Mix Sustentável

Design de embalagem sustentável no Brasil: estratégias e diretrizes projetuais

Sustainable packaging design in Brazil: strategies and design guidelines

Diseño de envases sostenibles en Brasil: estrategias y directrices proyectuales

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Resumo: O design sustentável de embalagens exige decisões que conciliem redução de impactos ambientais, desempenho funcional e condições reais de recuperação dos materiais. Este artigo tem como objetivo analisar e organizar estratégias projetuais aplicáveis ao contexto brasileiro. Foi realizada uma revisão integrativa com buscas sistematizadas na Scopus e na Web of Science, conduzida com apoio do PRISMA 2020. Vinte e quatro estudos foram avaliados integralmente e compuseram a síntese. A análise atualizou nove diretrizes: remover componentes desnecessários, adotar monomateriais, prolongar a vida dos materiais, reutilizar, preferir refis, permitir retorno, otimizar, facilitar a desmontagem e informar. Os resultados demonstram que a efetividade dessas estratégias depende da função da embalagem, da infraestrutura disponível, da avaliação do ciclo de vida e da coordenação entre os agentes da cadeia. Como contribuição, o estudo relaciona as diretrizes às evidências e às condições ne-

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cessárias para orientar decisões de projeto no Brasil.

Palavras-chave: design de embalagens sustentáveis; ciclo de vida das embalagens; economia circular; inovação tecnológica.

Abstract: Sustainable packaging design requires decisions that reconcile environmental impact reduction, functional performance, and actual conditions for material recovery. This article aims to analyze and organize design strategies applicable to the Brazilian context. An integrative review was conducted through systematic searches in Scopus and Web of Science with support from PRISMA 2020. Twenty-four studies were assessed in full and included in the synthesis. The analysis updated nine guidelines: remove unnecessary components, adopt monomaterials, extend material life, reuse, prefer refills, allow return, optimize, facilitate disassembly, and inform. The findings show that the effectiveness of these strategies depends on packaging function, available infrastructure, life-cycle assessment, and coordination among supply-chain actors. As its main contribution, the study links the guidelines to the evidence and conditions required to support packaging design decisions in Brazil.

Keywords: sustainable packaging design; packaging life cycle; circular economy; technological innovation.

Resumen: El diseño sostenible de envases exige decisiones que concilien la reducción de impactos ambientales, el desempeño funcional y las condiciones reales de recuperación de los materiales. Este artículo tiene como objetivo analizar y organizar estrategias proyectuales aplicables al contexto brasileño. Se realizó una revisión integradora mediante búsquedas sistematizadas en Scopus y Web of Science con apoyo de PRISMA 2020. Veinticuatro estudios fueron evaluados íntegramente e incluidos en la síntesis. El análisis actualizó nueve directrices: eliminar componentes innecesarios, adoptar monomateriales, prolongar la vida de los materiales, reutilizar, preferir recargas, permitir el retorno, optimizar, facilitar el desmontaje e informar. Los resultados muestran que la efectividad de estas estrategias depende de la función del envase, la infraestructura disponible, la evaluación del ciclo de vida y la coordinación entre los agentes de la cadena. Como contribución, el estudio relaciona las directrices con las evidencias y las condiciones necesarias para orientar decisiones de diseño en Brasil.

Palabras clave: diseño de empaques sostenibles; ciclo de vida del empaque; economía circular; innovación tecnológica.

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1 INTRODUCTION

Packaging design influences material consumption, product protection, distribution efficiency, use, and post-consumer recovery. Environmental criteria therefore need to enter the project before materials, formats, and production processes become difficult to change (Vezzoli; Manzini, 2008). In the Brazilian market, these technical decisions also affect the environmental value perceived by consumers (Clementino, 2020).

The accumulation and inadequate disposal of plastic waste have documented environmental consequences (Geyer; Jambeck; Law, 2017). In Brazil, the National Solid Waste Policy assigns shared responsibility for the product life cycle and requires reverse-logistics arrangements (Brasil, 2010). Packaging guidelines can support these obligations when they connect project specifications to available production and recovery systems.

Previous studies have established criteria for perceived environmental value and for the incorporation of sustainability into product development (Clementino, 2020; Braga, 2012). Their recommendations, however, differ in scope, type of evidence, and assumptions about collection, recycling, reuse, and industrial capacity. A synthesis is needed to distinguish broadly stated principles from recommendations supported by operational or life-cycle evidence.

The guiding question is: "Which sustainable packaging design strategies and guidelines are supported by traceable scientific evidence, and under what conditions can they guide design decisions in Brazil?" International findings were interpreted in relation to Brazilian regulation, industrial capabilities, reverse-logistics arrangements, and recovery infrastructure.

The objective is to identify, critically analyze, and organize sustainable packaging design strategies through an integrative review of 24 studies. Specifically, the study examines the evidence supporting the guidelines, identifies limitations and implementation conditions, distinguishes the analytical role of different study designs, and proposes a structured synthesis for Brazilian design and industrial decision-making.

2 THEORETICAL FRAMEWORK

2.1 Sustainability: concept and development

The concept of sustainability has moved beyond a strictly conservationist perspective toward the combined consideration of human well-being and natural capital (Kuhlman; Farrington, 2010). In Brazil, Law No. 12,305/2010 incorporated this systemic perspective into waste policy by establishing shared responsibility for the product life cycle (Brasil, 2010).

This regulatory approach is consistent with the shift described by Manzini e Vezzoli (2011) from isolated product improvement toward changes in production, consumption, and service systems. For packaging design, the relevant unit of analysis consequently extends beyond the package itself to its relationships with the product, distribution chain, user, and recovery network.

2.2 Sustainable packaging and the circular economy

Circular-economy approaches seek to retain the utility and value of materials while reducing waste generation (Webster, 2017). Applied to packaging, this objective involves material selection, product protection, recovery routes, and repeated-use systems. Technical performance must also be reconciled with communication and aesthetics because environmental requirements influence the visual and material configuration perceived by users (Clementino; Arruda, 2018).

The concept of "perceived environmental value" indicates that consumers must be able to recognize relevant environmental attributes (Clementino, 2020). Communication alone, however, does not establish environmental performance. Claims associated with monomaterials, recycled content, or refill systems need technical verification, while implementation depends on coordinated competencies across the supply chain (Gonçalves-dias; Guimarães; Santos, 2012).

2.3 Packaging life cycle

The packaging life cycle covers raw-material extraction, production, distribution, use, and end-of-life processes. Life Cycle Assessment (LCA) compares environmental impacts across these stages. ABNT NBR ISO 14040:2009 organizes LCA into goal and scope definition, inventory analysis, impact assessment, and interpretation (Associação brasileira de normas técnicas, 2009).

The Brazilian Association of the PET Industry published a 2024 comparative assessment of PET, aluminum, glass, and steel packaging (Associação brasileira da indústria do pet, 2024). Under the functional units and scenarios adopted in that study, PET presented lower results for several impact indicators. These findings are context-dependent and should not be generalized without examining system boundaries, transport, product function, reuse, and recovery assumptions.

Law No. 12,305/2010 establishes waste-management principles and shared responsibility in Brazil (Brasil, 2010). Decree No. 12,688/2025 subsequently instituted the reverse-logistics system for plastic packaging and specified responsibilities within this chain (Brasil, 2025).

Larini (2021) applies Life Cycle Assessment to packaging used for delivery services, highlighting the need for comparative studies to guide decisions among packaging alternatives. The work illustrates how LCA can support more informed choices, although its findings must be interpreted within the boundaries and scenarios defined in the study.

The responsibilities established by the PNRS encompass manufacturers, importers, distributors, retailers, consumers, and public authorities (Brasil, 2010). Their coordination affects whether technical innovations can move from prototypes to functioning recovery systems (Gonçalves-dias; Guimarães; Santos, 2012).

When incorporated into packaging development, life-cycle information makes trade-offs visible among material reduction, product protection, logistics, use, and end-of-life alternatives (Associação brasileira de normas técnicas, 2009; Svanes *et al.*, 2010). This comparison is especially relevant when a reduction in packaging increases product loss or when a reusable format requires additional transport and

cleaning.

Communication and transparency also influence how consumers interpret environmental attributes. Comparative research shows that consumers use multiple visual and informational cues to recognize environmentally preferable packaging, and that these cues vary across contexts (Herbes; Beuthner; Ramme, 2020). Clear labeling should therefore communicate verifiable attributes and disposal instructions without replacing improvements in the packaging system itself.

Packaging durability, reduction, recyclability, and reuse should therefore be evaluated together with product protection, distribution, use patterns, and end-of-life scenarios. Their environmental result depends on the complete packaging system rather than on a single material attribute (Svanes *et al.*, 2010).

3 METHODOLOGICAL PROCEDURES

3.1 Study characterization and protocol

This integrative review followed the stages of problem identification, literature search, data evaluation, data analysis, and presentation of the synthesis (Whittemore; Knafl, 2005). Identification, deduplication, screening, eligibility, and inclusion were documented with support from PRISMA 2020 (Page *et al.*, 2021). The protocol and selection records were checked against the database exports, titles, abstracts, DOIs, and full texts.

3.2 Search strategy and data collection

The searches were run on September 1, 2026, in Scopus and the Web of Science Core Collection and covered publications from January 2010 to the search date. Articles, reviews, and full conference papers in English, Portuguese, or Spanish were eligible. The search combined thirteen expressions for sustainable packaging in the three languages with terms related to design, guidelines, strategies, requirements, criteria, and frameworks. Scopus applied the blocks to title, abstract, and keywords, while Web of Science applied them to the Topic field. The exact strings, filters, interfaces, dates, and exported files are reproduced in the supplementary search record.

The exports comprised 1,060 Scopus records and 1,026 Web of Science records, totaling 2,086 occurrences. DOI normalization and title matching identified 843 cross-database correspondences, resulting in 1,243 consolidated records. Title and DOI were retained as the primary traceability keys.

3.3 Selection criteria and sample

Screening was performed in two stages. The broad title-and-abstract screening excluded 855 records whose main focus was material formulation, food preservation, market perception, waste management, or

logistics without a direct contribution to sustainable packaging design. The remaining 388 records underwent a refined assessment of project relevance. At this stage, 364 records were excluded because they did not simultaneously present packaging as a central object, an identifiable design strategy or tool, and results applicable to project decisions. Twenty-four reports were sought, retrieved, and assessed in full. All 24 met the integrative review's thematic eligibility criteria and were included. Figure 1 summarizes the process.

The 24 included studies were classified according to their analytical role. Fifteen supplied direct empirical, life-cycle, industrial, or decision-support evidence. Four reviews organized secondary evidence. Five studies contributed to the discussion of perception, aesthetics, descriptive methods, or conceptual decision models. The latter group informed specific aspects of the guidelines but did not independently support claims of measured environmental or operational performance.

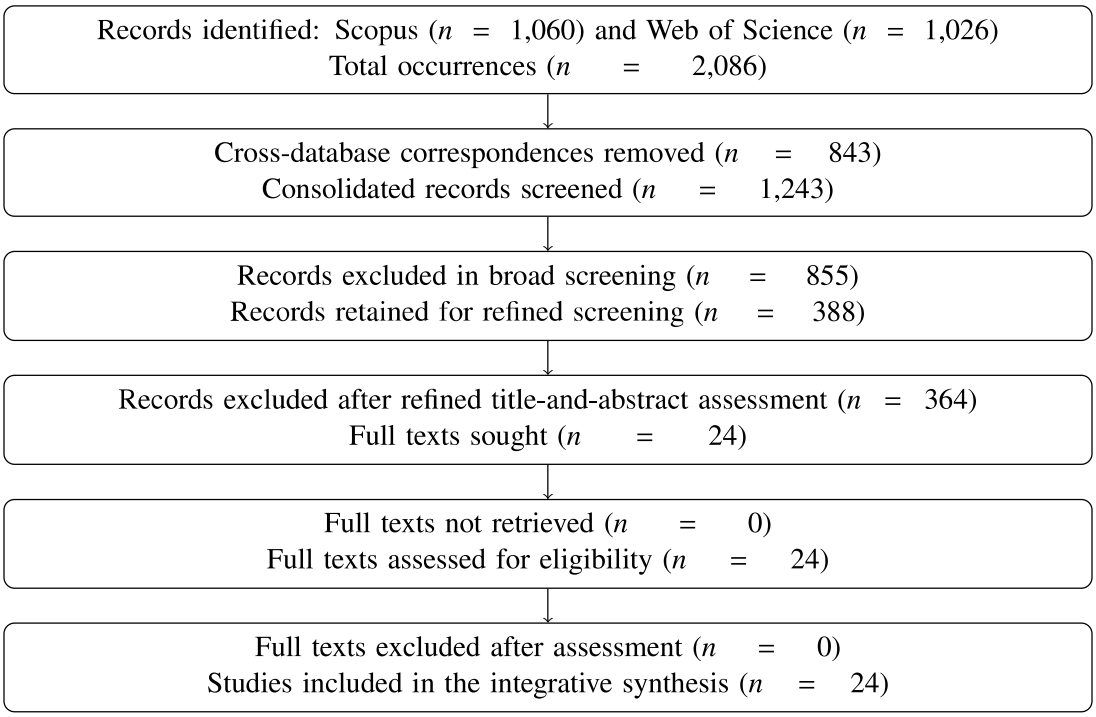


Figure 1 – Study selection flow adapted from PRISMA 2020

3.4 Critical appraisal

The full texts were appraised for bibliographic traceability, clarity of objectives, description and adequacy of methods, identification of participants, cases, inventories or data sources, coherence between analysis and conclusions, explicit limitations, contribution to packaging decisions, and conditions for transfer to Brazil. Each criterion was classified as yes, partial, no, or not applicable. No aggregate score or automatic quality threshold was used. Methodological limitations informed the interpretive weight assigned to each source.

3.5 Data extraction and synthesis

For each publication, the extraction matrix recorded context, objective, method, packaging type and sector, materials, life-cycle stage, design strategy, claimed environmental benefit, supporting evidence, limitations, implementation conditions, and potential application in Brazil. Deductive coding retained the nine guidelines present in the original analytical framework. Inductive comparison then identified cross-cutting relationships involving early decision-making, life-cycle assessment, recovery infrastructure, user requirements, and organizational coordination. The synthesis emphasized convergence, divergence, uncertainty, and conditions of application rather than simple frequency counts.

4 ANALYSIS OF RESULTS

4.1 Composition and critical profile of the corpus

The 24 included studies comprised decision frameworks, life-cycle and recyclability assessments, industrial applications, qualitative investigations, perception and usability studies, and literature syntheses. Fifteen studies provided direct evidence, four organized secondary evidence, and five offered complementary contributions on methods, aesthetics, perception, or conceptual decision models. This diversity reflects the technical, environmental, organizational, and user-related dimensions of packaging design. Measured impacts, modeled scenarios, qualitative barriers, and literature-derived recommendations were compared without being treated as equivalent forms of evidence. Table 1 identifies the studies, methodological approaches, contributions, and DOI links.

The integrative analysis retained the nine guideline categories originally adapted from Clementino e Arruda (2018) in the submitted manuscript and revised their content in light of the 24 studies. No material or format was consistently preferable across the reviewed contexts. The studies supported a process that begins by defining the function delivered jointly by product and packaging, compares alternatives across the life cycle, and verifies whether the proposed recovery route operates in practice. Table 2 presents the updated guidelines, their design requirements, and the conditions identified for Brazil.

Table 1 – Characterization of the 24 studies included in the integrative review

Study and traceability	Method or context	Main contribution to the synthesis
Bronsky, Nikou and Jager (2026) [DOI]	Qualitative multimethod case study with packaging assessment, interviews, co-creation, and validation.	Design-led tools for recyclability, early stakeholder coordination, and compatibility with actual sorting systems.
Camilleri et al. (2025) [DOI]	Conceptual framework supported by interviews, focus groups, consumer data, and prior studies.	Integration of multiple-user requirements and measurable specifications during early design stages.
Yudison, Bher and Auras (2026) [DOI]	Comparative life-cycle assessment of 16 product and packaging systems with uncertainty analysis.	Joint evaluation of product protection, packaging, losses, recycled content, and end-of-life scenarios.
Tarantino et al. (2026) [DOI]	Systematic literature review structured by CIMO and PRISMA.	Multidisciplinary organization of critical factors for circularity in the packaging sector.
Mofatteh et al. (2026) [DOI]	Design research with blockchain proof of concept, probabilistic simulation, and sensitivity analysis.	Digital traceability, deposits, incentives, and reverse flows for packaging return and reuse.
Fang and Qu (2026) [DOI]	Affective semantics, affinity diagrams, precedence analysis, and quality function deployment.	Relationship between biomimetic form, aesthetic perception, and sustainable packaging decisions.
Garzoni, Stefanini and Vignali (2026) [DOI]	ISO-based life-cycle assessment of closed-loop opaque rPET bottles for UHT milk.	Conditions under which recycled content and closed-loop systems can reduce environmental impacts.
Ahmad, Ahmad and Arman (2026) [DOI]	Cross-sectional online survey with 386 participants.	User perception and usability implications of tethered closures in circular packaging.
Pott et al. (2026) [DOI]	Exploratory qualitative study of reusable packaging for raw meat in food service.	Operational requirements for reuse, including inspection, washing, tracking, storage, and training.
Keller, Scagnetti and Albrecht (2022) [DOI]	Life-cycle comparison of 14 recyclability scenarios for polypropylene packaging.	Evidence that effective recyclability depends on sorting, substitution, material quality, and system boundaries.
Civancik-Uslu et al. (2019) [DOI]	Industrial case combining life-cycle assessment and ecodesign for cosmetic packaging.	Identification of environmental trade-offs in material reduction, substitution, production, and logistics.
Mudgal, Pagone and Salonitis (2024) [DOI]	Kano model, Ashby diagrams, life-cycle assessment, life-cycle costing, and TOPSIS.	Selection of materials and strategies according to function, cost, environment, and customer preferences.

Table 1 – Characterization of the 24 studies included in the integrative review (continued)

Study and traceability	Method or context	Main contribution to the synthesis
Markevičiūtė and Varžinskas (2022) [DOI]	Literature synthesis of bio-based polymers and circular design strategies.	Distinction between renewable origin, technical performance, and feasible end-of-life routes.
Varžinskas et al. (2020) [DOI]	Descriptive review of ecodesign methods and tools applicable to packaging.	Overview of instruments available for integrating environmental criteria into design.
Rajendran and Ranjitharamasamy (2024) [DOI]	Fuzzy DEMATEL-TOPSIS model with expert judgments and weight sensitivity tests.	Multicriteria comparison of circular packaging models and explicit treatment of decision priorities.
Xu et al. (2025) [DOI]	Design Research Methodology used to develop a preliminary decision-support tool.	Early comparison of packaging concepts through environmental, functional, and practical indicators.
Escurís-Ouviña, García-Arca and Prado-Prado (2025) [DOI]	Literature review and corporate benchmarking in fashion e-commerce.	Practices for right-sizing, logistics, communication, reuse, and reduction of unnecessary components.
Sastre, de Paula and Echeveste (2022) [DOI]	Systematic review of 472 publications on packaging sustainability.	Organization of opportunities, guidelines, stakeholders, and research gaps.
Georgakoudis, Pechlivanidou and Tipi (2025) [DOI]	Parametric geometry and computer-aided design modeling.	Potential material reduction through geometric optimization, subject to physical and environmental validation.
Weinrich et al. (2024) [DOI]	Seventeen interviews with actors from the European food packaging sector.	Organizational, regulatory, cost, equipment, and supplier factors affecting implementation decisions.
Rezaei et al. (2019) [DOI]	Multicriteria life-cycle approach applied to a food supply chain.	Integrated optimization of product and packaging rather than isolated minimization of packaging.
Camilleri, Farrugia and Refalo (2023) [DOI]	Multi-user-centred framework applied to over-the-counter pharmaceutical packaging.	Reconciliation of sustainability, aesthetics, functionality, and stakeholder requirements.
Tran Dinh et al. (2022) [DOI]	Conceptual development and empirical measurement of eco-designed retail packaging.	Consumer-facing dimensions of reduction, material choice, information, and perceived ecodesign.
Verghese, Horne and Carre (2010) [DOI]	Iterative development of the PIQET streamlined life-cycle assessment tool with industry participation.	Integration of life-cycle information into early packaging design and comparison of alternatives.

Source: Authors' synthesis based on the full-text assessment. The DOI label in each row provides direct access to the publication.

Table 2 – Evidence-based update of sustainable packaging design guidelines

Guideline	Updated design requirement	Evidence and conditions for Brazil
Remove	Eliminate unnecessary components and reduce mass or empty volume without compromising protection, shelf life, transport, or use.	Benefits must be confirmed by technical tests and life-cycle comparison because product loss can outweigh material savings (Civancik-uslu *et al.*, 2019; Georgakoudis; Pechlivanidou; Tipi, 2025; Rezaei *et al.*, 2019).
Adopt monomaterial	Prefer compatible single-material structures when barrier, sealing, safety, and processing requirements can be maintained.	Compatibility with Brazilian collection, sorting, and recycling must be tested. A nominally monomaterial package may still contain disruptive labels, inks, adhesives, or coatings (Bronsky; Nikou; Jager, 2026; Keller; Scagnetti; Albrecht, 2022; Markeviciute; Varzinskas, 2022).
Extend material life	Design for effective recycling and the safe incorporation of recycled content while preserving traceability and functional quality.	Results depend on collection rates, recycling yield, energy, transport, quality of the recovered material, and sanitary regulation (Yudison; Bher; Auras, 2026; Garzoni; Stefanini; Vignali, 2026; Keller; Scagnetti; Albrecht, 2022).
Reuse	Develop durable packaging together with inspection, washing, storage, tracking, and redistribution procedures.	The environmental result depends on the achieved number of cycles, return rate, transport distance, cleaning system, and prevention of product loss (Pott *et al.*, 2026; Rezaei *et al.*, 2019).
Prefer refills	Separate repeated product delivery from the production of a complete new package and ensure compatibility between the durable container and the refill system.	A refill is advantageous only when consumer adherence, residual packaging, distribution, hygiene, and recovery routes are jointly evaluated (Yudison; Bher; Auras, 2026; Rajendran; Ranjitharamasamy, 2024; Sastre; Paula; Echeveste, 2022).
Allow return	Treat the package, return point, deposit or incentive, reverse flow, inspection, and destination as one service system.	Local pilots must validate accessibility, costs, behavior, contracts, data governance, and reverse-logistics capacity (Mofatteh *et al.*, 2026; Pott *et al.*, 2026; Weinrich *et al.*, 2024).
Optimize	Balance material and energy use, geometry, palletization, transport, cost, usability, and product protection from the initial design stages.	Multicriteria rankings are context-dependent and require Brazilian inventories, costs, technical constraints, and stakeholder priorities (Mudgal; Pagone; Salonitis, 2024; Xu *et al.*, 2025; Georgakoudis; Pechlivanidou; Tipi, 2025; Verghese; Horne; Carre, 2010).
Facilitate disassembly	Reduce incompatible components and use reversible connections or clear separation features when a single-material structure is not feasible.	Separation must be understandable to users and operationally compatible with sorting and reprocessing facilities (Bronsky; Nikou; Jager, 2026; Keller; Scagnetti; Albrecht, 2022; Varzinskas *et al.*, 2020).
Inform	Communicate verifiable environmental attributes and realistic post-consumer actions while documenting materials and decisions throughout the chain.	Information must be tested for comprehension and matched to actual local routes. Perceived sustainability or aesthetic preference does not by itself demonstrate environmental benefit (Camilleri *et al.*, 2025; Fang; Qu, 2026; Ahmad; Ahmad; Arman, 2026; Escuris-ouvina; Garcia-arca; Prado-prado, 2025; Camilleri; Farrugia; Refalo, 2023; Dinh *et al.*, 2022).

Source: Adapted and expanded from Clementino e Arruda (2018), based on the integrative synthesis of the 24 included studies. The organization of circular strategies was also supported by the secondary syntheses (Tarantino *et al.*, 2026; Markeviciute; Varzinskas, 2022; Escuris-ouvina; Garcia-arca; Prado-prado, 2025; Sastre; Paula; Echeveste, 2022).

4.2 From isolated attributes to conditional design decisions

The corpus challenges the use of material labels as stand-alone sustainability criteria. Monomaterial structures, recycled content, bio-based polymers, lightweighting, and reuse can each improve performance, but only when the relevant function and recovery route are preserved. In the recyclability studies, colors, labels, adhesives, fillers, and separability altered sorting and substitution outcomes even when the main polymer remained unchanged (Bronsky; Nikou; Jager, 2026; Keller; Scagnetti; Albrecht, 2022). Likewise, the closed-loop rPET case produced favorable results under a coordinated Italian collection and recycling arrangement, which cannot be assumed for other regions (Garzoni; Stefanini; Vignali, 2026). The secondary literature reinforces that renewable origin or theoretical recyclability does not guarantee circularity without compatible infrastructure (Tarantino *et al.*, 2026; Markeviciute; Varzinskas, 2022; Sastre; Paula; Echeveste, 2022).

Reduction also emerged as a conditional rather than absolute principle. Industrial LCA and ecodesign showed that material substitution and downgauging may lower several impacts while increasing others (Civancik-uslu *et al.*, 2019). Parametric geometry indicated a theoretical material-saving potential, but without prototypes, mechanical tests, transport analysis, or a complete LCA (Georgakoudis; Pechlivanidou; Tipi, 2025). Decision frameworks therefore recommend comparing protection, customer requirements, cost, logistics, and environmental indicators instead of minimizing mass in isolation (Yudison; Bher; Auras, 2026; Mudgal; Pagone; Salonitis, 2024; Rezaei *et al.*, 2019; Camilleri; Farrugia; Refalo, 2023).

The complementary studies expanded the analysis of the *Inform* guideline by showing that form, semantics, closure systems, and environmental cues affect perception and usability (Fang; Qu, 2026; Ahmad; Ahmad; Arman, 2026; Dinh *et al.*, 2022). These findings are relevant to acceptance and correct use, but they do not replace environmental assessment. A package can appear sustainable without producing a verified reduction in impact. Communication must therefore be consistent with technical specifications and with the destination that is actually available after consumption.

4.3 Implementation depends on systems and organizations

Reuse and return systems require more than durable packaging. The meat-service study identified stacking, visual inspection, HACCP coding, certified washing, storage, tracking, contracts, and training as interdependent design requirements (Pott *et al.*, 2026). The blockchain model added deposits, digital identities, return points, and automated reimbursement, but its environmental and behavioral results remained simulated (Mofatteh *et al.*, 2026). These findings converge with the broader circularity review and e-commerce benchmarking, while also showing that reported corporate benefits require independent verification (Tarantino *et al.*, 2026; Escuris-ouvina; Garcia-arca; Prado-prado, 2025).

Organizational evidence further shows that sustainable options are filtered by cost, equipment, suppliers, regulation, and internal responsibilities. Multidisciplinary teams and explicit decision criteria can make these constraints visible early (Bronsky; Nikou; Jager, 2026; Weinrich *et al.*, 2024). Multi-user frameworks expand the relevant participants beyond buyers to include producers, logistics operators, users,

waste handlers, and regulators (Camilleri *et al.*, 2025; Camilleri; Farrugia; Refalo, 2023). For Brazil, this implies including cooperatives and regional recovery actors in the design process rather than treating post-consumer management as a later communication task.

4.4 Role and limits of life-cycle tools

Life-cycle evidence provided the strongest basis for comparing alternatives, but it also exposed the sensitivity of results. Product losses, packaging mass, reuse cycles, recycled content, transport, and end-of-life rates can change the preferred strategy (Yudison; Bher; Auras, 2026; Garzoni; Stefanini; Vignali, 2026; Keller; Scagnetti; Albrecht, 2022). Streamlined tools such as PIQET and preliminary design indices can bring environmental information into concept development, provided that their assumptions remain transparent and a complete LCA is used when robust comparative or public claims are required (Xu *et al.*, 2025; Verghese; Horne; Carre, 2010). Reviews of ecodesign methods and abstract multicriteria models broaden the available toolkit, although their suitability must be demonstrated in the specific industrial context (Varzinskas *et al.*, 2020; Rajendran; Ranjitharamasamy, 2024).

Taken together, the studies support an evidence-based update of the nine guidelines. Each recommendation is linked to its technical purpose, supporting evidence, limitations, and conditions for Brazilian implementation. Five relationships recur across the guidelines: early decision-making, preservation of packaging function, life-cycle verification, compatibility with recovery infrastructure, and coordination among supply-chain actors. Incorporating these relationships converts the guidelines from a list of desirable attributes into a basis for comparing project alternatives.

5 CONCLUSION

The integrative review of 24 studies confirmed and updated nine guidelines for sustainable packaging design: remove, adopt monomaterial, extend material life, reuse, prefer refills, allow return, optimize, facilitate disassembly, and inform. None constitutes a universal prescription. Environmental performance depends on preserving the functions delivered by product and packaging, comparing alternatives across the life cycle, and verifying the operational conditions of collection, return, sorting, washing, recycling, or disposal.

For Brazilian application, the first priority is to connect design specifications to real collection, sorting, recycling, washing, and return systems. Monomaterial, recycled-content, refill, and reuse solutions require technical and environmental validation with national inventories, distances, energy, loss rates, sanitary rules, and regional markets. Communication should describe verifiable attributes and routes, while cooperation with suppliers, logistics operators, cooperatives, recyclers, and users should begin before design detailing.

The resulting structure preserves the practical clarity of the original guidelines and specifies the evidence and conditions associated with each one. The use of two bibliographic databases, the heterogeneity

of the study designs, and the concentration of empirical evidence outside Brazil limit the direct transfer of numerical results. Future research should test the nine guidelines in Brazilian industrial projects, use national life-cycle inventories, and measure technical performance, costs, user behavior, recovery rates, and environmental outcomes over time.

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