PACKAGING IMPACTS: FROM ASSESSMENT METHODS AND TOOLS TO DESIGN STRATEGIES

4. PACKAGING IMPACTS: FROM ASSESSMENT METHODS AND TOOLS TO DESIGN STRATEGIES

Caterina Antonia Dattilo, Massimo Delogu, Veronica Pasini, Lisa Filippini, Martina Spinelli

Abstract: Designing sustainable and circular packaging involves a thorough evaluation of environmental, economic, and social aspects throughout the entire life cycle. This chapter provides an overview of various approaches and tools that assist designers in assessing impacts and translating those results into effective strategies. It begins with a discussion of quantitative methods, such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC), which are useful for measuring material, logistical, and performance elements of packaging. Next, it explores qualitative perspectives, including Social Life Cycle Assessment, which offers insights into cultural, ethical, and experiential values. By integrating these different dimensions, the Life Cycle Sustainability Assessment framework emerges as a comprehensive approach to guide design decisions. The chapter includes a survey of methods and tools currently in use, showcasing a variety of resources ranging from sector-specific calculators to participatory toolkits and digital platforms. Finally, the chapter presents a set of principles for sustainable packaging design, highlighting their importance in mediating among stakeholders, aligning design practices with regulations, and supporting the transition toward more circular and responsible packaging systems.

Keywords: impact assessment, packaging sustainability, Life Cycle Assessment, circular design, integrated approach.

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4.1. Measuring packaging sustainability through quantitative methods

A comprehensive evaluation combining quantitative and qualitative methods is essential. It ensures packaging is effective, efficient, and sustainable, and aligns with commercial, technical, and communication objectives. These approaches facilitate informed decision-making and enhance the overall impact of design strategies.

Quantitative assessment uses numerical and measurable analyses to evaluate various aspects of packaging (Verghese et al., 2012). This process considers critical factors such as material choices, production methods, transportation logistics, storage conditions, and disposal options. One key component of this assessment is Life Cycle Assessment (LCA) (International Organization for Standardization, 2006a; 2006b), which examines the environmental impact throughout the product's entire life cycle, from the initial design phase to production, transportation, storage, and eventual disposal. Additionally, Life Cycle Costing (LCC) (International Organization for Standardization, 2019) evaluates the economic implications associated with these stages. By integrating insights from both LCA and LCC, businesses can develop packaging solutions that are not only effective and efficient but also promote sustainability and support a circular economy. This holistic approach ensures that decisions balance environmental responsibility with cost-effectiveness, leading to more informed choices (Stramarkou et al., 2022).

In addition, it is crucial to assess both logistical efficiency and mechanical performance when designing packaging solutions. Logistical efficiency encompasses several key factors, including the weight of the container, its dimensions, and the ability to stack multiple packages without compromising stability. These considerations are vital for optimizing space during transportation and minimizing shipping costs, which can significantly impact overall project budgets. On the other hand, mechanical performance refers to durability and resilience. This includes the capacity to endure impacts during handling, compression from stacking, and exposure to humidity, which can affect the integrity of the contents. By thoroughly examining these aspects, one can ensure that the product is well-protected throughout its journey from manufacturer to end user. Such detailed attention to both efficiency and performance guarantees that packaging both meets logistical requirements and safeguards the product effectively.

Sustainability also includes social and ethical dimensions, reflecting a qualitative perspective through Social Life Cycle Assessment (S-LCA) (International Organization for Standardization, 2024). In this context, Life Cycle Sustainability Assessment (LCSA) has emerged as a robust and integrative framework for evaluating sustainability in products and processes, as it combines LCA, LCC, and S-LCA. In the packaging industry, using analytical tools offers a valuable opportunity to understand the differences between traditional methods and those designed specifically for e-commerce. These resources enable an in-depth assessment of various trade-offs, such as the increase in carbon emissions associated with transportation logistics, compared to the significant reduction in waste generated at the retail level. This detailed analysis allows for more informed decision-making regarding sustainable packaging practices and their environmental impacts.

Two principal approaches to LCSA have been proposed. The first, suggested by Kloepffer (2008) and Finkbeiner (2010), extends the traditional ISO-based LCA methodology by incorporating economic and social dimensions, in line with the "triple bottom line" paradigm. The second, introduced by Guinée et al. (2011), presents an integrated conceptual framework that systematically expands conventional LCA to include socio-economic aspects, thereby facilitating multi-level and cross-dimensional analysis. Both approaches expand sustainability assessment beyond environmental impacts to include economic and social dimensions, but they differ in conceptual structure and modelling strategies. The LCSA analysis approach, proposed by Kloepffer (2008) and Finkbeiner (2010), integrates life cycle inventory and impact assessment within a unified modelling phase, rendering it particularly suitable for system-level analyses. In contrast, the LCSA assessment approach, presented by Guinée et al. (2011), is more effectively applied at the product level, where discrete sustainability performance metrics are required.

It is important to recognize that LCA, LCC, and S-LCA differ in methodological development, data availability, and analytical maturity. These discrepancies require methodological alignment and tailored considerations to ensure coherent sustainability assessment. Significant methodological challenges persist across various stages of LCSA, including the definition of goal and scope, the selection of appropriate indicators, and the integration and interpretation of results. For instance, the identification of suitable indicators for the social dimension remains a particularly complex issue due to the absence of standardised selection criteria (Zanchi et al., 2021).

Following the identification of methodologies for assessing impacts across the three pillars of sustainability (environmental, economic, and social), it becomes particularly relevant to investigate their application within the packaging sector. To this end, a review of 25 peer-reviewed publications (FuturE-Pack, 2024) revealed that LCA is the most frequently discussed topic (14 mentions), followed by LCSA (9 mentions); in contrast, S-LCA and LCC are rarely addressed, with only one mention each. The analysis of application fields shows that food packaging is the most recurrent sector across multiple topics, especially LCA and LCSA, followed by the fashion industry. Though other sectors are less frequently studied, they contribute to the diversity of the research landscape.

From a temporal perspective, publications increased steadily from 2000 to 2021, with a peak in 2021. A slight decline in publications is noted from 2021 to 2023. Geographically, Italy and Canada are leading contributors. Italian research focuses largely on food packaging and automotive, while Canadian studies span all major categories. The fashion industry is addressed in various countries, including Australia, Austria, Canada, Sweden, and the UK. Scientific journals are the dominant publication type, accounting for 72% of the analysed works. These journals primarily focus on LCA, particularly in food and fashion sectors. The LCSA method is gaining traction across multiple fields, reflecting its potential as an integrated approach to sustainability assessment (FuturE-Pack, 2024).

4.2. Methods and tools for assessing packaging sustainability

Quantitative methods with standardised metrics can be integrated with qualitative tools during the design and evaluation phases to strengthen analysis. Qualitative evaluation (e.g., S-LCA) explores subjective nuances that numbers alone cannot capture. This perspective is crucial, as it relates to the allure and visual storytelling of a product. Packaging often represents a brand's first impression on the consumer, making it vital to invest in thoughtful, distinctive designs and a robust brand identity. These elements serve a dual purpose for manufacturers; they not only express the brand's core values (including environmental sustainability, luxury, and artisanal craftsmanship) but also elevate the overall user experience (Lindh et al., 2016). Well-designed packaging can foster customer satisfaction and pave the way for deeper brand loyalty. Moreover, for packaging to truly resonate, it must excel in ergonomics and usability. Consider how effortlessly it can be opened, securely closed, and comfortably held. Each tactile interaction forms a critical part of the consumer experience. Finally, regulatory and cultural nuances must also be considered, ensuring that packaging aligns with legal standards and resonates appropriately with regional symbols, colours, and messaging. These factors are not just details; they are the threads that weave a compelling narrative for both the brand and its consumers.

Mixed *quantitative-qualitative approaches* aim to integrate these dimensions, generating contextual and cross-disciplinary insights that embrace the inherent complexity of packaging design. Compared to purely numerical methods, these hybrid tools offer enhanced flexibility, contextual sensitivity, and interpretative depth. They reinforce co-design processes by actively engaging stakeholders, supporting the development of more contextually appropriate and collectively defined solutions. Rather than seeking definitive or universally applicable answers, such tools are intended to elicit multidimensional frameworks, promote reflective judgement, and foster more responsible innovation practices.

Within this framework, an in-depth analysis was conducted on 112 case studies of methods and tools used in packaging design and evaluation. The selected sample includes 59 cases developed specifically for packaging analysis and 53 derived from broader design domains, adaptable to sustainability and innovation-oriented contexts. The former are primarily focused on quantifying *tangible impacts*, particularly those associated with environmental and economic performance (e.g., carbon footprint of materials and processes, component recyclability, logistical efficiency, and end-of-life scenarios). The latter support decision-making throughout the entire design process, with a focus on *intangible impacts* such as consumer perception, brand coherence, ethical values, aesthetic quality, and stakeholder engagement. These aspects are particularly relevant to defining desirability, usability, and social acceptance, especially in highly symbolic and rapidly evolving sectors, such as food, cosmetics, fashion, and e-commerce.

The identified methods and tools are characterised by high heterogeneity and typological diversity. Available in analogue, digital, or hybrid formats, they include a broad range of operational solutions, including toolkits, guidelines, software applications, digital platforms, checklists, and other design support mechanisms. Their application spans the full design life cycle, from exploratory and conceptual stages to execution and implementation. Their adoption is driven by various operational aims: supporting design development, critically evaluating design alternatives, communicating outcomes, and, complementarily, informing and sensitising involved stakeholders. These functions are supported by diverse modes of use and interaction: tools may be static, dynamic, or interactive; intended for individual or collaborative use; and equipped with interfaces that vary in terms of accessibility and complexity. A further distinctive parameter lies in the adopted communicative register, which may range from technical-scientific formats aimed at rigorous data analysis and validation, to more educational or dissemination-focused modes intended to reach broader audiences. According to their intended objectives, these methods and tools generate a variety of outputs, including quantitative data, simulations, conceptual maps, analytical reports, interactive games, and participatory formats.

Taken together, these characteristics contribute to outlining the potential positive impact of such tools across environmental, social, and economic dimensions. In some cases, a high degree of sectoral or material specialisation is evident, with tools specifically designed for certain application contexts or materials with technical properties. Within this evolving methodological landscape, several trajectories are emerging that are reshaping the role and potential of tools supporting packaging design and impact assessment. A clear trend is the growing integration of technological, participatory, and systemic dimensions.

Digital transformation represents one of the main drivers of change. The adoption of online platforms, simulators, interactive repositories, and collaborative software enhances both the accessibility and effectiveness of methodological resources, facilitating decision-making through the dynamic integration of visual content, data, and feedback. PackExpert, developed by Smurfit Kappa,[1] is a tool that enables the virtual simulation of optimised logistics scenarios, helping to reduce waste and minimise errors across the supply chain. Similarly, tools used in digital design, such as Figma,[2] are increasingly repurposed for packaging contexts, offering advanced real-time collaborative prototyping capabilities.

Another strategic direction involves strengthening co-design processes and actively engaging stakeholders. Many tools adopt a modular, flexible, and scalable structure, designed to facilitate interaction among designers, users, clients, and local communities. The Community Branding Co-Design Toolkit[3] encourages the emergence of shared visions through structured collaborative pathways. Similarly, more narrative and visual approaches, such as Design the Life You Love,[4] focus on emotional and creative engagement, fostering in-depth reflection on the values and expectations of those involved.

Design flexibility is another key dimension. Many tools are conceived to adapt to various contexts, sectors, and levels of complexity. Innovation Tactics,[5] for example, offers a broad set of techniques applicable across different scenarios, supporting ideation and tailoring solutions to specific operational needs. Their modular configuration enables independent or integrated use, facilitating their incorporation into broader and non-linear workflows.

Beyond supporting design decisions and generating alternatives, many tools play a key role in structuring and documenting design processes. For instance, Packaging Design Archive[6] at the Politecnico di Milano provides a structured collection of case studies and visual references, supporting comparative analysis and the dissemination of best practices. Similarly, the Packaging Innovation Observatory[7] at the University of Bologna (see Chapter 2), in addition to offering a database of innovative packaging projects, promotes a sustainability-oriented innovation culture by fostering dialogue between academic research, industry, and education.

A further expanding domain concerns the shift towards systemic sustainability. This encompasses environmental considerations (such as improved recyclability or waste reduction), as well as social and economic implications. Tools like Circular Packaging Assessment Tool[8] and RecyClass[9] offer methodological frameworks and practical guidelines for evaluating materials, processes, and end-of-life strategies, aligning design development with circular economy principles.

Equally relevant is the increasing sectoral and material specificity of many tools. Some are explicitly designed to meet the requirements of highly regulated or fast-moving sectors, for example food, cosmetics, fashion, or e-commerce, or to evaluate materials with specific technical and regulatory characteristics, such as plastics, paper, glass, or textiles. In this regard, *Osservatorio Packaging del Largo Consumo* (Large-Scale Retail Packaging Observatory)[10] and IdentiPack[11] provide updated benchmarks, trend scenarios, and regulatory monitoring tools that support strategic design decisions.

The diversity and richness of the tools analysed reflect the growing complexity and interdisciplinarity of contemporary packaging design, as well as the urgent need for comprehensive, accessible, and adaptable methodological approaches. Therefore, the integration of quantitative and qualitative dimensions enhances the capacity to assess both tangible and intangible impacts, promoting a systemic, participatory, and reflective approach to innovation in packaging. These tools should not be regarded as mere operational supports but as strategic mediators capable of guiding practices, aligning values, and facilitating the transition towards more sustainable design models.

4.3. Design principles for circular and sustainable packaging

The progressive integration of quantitative and qualitative methods for impact assessment, as previously outlined, provides the basis for defining criteria that steer packaging towards sustainability and circularity. Metrics and tools enable performance measurement, whereas these criteria operate as frameworks that translate analytical outcomes into actionable design strategies. Historically, such principles have evolved alongside shifts in design thinking. Early approaches, rooted in eco-efficiency during the 1990s (Schmidheiny, 1998; Schaltegger, 1990; DeSimone & Popoff, 2000), emphasised material reduction and process optimisation. The diffusion of life cycle thinking in the 2000s introduced strategies such as *design for recycling* and *design for disassembly* (Zussman et al., 1994; Favi & Germani, 2014), broadening the scope to include end-of-life scenarios (Figge & Hahn, 2004; Krajnc & Glavic, 2003). The rise of the circular economy in the 2010s expanded this vision (Zhu et al., 2022; Hellweg & Milà i Canals, 2014), encouraging practitioners to situate packaging within wider industrial and socio-technical ecosystems, where consumer perception and emotional engagement became critical to acceptance.

Today, under frameworks such as Transition Design (Irwin, 2015; 2018) and Industry 5.0 (Xu et al., 2021), design criteria are increasingly systemic and anticipatory, integrating environmental, economic, and social considerations with the aim of enabling long-term transformation. Within this trajectory, designing sustainable packaging requires more than the adoption of environmentally friendly materials or the reduction of production impacts. It implies the definition of reference frameworks capable of guiding decision-making throughout the entire life cycle of packaging, from conception to end of life (Pathan & Aurisicchio, 2025). In this sense, these principles operate as translation devices within a conceptual framework, guiding the interpretation of assessment outcomes and their application in design decisions (Liu et al., 2023). Quantitative tools such as LCA or carbon footprint analyses provide measurable evidence of performance, enabling comparison and priority-setting. At the same time, qualitative approaches, focused on user perception, cultural meaning, or emotional response, reveal aspects that numbers alone cannot capture but that are decisive for acceptance and long-term success (Viglia et al., 2013).

Regulatory frameworks actively support this approach. The EU's recently enacted *Packaging and Packaging Waste Regulation* (PPWR) (European Parliament & Council of the European Union, 2025) establishes mandatory requirements across the entire packaging life cycle. By 2030, all containers placed on the EU market must be designed for recyclability, incorporate minimum shares of recycled content, avoid unnecessary layers and harmful substances, for example PFAS, and promote reuse and refill systems, as well as transparent labelling to facilitate effective consumer sorting and awareness.

The convergence of these perspectives fosters the emergence of *quali-quantitative design criteria* (Krippendorff, 2006), as demonstrated by the case studies analysed, marking a shift from isolated metrics to systemic evaluation. Packaging is no longer understood as a static container, but as a dynamic interface between product and consumer, industry and environment, regulation and market (Ciravegna, 2010; Ciravegna, 2017). In this context, design principles ensure that sustainability is not viewed as an external constraint or an afterthought; instead, it becomes an intrinsic quality of the packaging system. This means that environmental and social considerations are integrated from the outset of the design process, influencing materials, functions, and interactions consistently. At the same time, sustainability is conceived as an anticipatory quality, in the sense that design decisions are both responsible for current requirements and oriented towards future scenarios, adapting to evolving regulations, emerging user behaviours, and long-term ecological challenges.

A concrete example of how such design principles can be operationalised is provided by the *Guidelines for facilitating the recycling of steel packaging*,[12] developed within the *Progettare Riciclo* initiative[13] promoted by CONAI (see Chapter 2). Conceived as a *meta-design tool* (Ciravegna et al., 2024), these guidelines do not prescribe ready-made solutions but offer a structured framework that helps designers and companies verify, compare, and align their decisions with sustainability objectives. Their development was characterised by a strong collaborative dimension, involving the Advanced Design Unit[14] of the University of Bologna, RICREA consortium,[15] and ANFIMA association,[16] thereby ensuring the active participation of different actors along the steel packaging value chain. To support implementation, a checklist was created as an operational device, translating complex assessment outcomes into a set of practical and understandable questions (ranging from material selection and logistics optimisation to recyclability and consumer usability).

Therefore, the guidelines serve as a cognitive bridge and represent an evolution of the concept of boundary objects (Star & Griesemer, 1989; Vinck, 2011). They facilitate collaboration among diverse stakeholders by presenting sustainability challenges and introducing new design criteria. This statement underscores the critical importance for designers to employ qualitative assessment tools that effectively capture cultural meanings, user perceptions, and relational dynamics—elements that quantitative metrics may overlook. By doing so, we can develop packaging solutions that are both technically sustainable and socially meaningful. Building on these examples, another tool worth mentioning is the sustainability assessment framework developed at the Politecnico di Torino and applied in design education in the course *Requisiti ambientali del prodotto*, which was developed in the context of the *Osservatorio Eco-Packaging* (OEP) (Barbero & Tamborrini, 2018). Conceived as a pedagogical framework, it enables the evaluation and comparison of designed solutions of the same type by integrating quantitative indicators, such as material efficiency, recyclability rates, or carbon footprint, with qualitative assessments concerning usability, communicative clarity, and perceived value.

This dual perspective moves beyond approaches that rely exclusively on numerical metrics or user perceptions taken in isolation, providing a more comprehensive understanding of packaging performance (Vicente & Camocho, 2024). The framework considers packaging across its entire life cycle, assessing recycling potential and resource efficiency, while also acknowledging its communicative role by highlighting the importance of end-of-life information, message clarity, and environmental certifications. The synthesis of these observations facilitates comparative evaluations of different solutions, grounding design decisions in both empirical evidence and qualitative insights and making trade-offs more transparent.

The adoption of tools such as sustainability guidelines, checklists, or evaluation matrices highlights both the strengths and limitations of meta-design tools in packaging innovation. Operational clarity is one of the most appealing advantages, as it allows abstract sustainability goals to be translated into clear and verifiable questions. This provides designers and companies with a straightforward roadmap. To achieve this, a shared language is essential; it enables stakeholder alignment, reduces misunderstandings, and promotes interdisciplinary collaboration. Another crucial aspect is scalability and replicability, which ensure broad accessibility for companies. Additionally, these tools contribute to organizational learning by raising sustainability awareness throughout the supply chain.

However, there are risks associated with these tools. They can oversimplify complex assessments, potentially obscuring systemic interdependencies. This may lead to context dependency, making it difficult to capture industry-specific or cultural variables. Furthermore, the rapid evolution of packaging sustainability presents a challenge, as the static nature of these tools can quickly become outdated if not regularly reviewed. From a meta-design perspective, the advantages and limitations of sustainability tools highlight the importance of viewing them not as rigid prescriptions but as flexible frameworks. Their true value lies in fostering reflection, facilitating dialogue, and guiding design choices, all while remaining adaptable to iteration, contextualisation, and integration with more advanced qualitative and quantitative assessment methods. Consequently, the challenge for designers is to incorporate these tools into their practice. By leveraging qualitative and quantitative assessments, designers can navigate complexity, mediate among various stakeholders, and actively help position packaging as a key driver of sustainable transition.

4.4. From impact assessment to design strategies

A detailed and systematic evaluation of packaging design, which integrates quantitative metrics and qualitative insights, is crucial for achieving multiple objectives. This evaluation ensures that packaging is not only effective in preserving and protecting products but also efficient in minimising waste and resource consumption. Additionally, it should be sustainable, considering environmental impacts and recyclability. Moreover, it is essential to align packaging with commercial goals (such as brand recognition, marketability, and customer preference), technical specifications regarding production and functionality, and communication objectives that convey key messages to consumers. Using these varied approaches allows companies to make informed decisions that enhance their packaging strategies, ultimately maximising their impact in the market and ensuring a better experience for the consumer. This approach fosters loyalty and encourages repeat purchases.

Rettie and Brewer (2000) state that 73% of purchase decisions are made at the point of sale. When scanning packaging at this stage, perceptions occur rapidly, making quick recognition crucial for decision-making. Research indicates that verbal stimuli are more effectively processed when perceived on the right side, while nonverbal stimuli are better understood when seen on the left. This advantage likely stems from the brain's lateralisation; the left hemisphere generally handles word processing, whereas the right is more adept at processing visual information. Lombardi et al. (2024) examine the factors influencing packaging selection, emphasising the role of emotions among a representative sample of Italian consumers. Emotions significantly shape consumer intentions and behaviours, suggesting that marketing strategies should target consumers' emotional responses. These strategies should also address cognitive concerns and highlight the benefits of sustainable packaging.

Author role acknowledgement: This chapter is the result of a collective effort by all Authors. Specific contributions are acknowledged as follows: Section 4.1. was authored by C. A. Dattilo and M. Delogu; Section 4.2. by C. A. Dattilo and L. Filippini; Section 4.3. by V. Pasini and M. Spinelli; Section 4.4. by C. A. Dattilo.

Notes

[1] https://www.smurfitkappa.com/it/innovation/tools/packexpert
[2] https://www.figma.com/
[3] https://www.figma.com/community/file/1084513568357198052
[4] https://www.aysebirsel.com/book
[5] https://pipdecks.com/products/innovation-tactics?srsltid=AfmBOoqvr9l-RpN8uaAiWJZ1b8RCWUZ5gBwDfJ1PSF8K4ieE_HsH-GUEo
[6] https://adu.unibo.it/osservatoriopack/
[7] http://www.packagingdesignarchive.org/
[8] https://recyclingpartnership.org/circular-packaging-assessment/
[9] https://tool.recyclass.eu/it
[10] https://www.nomisma.it/soluzioni/ricerca/osservatori-on-demand/osservatorio-packaging-consumo
[11] https://osservatorioidentipack.it
[12] https://www.progettarericiclo.com/en/docs/guidelines-facilitating-recycling-steel-packaging
[13] https://www.progettarericiclo.com/
[14] https://site.unibo.it/advanceddesignunit/
[15] https://www.consorzioricrea.org/en/
[16] https://anfima.it/en/anfima-en/

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