DESIGN FOR RECYCLING GUIDELINES OF PAPER-BASED PACKAGING – A REVIEW FOR PACKAGING DESIGNERS

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Abstract: *Circular Economy requires products and material resources to be efficiently managed and used. For packaging, recycling is crucial to close the loop. Hence, packaging designers must balance pack performance, morphology, and communication to ensure its recyclability. This is particularly true for fibre-based packaging, which is the prevalent market packaging material, forecasted to increase its usage volumes. To help designers in their activities, several bodies provided Design for Recycling Guidelines (DGs). In this work, national and European DGs are discussed, providing shared design rules ranging from the substrate and its surface treatment to the packaging components. Such design rules can enable designers' creative process and enhance the exploration of new, efficient packaging solutions. Consequently, packaging designers may achieve a broader view and play an active role in extending fibre life time; hence, reducing landfilling or energy-recovery of valuable fibres.*

Keywords: Design for Recycling, Packaging, Design Guidelines, Circular Economy, Paper and board.

1 INTRODUCTION

Governments and institutions have been demanding industrial companies to innovate packaging materials and production systems due to, e.g., single-use plastics ban and reuse enforcing schemes. However, depending on the application, packaging – specially paper-based packaging – may not be readily reusable or remanufactured, making recycling the most viable choice. Within Europe, paper and board packaging represents – with 40.9% – most of the packaging waste (Eurostat, 2020). However, looking at recent data, paper-based packaging recycling rate seemed to slightly decrease (EPRC, 2021, 2022). This might be associated to increasing multi-material paper-based packaging that is placed on the market; indeed, polymeric films, coatings, and components are generally non-cellullosic materials that end as rejects, reducing recycling yield. To guide the packaging designers in the Design for Recycling perspective, Design for Recycling Guidelines (DGs) were sometimes provided by recycling bodies as best practices to facilitate end-of-life material recovery. Such DGs represent the baseline for an aware packaging design, responding to "containment" needs, to valorise aesthetics, usability, and expressivity of packaging (Ciravegna, 2017; Giardina and Celaschi, 2020) without compromising the material recyclability. According to the specific application, packaging can impact on the Global Warming Potential more than the content itself (Licciardello, 2017). Aiming to sustain the recycling rate of paper-based packaging, in this study the authors analysed and systematised the white literature provided by the major European paper and cardboard recycling bodies, confederations, and associations. By doing so, this works aims to bridge industrial constraints and professionals' activities. Finally, common guidelines suitable for an EU-wide application were defined to help the design of packaging that eases the recycling process further helping recycling targets (European Parliament and Council, 2018).

2 MATERIAL AND METHODS

DGs were retrieved from European bodies involved in the paper-packaging recycling stream. Therefore, members of the PRO Europe (https://www.pro-e.org/) were – among others – investigated. In particular, documents covering six countries across Europe and three documents published by bodies referring to the European territory were retrieved (Ecodesign guidelines paper and board Packaging, no date; FostPlus, no date; ECOEMBES, 2017; Cepi, 2020; Marinelli, Santi and Del Curto, 2020; ARA, 2022; CEREC, 2022; CPI, 2022; FTI, 2022; 4evergreen, 2023). DGs were investigated to systematise recommendations according to several factors, as reported in Figure 1. A dual classification was followed, distinguishing between "Packaging Factors" and "Content Factors". Packaging factors refer to bulk substrate, surface of the substrate, and even to packaging accessories, whereas "Content Factors" affecting recyclability are essentially two: either the presence of residual content or surface contamination. DGs were filtered to refer to standard paper mills, which differ from special paper mills since the latters are designed to cope with packaging that is more difficult to be recycled.

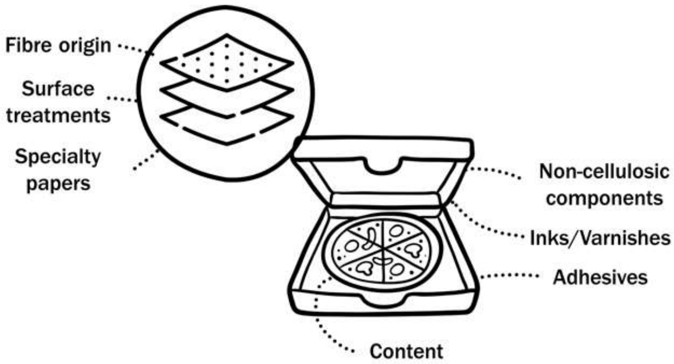

Figure 1. Main topics affecting recyclability.

3 RESULTS

Packaging designers' intrinsic role depends on designing formal, functional, as well as specific features like aesthetics, affordance, accessories, and possible barrier films and coatings. Such features can impact on migration, which can occur from the content to the packaging, from the packaging to the content or both ways. The topics covered by the retrieved DGs that should be addressed in the packaging design phase are reported in Figure 2. All the references discussed adhesives as well as inks and varnishes, followed by laminates, multi-layers, and non-cellulsoic components. On the contrary, only few DGs included topics such as fibre origin, contaminations, and specialty papers.

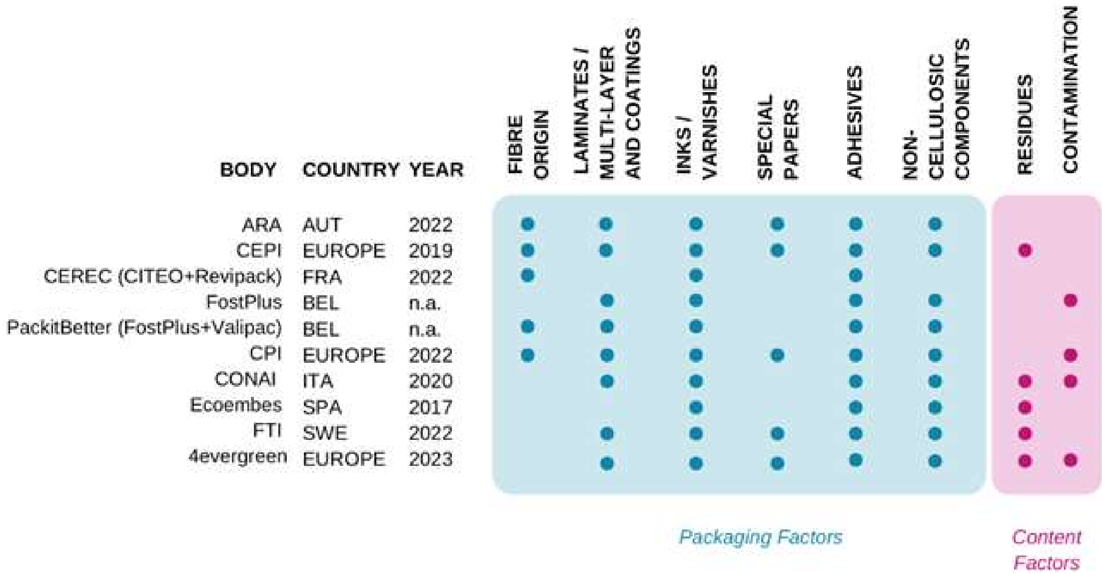

Figure 2. Topics covered by the Design for Recycling guidelines across different Institutional bodies.

3. 1 Results: Packaging factors

3. 1. 1 Fibre origin

The feedstock used to make paper is usually wood. However, some countries explored the use of different feedstocks (Laftah and Rahman, 2015). Fibres from different plant species differ in cellulose, hemicellulose, and lignin content, among other substances. Being cellulose the most important constituent of paper-based products, pulp feedstock affects possible chemical processing, mechanical processing, or a combination of the two to remove unneeded substances. Both the process and pulp feedstock determine fibre length, branching, colour, and mechanical properties. Therefore, depending on the use, the designer needs to clearly consider both the functional and aesthetic properties of the packaging to select the proper grade. DGs aren't univocal about such topic, yet a general guideline might be to prefer wood fibres against alternative sources, since the latters might not be readily recyclable or lead to poor Secondary Raw Material (SRM) quality. The use of non-wood fibres should be based on proven recyclability.

3. 1. 2 Surface treatments (Laminates, Multilayers, Coatings, and Transfer foil)

Packaging barrier is of highest concern when it comes to perishable goods such as food. To cope with paper's lower barrier properties to both gasses and liquid/oils, polymers and/or aluminium is generally used in film form and (co-) extruded or laminated (using adhesives) onto paper. Additionally, aqueous dispersion technology proved to be viable alternative, providing lower non-cellulosic content for similar barrier properties (Marinelli, Diamanti, *et al.*, 2023). Improved barrier is required due to food higher environmental burden compared to packaging one (Licciardello, 2017; Licciardello and Piergiovanni, 2020). Multiple layers might be used to sum single materials' barrier. Additionally, a polymeric layer may work as sealant for specific applications (Marinelli, Profaizer, *et al.*, 2023). Main lamination and extrusion coating materials are PE, PP, and PET. Recently, the use of biodegradable, compostable, and/or biobased polymers gained strong interest from both the industry and research (Khwaldia, Arab-Tehrany and Desobry, 2010; Peelman *et al.*, 2013), as well as nanomaterials (Li, Mascheroni and Piergiovanni, 2015; Herrera, Mathew and Oksman, 2017). The main issue with surface treatments is that they are generally insoluble non-cellulosic materials, hence they lower the overall quality of the SRMs if proper separation doesn't occur in the pulping stage. Therefore, given packaging's functionality, DGs agree on minimising polymeric content, as well as avoiding polymeric layers on both sides of the substrate−they prevent water from reaching packaging fibres, requiring higher temperature or processing times to countereffect recycling yield reduction. Things might change when considering peelable solutions, which should be clearly communicated to the consumers for their call-to-action. Cepi harmonised European and UNI 11743 recyclability laboratory test methods request the packaging to produce minimum amounts of coarse and fine rejects. Many DGs agree that the maximum amount of non-fibrous material should be lower than 5% w/w.Finally, several DGs discuss foil transfer technology, whose covering area should be minimised to avoid scanning errors at the near-infrared selector at a sorting facility. About metallic layers, 4evergreen reports how metallised layer whose thickness is <1 μm do not affect recyclability.

3. 1. 3 Specialty papers

Specialty papers include silicone, wax, and bitumen papers, as well as cigarette and photography paper. Specialty papers can be produced using special chemicals in bulk or as a coating to implement properties in, e.g., release liners, grease-proof papers, and performant printable substrates. The main issue with specialty papers is that they are hardly recyclable; indeed, they usually need higher pulping time and temperatures to let defibring occur. Therefore, only special paper mills can recycle them, requiring specific collection and selection systems. Generally, DGs agree on limiting the use of specialty papers; in particular, they suggest avoiding the use of silicone and wax papers.

3. 1. 4 Adhesives

Adhesives lay in between layers of mono or multimaterial sandwiches. The nature and application parameters differentiate adhesives, i.e., hot-melt adhesives require heat before being applied, starch-based adhesives need water evaporation, whereas pressure-sensitive adhesives need pressure to adhere. Being non-cellulosic in nature and possibly leading to micro- and macro-stickies possibly machine downtime, their use is generally considered to be minimised. Generally, DGs stress on few, but broadely agreed factors: if hot-melt adhesives are used, it should be guaranteed that they do not fragment into pieces smaller than ~2 mm in diameter (4evergreen provides specific information depending on final application) so that mechanical screening can intercept them; additionally, particular attention should be given to their softening point, which should be generally higher than 70°C (although CONAI guidelines report 45°C as limit, and Ecoembes 65−80°C range). Emphasis is given to water-soluble adhesives, which are widely regarded as preferrable solutions. However, some pointed out that they might accumulate in the water circuit and increase Chemical Oxygen Demand (COD). Indeed, soluble content is considered in Cepi’s European harmonised recycling lab test method. Finally, pressure-sensitive adhesives are generally regarded as avoidable since have higher persisting rate in the recycling facility.

3. 1. 5 Inks and varnishes

Inks are generally used to convey meaningful information to the user/consumer, to stand out once exposed on shelves (if applicable), and to comply to regulations and labelling requirements. EuPIA association provided information and guidelines about inks and their safety which are encouraged to be followed. Due to marketing reasons, several colours as well as heavily printed substrates are, unfortunately, common. Despite not affecting the recycling pocess *per se*, such artefacts reduce the optical homogeneity of the SRM. Indeed, heavily inked packaging should undergo a deinking process. Therefore, DGs agree on optimising – i.e., minimising – ink content. Additionally, it is broadly reported to avoid mineral oils since can migrate from recycled food packaging to food. Very thin varnish layers aren't usually used to improve barrier properties; on the contrary, they improve, e.g., printability, opacity, and roughness. UV-cured varnishes require a specific focus; indeed, they are not readily removed by conventional paper mills, possibly ending up in the SRM and causing flecking. Hence, UV varnishes should be avoided and used only if needed.

3. 1. 6 Non-cellulosic components

Paper-based packaging sometimes needs functional components that are polymeric. Examples are transparent windows that allow to see the content, caps, zippers, and sometimes handles and tape. Metallic accessories like grafts may be included, too. Despite cellulose-derivatives such as cellulose acetate − featuring optical transparency − were sometimes used, it should be considered that such material underwent chemical modification that do not allow a paper mill to recover fibres, since they exist no more. Moreover, the density of non-cellulosic components should not be in the $0.95 \div 1.15$ g/cm^3 range, as reported by CPI. Non-cellulosic components increase coarse rejects, reducing paper mill recovery yield. Additionally, it is widely reported how such accessories, once they become waste, are often energy-recovered. Generally, DGs suggest their use should be limited, preferring peelable solutions. If peelable solutions are adopted, consumers' call-to-action must be clear.

3. 2 Results: Content factors

The content and the packaging interact each other. Issues related to the content that may affect the recyclability relate to the content migration on the substrate, as well as entrapped content residues in the packaging. This is especially true for food packaging application, as well as for other fields, e.g., packaging for powders and granules for industrial use. Solid residues increase reject fraction and might end in the SRM. Instead, water-soluble substances may impact on the, e.g., COD and filtering system, which are critical elements since paper mills generally operate in almost-closed water circuits.

DGs report how it is crucial designing packaging that optimises its emptying. Therefore, depending on the content nature, packaging designers should enable consumers and communicate them to easily empty the packaging from residues. However, contamination includes even stains, especially for food packaging. Stains are due to oil and grease. As a rule of thumb, light staining is still acceptable, though higher degrees might lead to microbial growth. Interestingly, CONAI reported that heavily stained food packaging (or with high amounts of food residues) should be designed to make it compostable – according to existing regulations – instead of recyclable in the paper stream.

4 DISCUSSION: THE DESIGNER CONTRIBUTION

Packaging functionalities include content protection, transportation, handling, and presentation to the consumer. However, there are several possible issues that reduce packaging recyclability and SRM quality. Monomaterial packaging – whether cellulosic or polymeric – should be preferred since it is easier to recycle and provides higher recycling yields. When this isn't possible, experienced designers with a broad overview of the recycling processes can design solutions implementing, e.g., material separation (Figure 3.a). Involving recycled content in the chosen substrate limits virgin material use, hence reduces felling operations. Additionally, recycled content could represent an interesting opportunity to explore new packaging aesthetics (Figure 3.b), playing with the texture to convey perceptual information.

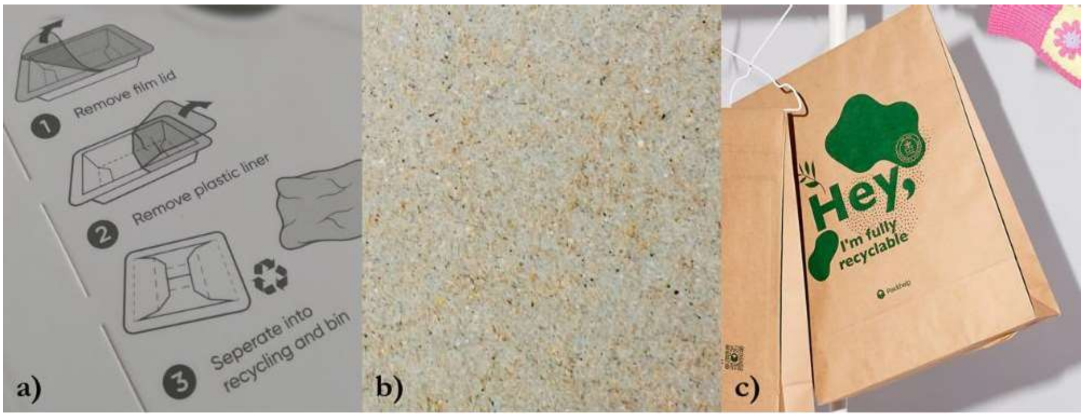

Figure 3. Communication and aesthetical properties of packaging. From left to right: a) Example of communication on how to confer peelable packaging; b) Recycled paper aesthetics; c) Paper bag graphic engaging customers attention on recyclability.

DESIGN FOR PAPER PACKAGING RECYCLING GUIDELINES

	GUIDELINE	WHAT TO LOOK AT?	WHY IS IT CRITICAL?	CHECKLIST	DESIGN FEATURES
Packaging Factors	***CONSIDER*** FIBRE ORIGIN	• CELLULOSE CONTENT • RECYCLED CONTENT (IF APPLICABLE)	• POSSIBLE POOR RECYCLABILITY IN STANDARD MILLS	• PREFER WOOD FIBRES • IF POSSIBLE, PREFER HIGH RECYCLED CONTENT	• FIBRE COLOUR • MECHANICAL PROPERTIES
Packaging Factors	***ANALYSE*** SURFACE TREATMENTS	• LAMINATES, MULTILAYERS	• INCREASE REJECTS • PREVENTS WATER FROM REACHING THE FIBRES	• MAX. 5% BY WEIGHT (CUMULATIVE) • NO DOUBLE-SIDED LAMINATIONS OR MULTILAYERS	• BARRIER PROPERTIES
		• COATINGS	• NON-CELLULOSIC CONTENT THAT MAY ACCUMULATE IN THE WATER • INCREASE REJECTS • PREVENTS WATER FROM REACHING THE FIBRES	• MAX. 5% BY WEIGHT (CUMULATIVE) • NO DOUBLE-SIDED LAMINATIONS OR MULTILAYERS (IF WATER-REPELLENT)	• BARRIER PROPERTIES • PRINTABILITY • FINISHING
		• TRANSFER FOIL	• WORSENED MATERIAL DETECTION • INCREASE REJECTS	• MAX 60% OF THE AVAILABLE SURFACE	• COMMUNICATION AND MARKETING; GRAPHICS
Packaging Factors	***AVOID*** SPECIALTY PAPERS	• SILICONE, WAX, BITUMEN PAPERS, PHOTOGRAPHY PAPERS...	• ·REQUIRE RECYCLING IN UNCONVENTIONAL PAPER MILLS	• AVOID SPECIAL PAPERS	• SPECIAL APPLICATION OR SPECIFIC PROPERTIES TO BE ACHIEVED
Packaging Factors	***MINIMISE*** ADHESIVES	• PARTS OR LAYERS TO BE JOINED	• ADHESIVES MAY LEAD TO MICRO- AND MACRO-STICKIES • ADHESIVES ARE NOT FIBROUS MATERIALS	• PREFER, IF POSSIBLE, MECHANICAL INTERLOCKING • PREFER WATER-SOLUBLE ADHESIVES • HOT-MELT: MIN. PLASTICISING TEMP. RANGES 35÷70 °C	• MECHANICAL INTERLOCKING • FOLDING ALTERNATIVES • ALTERNATIVE SHAPES
Packaging Factors	***LIMIT*** INKS AND VARNISHES	• COMMUNICATION AND MARKETING	• INKS REDUCE OPTICAL HOMOGENEITY IN THE SRM	• FULFILMENT OF THE LABELLING REQUIREMENTS • CONSUMER INSTRUCTION • AVOID HEAVILY PRINTED AREAS • AVOID UV VARNISHES • NO MINERAL OIL IN THE INK FORMULATION	• GRAPHICS PRIME MATTER
Packaging Factors	***REDUCE*** NON-CELLULOSIC ELEMENTS	• PACKAGING ACCESSORIES	• INCREASE REJECTS	• MAX. 5% BY WEIGHT (CUMULATIVE)	• AVOID UNNECESSARY ACCESSORIES
Content Factors	***ANALYSE*** PACKAGING CONTENT	• (POSSIBLE) CONTENT CONTAMINATION	• NON-CELLULOSIC CONTENT THAT ACCUMULATES IN THE WATER • INCREASE REJECTS • MICROBIAL GROWTH	• EASY EMPTYING • PEELABLE LAYERS	• PACKAGING MORPHOLOGY

Figure 4. Design for Recycling guidelines and prompt to support paper-based packaging design.

It is worth to stress once again how the design process should consider each of the analysed topics, still including both the role of the end consumer, communication (Figure 3.c), and packaging affordance, striving for a holistic approach. It is not the aim of the authors to include here a complete analysis of consumer behaviour on proper waste sorting. Nevertheless, correct consumer actions must be encouraged with clear instruction, otherwise all the previous argumentation is pointless. Therefore, environmental labelling and graphics should be carefully designed, too. Since packaging producers market generally crosses a single country's border and their packaging should adapt to different collection and recycling streams, the authors tried to systematise DGs to determine a comprehensive checklist of DGs to guide packaging designers to properly assess paper and cardboard projects entering the EU market in the recycling perspective (Figure 4). The provided tool merges the guidelines provided by the European bodies with the previous considerations, highlighting in the last column the features that packaging designers may undertake to develop new paper-based packaging that fosters material recyclability.

5 CONCLUSIONS

As designers are involved in packaging design, several factors should be considered, ranging from the substrate, up to the communication functions. Nothing should be left to chance, especially when it comes to recyclability. The tool here proposed may pave the ground for shared knowledge. On the one hand the guidelines set constraints, while on the other one they should be considered as stimuli to rethink the packaging. Therefore, packaging designers may become innovators embracing both aesthetic and functional features, yet being aware of the effects that any decision in the design process produces in the end-of-life of the product. Nevertheless, the packaging must ensure its functionality in protecting and enhancing the shelf life of the content, as well as conveying information to the consumer. Recycling must be evaluated with specific regulations, though it will not work if the consumer is not aware of its fundamental role, as well as the packaging designers in their activities. Future works on the topic could include integration of new literature, both white and scientific, to update and widen the DGs tool.

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