create value from waste and by-products, it involves identifying opportunities for product reuse and recycling. Finally, there should have a collaboration commitment across the supply chain to create a closed-loop system, which involves working with all supply chain's agents to promote that materials and products are reused/recycled at every stage of the supply chain.

5 | Conclusion

Knowing that the current food supply chain requires the implementation of a circular economy as a better alternative to the linear configuration (take, make and dispose), Farooque [78] argues that this constitutes a relevant incentive to achieve breakthroughs in sustainability performance. Therefore, Van der Vorst, Van Donk, and van Nunen [54] consider it essential to channel food consumer demand towards sustainability, highlighting the importance of analysing the environmental impact of the food supply chain from the perspective of its efficiency and responsiveness.

The evidence taken from case analysis supports Ruggieri et al. [79], who demonstrated that achieving a combination of product-package design in a food supply chain with sustainability principles requires a multi-stakeholder approach. This approach not only considers the entire lifecycle of the product and packaging but also extends their life to create a circular supply chain.

The methodology to prioritize the benefits of collaboration among various agents in the food supply chain (designers, manufacturers, retailers and consumers) is appropriately ranked using multicriteria methods [80]. This collaboration is regulated by waste management authorities, aiming to create value by reducing the environmental impact of food packaging and promoting a circular supply chain.

On the other hand, Ruggieri et al. [79] emphasized that achieving sustainable product-package design in the food supply chain involves considering the entire lifecycle and extending product life for a circular system. Multicriteria methods [80] aid in prioritizing actions, including the assessment of recyclability and composability indices. Waste management authorities [31] regulate efforts to reduce the environmental impact of food packaging and promote circularity by encouraging high recyclability and composability indices in packaging materials. These indices contribute to waste reduction and a greener approach.

Recent research by Ketelsen, van der Vorst, and van Beek [81] highlight the importance of product-package design in the food supply chain for sustainability. Effective design can reduce food waste, minimize the environmental impact of packaging materials, and promote a circular economy by reducing the need for virgin materials. In assessing sustainability, LCA should examine the environmental impacts of a product throughout its life and Material Intensity Indicators (MIIs) should play a role in evaluating material efficiency and resource use in the packaging design. By considering LCA and MIIs, supply chain agents can make informed decisions to advance sustainable packaging solutions and support circular economy principles.

In conclusion, the development of sustainable product packaging within the food supply chain necessitates comprehensive consideration not only of material choices but also the entire lifecycle of the packaging, from its initial design to its eventual disposal. According to Mishra, Chiwenga, and Ali [82], achieving this objective can be realized through the collaborative efforts of supply chain agents and a shift towards adopting a circular economy model, which prioritizes resource efficiency and the implementation of waste reduction measures.

The paper successfully delineates the expanded significance of sustainable packaging within the context of circularizing the food supply chain. It systematically outlines the distinct roles that sustainable packaging assumes at various stages of the circularization process. Consequently, this study conclusively establishes that sustainable packaging holds substantial relevance within the circular food supply chain. This relevance primarily stems from its direct contributions to reducing food waste, conserving resources, mitigating carbon emissions, and aligning with consumer preferences for environmentally friendly products.

These contributions promote a more responsible approach to food production, distribution, and consumption, mainly by encouraging practices that include recycling, efficient resource use and innovation. In addition to the assessment of sustainable packaging within the circularization process, the paper confirms the multi-criteria approach as a methodology susceptible to being used by the supply agents for selecting the most appropriate and sustainable design. However, Rezaei et al. [30] highlight several challenges associated with attaining sustainable product-package design in the food supply chain. These challenges include conflicting interests among supply chain agents, limited availability of sustainable packaging materials, and a lack of consumer awareness and acceptance of sustainable alternatives.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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Appendix A

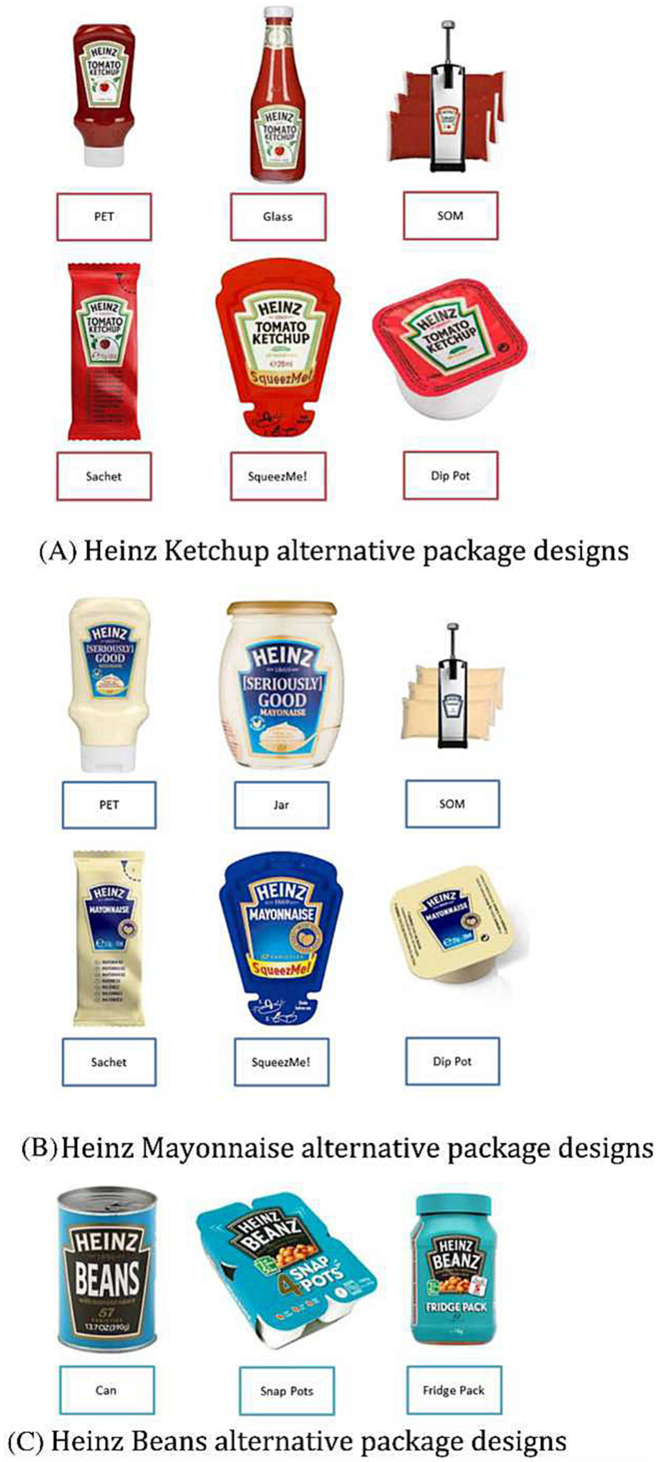

FIGURE A1 | Alternative package designs [30].