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ScienceDirect

Procedia CIRP 122 (2024) 647–652

www.elsevier.com/locate/procedia

31st CIRP Conference on Life Cycle Engineering (LCE 2024)

Closing the Perception-Reality Gap for Sustainable Fresh Food Plastic Packaging

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Abstract

The global discourse surrounding plastics has been marked by a profound perceptual schism, also for plastic packaging in the fresh food industry. The public opinion expresses mounting concerns in terms of such plastic packaging solutions. However, in many cases the unique material properties and the well-established methodology of Life Cycle Assessment (LCA) actually demonstrate the environmental advantage of plastics for food packaging. This paper delves into the chasm between the two perspectives, leveraging empirical evidence to resolve the divide.
While performing both a consumer analysis and LCA, this paper underscores the potential for innovative, yet practical design solutions to harmonise the public opinion with counterintuitive positive environmental impacts. A transformative design solution that centres around the concept of shape and material renewal is proposed. It demonstrates how a simple, yet effective redesign can enhance both the environmental impact and consumer acceptance in the industry for mass-produced fresh food packaging. It emphasises the role of LCE in design, with a focus on the pre-consumer phase. The findings provide a practical approach, emphasising the need to reconcile theory with consumer desires, to forge a sustainable path forward in packaging design.

Keywords: *Packaging Design, Life Cycle Assessment, Design for Sustainability, Sustainable Manufacturing*

1. Introduction

The presence of plastics in our daily lives has become indispensable, including food packaging. However, there is an increasing concern among consumers about the use of plastics, mainly seen in the reports on the use of fossil resources and waste management issues such as pollution, marine litter, or the plastic soup [1], [2]. In recent years, rules and regulations have come into force in the European Union that limit the use of plastics in various applications [3]. However, the controversial results of Life Cycle Assessments (LCA) show the positive impact of plastic packaging solutions compared to other types of materials. Examples can be found in LCA studies of reusable plastic and glass food containers [4], single-use plastic (polyethylene terephthalate - PET) bottles compared to refillable aluminium water bottles [5] or glass bottles for olive oil [6]. Other examples can be found in the comparison of plastic bags and paper or cotton bags [7] and LCA studies of disposable packaging in a business-to-business situation [8] and many more [2].

Interestingly, consumer perceptions have been found to be inaccurate, and inconsistent with LCA results [9]. Research shows that consumers are susceptible to making ineffective environmental choices because they rely on misleading, inaccurate, or naïve beliefs to judge the sustainability of packaging [9]. Manufacturers have to comply with regulations and will respond to consumer demands, which may lead to the presence of greenwashing in the industry [2], [9], [10]. While the practice of greenwashing can appease the consumer and potentially increase the market share of the greenwashed

10.1016/j.procir.2024.02.019

product [10], the practice is misleading to consumers and does not reflect the true environmental commitment of manufacturers.

Despite consumer perceptions, literature (as well as the previously discussed LCA results) suggests that plastics still have a promising position in new food or beverage packaging applications [3]. In particular, the material PET is recommended for these applications due to the unique nature of the material, which allows for food grade recycling opportunities. The misalignment between consumer perception and LCA results instigates the need for a design solution that is truly sustainable and acceptable to consumers.

This paper aims to provide a unifying solution by performing an additional LCA to not only illustrate the most impactful processes, but also to motivate real action at the design stage. This approach is explained through a case study of a specific packaging for a specific product category. The packaging in this case study is a well-known and widely used packaging solution in Europe for food products (e.g. appetisers, fresh and moist spreads and refrigerated foods) in, amongst others, supermarkets: a disposable cylindrical PET packaging. Where other Life Cycle Assessments habitually focus on evaluating the total impact of the product under consideration, this paper emphasises the importance of identifying the impactful processes within the life cycle and actually using them in the redesign. This proposed strategy can significantly reduce the environmental impact, while meeting user and regulatory demands as the focus is now on those impacts that also allow for redesign.

2. Dealing with the Perception-Reality Gap

Interest in sustainability has increased over the years, also for environmentally friendly packaging compared to regular packaging. It is therefore important to design packaging that is sustainable, which can be supported by performing an LCA. However, the packaging should also be perceived as sustainable to benefit the purchase intention of the consumer. Accordingly, redesigning packaging is not just about reducing environmental impact. Consumer preferences should be identified and considered when redesigning a package, especially because the visual appearance of packaging design can influence consumer behaviour. Using these insights, together with real data on what is sustainable, a packaging solution can be created that consumers will buy while reducing environmental impact.

In the case of food packaging, it is the food that is the focus of attention, not the packaging. However, when two products are equally identified, sustainability attributes can determine which product is more likely to be purchased [11]. Consumers are even found to be willing to trade off product attributes for environmentally friendly packaging, with the exception of taste and price [11]. However, consumers' intuitions about sustainability are found to be very imprecise and sometimes even contrary to LCA results [9]. Despite this limited knowledge, consumers do not refrain from forming opinions and consequently mislead sustainable purchasing motivations [9]. Greenwashing is not uncommon in industry, and although it may appease the consumer, it does not benefit the environmental impact. Manufacturers should create packaging with a lower environmental impact, which consumers will buy in order to contribute to a sustainable environment. This requires an understanding of what consumers perceive as sustainable and how this can be communicated in new packaging solutions.

2.1. Consumer research

To verify and expand comprehension of the perception-reality gap, consumer research was conducted. A survey (n=211) was carried out among Dutch consumers (62% female, 38% male, aged 19-75) via an online tool. Initially, participants were presented with a series of selections of packaging for identical food products. They were repeatedly asked to choose their preferred packaging. Through this iterative process, it was possible to analyse the shared perspective of the respondents. Furthermore, a conjoint analysis has been carried out. By deconstructing the product (i.e. packaging) into its various components (e.g. attributes and levels) and presenting a sample group with different combinations, consumer preferences can be inferred. Lastly, open-ended questions were asked to solicit consumers' opinions on (recycled) plastic packaging. The survey results were assessed for consistency and quality and evident outliers were excluded from the research. The results of the consumer analysis, in conjunction with the results of the LCA, could be utilised to develop novel packaging solutions that incorporate sustainability as advocated by the principles of Life Cycle Engineering.

2.2. Results of the consumer research

As the aim of this paper is to stimulate conscious attention to sustainability in the design phase, only those parts of the consumer research that are used in the case study of this paper are highlighted.

Firstly, the research confirms that consumers are inconsistent in their opinions and are easily influenced by generalised information, which in most cases is not even visible in the impact of the packaging.

In terms of materials, there was a preference for food packaging made of paperboard or glass over plastic. However, plastic was preferred for certain product categories. For example, for high moisture foods such as spreads and dips, meat or luxury products such as appetisers. Reasons for this could be found in the visibility of the product due to the transparency of the material, in order to be able to check the quality of the product. The consumer research also shows, in line with existing literature [12], [13], that consumers are more influenced by graphics than by information or packaging shape. No specific shape preference is found, but a 'logical' shape for the packaged product is beneficial. For example, rectangular packaging corresponds to elongated products (e.g. herb stems).

In addition to shape, preference was expressed for uncoloured packaging (e.g. no black plastic or white paperboard) and packaging with labels that clearly communicate sustainability messages (e.g. text or signs). The same was true for discolouration of plastic packaging due to the use of recycled materials. A slight discolouration (with as much transparency as possible) is already accepted, but when notified, even more discolouration is accepted.

3. Life Cycle Assessment

The multidisciplinary field of Life Cycle Engineering provides a foundation that offers valuable insights into reconciling theoretical understanding with the counterintuitive perceptions of consumers. Within this field, LCA is a fundamental tool that enables a comprehensive evaluation of environmental impact. In this case study, an LCA is carried out on four different packaging solutions. A unique strength of LCA is its ability to dissect the entire life cycle and identify the processes with the largest environmental impact. It is the goal of this LCA to identify these processes and use these as a basis for redesign. Taking into account consumer demands, a sustainable path in packaging design can be taken.

3.1. Methodology

The ISO standards 14040:2006 and 14044:2006 [14], [15] explain the definition of the goal, scope, system boundaries, functional unit (FU), the collection of all input and output flows of the system, data analysis, and the quantification and interpretation of the resulting environmental impacts. The LCA was carried out using the Gabi Academic software with the EcoInvent 3.7 database, comparing four packaging solutions:

- Paperboard packaging: paperboard laminated with 10% polyethylene.
- Glass packaging: 60% recycled white glass, 40% new white glass.
- PET packaging: 100% virgin PET
- RPET packaging: 80% virgin PET and 20% recycled PET

It should be noted that the specifications of the plastic (PET and RPET) containers are almost identical, the only difference being the input material. For the RPET container it is theoretically feasible to increase the amount of recycled material in the composition, especially with the current presence of clear (transparent) RPET resulting from recycling of PET bottles. The used recycled PET for the RPET packaging in the LCA however, results from post-consumer waste and is significantly discoloured. Using a share of this recycled material, results in a grey-brown haze present in the transparent packaging. A share of 20% has little or no effect on the visual presentation of the food and is therefore still acceptable. In both the PET and RPET container, 45% of the virgin PET originates from pre-consumer “excess” material, known as trim.

3.1.1. Boundary conditions

The LCA performed is based on a cradle-to-grave principle, to assess the environmental impacts of nineteen midpoints and three endpoint categories. To ensure a consistent and comparable basis for assessing the environmental impact of the different packaging solutions, a functional unit was derived:

“To package 175 grams of fresh vegetable spreads per unit, at a total of 10,000 pieces”.

Logically, the input and output data of a complete product life cycle, as stated in the inventory, can never be fully comprehensive. However, with the defined system boundaries, it is possible to identify processes with significant impact that can be redesigned. Key aspects within these system boundaries are discussed, to provide a complete but concise overview of how the LCA is conducted.

The specifications for the packaging solutions were in line with packaging as seen in practice in Dutch supermarkets. This resulted, for example, in the paperboard packaging being coated with polyethylene to provide a good moisture barrier. According to the rules and regulations in force in the European Union, only certain types of recycled material can be used in plastic packaging under certain conditions.

The end-of-life scenarios for all packaging solutions are based on existing data from Dutch recycling and incineration systems [16], [17], verified by sources from prominent recycling facilities in the Netherlands. Among other things, this resulted in the exclusion of landfill and negligible recycling opportunities for cardboard packaging due to food residues and the plastic barrier, which is currently not recyclable.

The system boundaries included secondary packaging but excluded tertiary packaging. When empty, both the plastic and paperboard solutions could be stacked and are transported in plastic bags (high-density and low-density polyethylene) and cardboard boxes respectively. For the process of getting the product-packaging combinations to the supermarket, refrigerated transport and smaller batch size (n=20) cardboard boxes have been considered. Effects resulting from food waste and a small residue in the packaging were taken into account in the LCA.

As will be shown in more detail in Section 3.2, the plastic packaging containers were found to have a lower environmental impact than the glass and paperboard solutions. Therefore, only the specifications of the plastic containers are listed in Table 1, as these provide the basis for further research.

Table 1. Specifications of PET and RPET container

Capacity	175 grams vegetable spread
Materials	PET container: 100% virgin PET (45% trim) RPET container: 80% virgin PET (45% trim) + 20% recycled PET
Dimensions	Diameter: 115 millimeters Height: 41 millimeters Volume: 310 milliliters
Weight	7.79 grams
Use Cycles	1
End-of-life	33.5% incinerated with municipality waste 10.5% incinerated with plastic waste 6% recycled as mixed plastic waste 50% recycled as post-consumer PET
Production technique	Extrusion to create film Thermoforming to create packaging
Secondary packaging in production-phase	1 HDPE bag per 250 pieces and 1 LDPE bag per 10.000 pieces
Secondary packaging in use-phase	Cardboard box: 250x600x100 millimeters 0,5 kilograms Suitable for 20 packages (when filled)
Closing system	PET (extruded film): 100 % virgin

The data used for the plastic containers in the LCA was obtained from a prominent supplier of plastic packaging solutions to the food sector in the Netherlands. For justification, all sources have been checked with data from other manufacturers, resources, and the EcoInvent 3.7 database.

Further analysis of the life cycle of these containers will be discussed in order to identify the most impactful processes that can be redesigned. In this way, the findings can be used as an inspiration for using LCA in design decision making, with a focus on sustainability.

It is important to note that the LCA is evaluated to verify the result, as is discussed in the following section. The input data of the processes that had an extreme impact (either positive or negative) on the result were verified with other sources and checked for consistency with other product life cycles. Where necessary, this input data was changed, and the assessment was recalculated to ensure a correct assessment.

3.2. Results of the Life Cycle Assessment

In terms of the scope of the LCA, the two plastic packaging solutions were found to have the lowest environmental impact. When comparing the impacts of these two packaging solutions, the RPET container was found to have a lower overall environmental impact. The differences were mainly in the impact on fossil fuel depletion and climate change, where the result was favourable for the RPET packaging.

Significantly higher environmental impacts were found for the life cycle of paperboard and glass packaging. According to the scope of the LCA, the life cycle of the glass packaging has the highest impact on 18 of the 19 environmental impacts of the ReCiPe method [18]. For the effect of marine eutrophication, the highest impact can be attributed to the life cycle of paperboard packaging. Looking at this impact in more detail, it is mainly caused in the production phase of the packaging. More specifically, when pressing and heating the pulp. In the case of glass packaging, the highest impact can also be attributed to the production phase, due to the high energy consumption and the mass of the input material.

Only in the case of glass packaging can the largest contribution to environmental impact be attributed to the production phase, closely followed by the impact of the use phase. For the other three packaging materials, the use phase can be assessed as having the highest environmental impact.

Similar to the results of other studies [2], [19], [20], it appears that the input of ‘food’ (i.e. the vegetable spread) has a major impact to this use phase. This is interesting, as it highlights the potential of packaging in terms of sustainability in avoiding food waste. Especially in the case of a lightweight packaging as plastic, the impact related to the food is relatively higher than the impact of the packaging. So, when the packaging could both extend the shelf life of the food and leave as little residue as possible the impact on the whole product-packaging combination is reduced. Since, the positive impact of the packaging itself can outweigh the negative impacts of the product (the food waste).

The specific processes that cause the majority of the environmental impacts within the plastic packaging solutions were further analysed. It was found that the input process of the 'raw materials' in the production phase also has a significant impact. After comparing the life cycle of the RPET packaging to the PET packaging, it can be concluded that a different composition of the input material can already benefit the production process. The assessment results substantiate that increasing the recycled material content leads to decreased environmental impact of the packaging solution. However, other design opportunities that could affect this specific process as well could be thought of, in order to both reduce the total impact of the product packaging combination and satisfy consumer and manufacturing demands.

4. Results and Findings

The results discussed in this section relate to the LCA of the plastic packaging solutions, to provide an approach that validates how LCA can be used in the design of a more sustainable packaging solution.

The LCA comparison between the PET and the RPET container shows a slight preference for the RPET container in terms of environmental impact. The environmental impact of the RPET container was not lower for all 19 individual impacts of the ReCiPe process. After normalisation, it could be concluded that there is a real benefit in adding recycled PET to virgin PET to create a more sustainable packaging solution.

However, the addition of recycled PET can also result in discolouration of the material, which may not be visually beneficial at higher levels, as it affects the unique transparency property of the material. The consumer research showed a higher acceptance of the addition of recycled material, especially when consumers were informed about the origin of the discolouration. On the one hand, consumers want the packaging to be transparent, for example to check the quality of the product. This is possible with discolouration caused by 20% recycled content, but more difficult with 40%. On the other hand, when consumers were informed, the majority (more than 65%) preferred the example with significant discolouration (40% or more). An additional LCA was carried out changing the recycled PET content from 20% to 30% in order to harmonise the results of the consumer research. This LCA shows that it is advisable to increase the recycled content when designing a sustainable packaging solution.

Another influential process to be used as a basis for redesign was found in the production phase, namely the 'input material'. Although it may seem that the input of material is only a single process, it is an input that is reflected in many other processes. As the material is the core of the packaging, it has an impact on the quality and requirements of the product-packaging combination. This includes, for example, thickness, shape, production process (and hence energy consumption) and secondary packaging (and hence transport).

Plastic packaging is usually produced by thermoforming processes, using a mould, heat, vacuum and pressure to convert extruded sheet into three-dimensional shapes. By heating the film, the plastic can be stretched and pressed into the mould, after which the resulting shape can be cooled and trimmed. The excess material, the trim, is shredded and returned to the extrusion process.

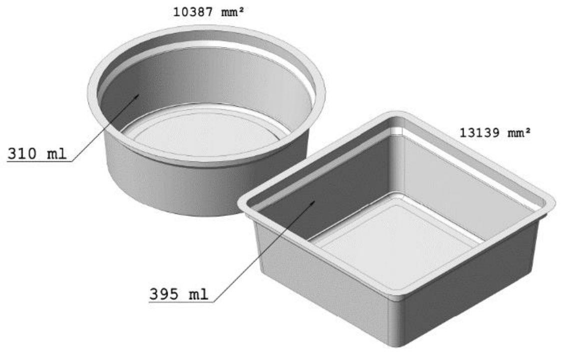

Fig. 1. Shape optimalization of RPET packaging, cylindrical to rectangular.

Logically, producing cylindrical shaped packages by thermoforming results in in a large amount of trim. If this shape is changed to a more efficient one, a smaller amount of trim is created.

By changing the shape from cylindrical to rectangular with the same dimensions (height of 41 millimetres, sheet sides of 115 millimetres), the volume of the packaging increases to 395 millilitres, as shown in Figure 1. As this does not comply with the functional unit of the LCA, the height of the rectangular packaging has been reduced to 32 millimetres. With these dimensions, the rectangular packaging can be thermoformed using the same amount of material (with a wall thickness of 0.43 millimetres). Although the amount of material required to produce the individual packaging does not change, the assessment of the processes in the life cycle provides promising insights. Especially, as the consumer research brought to light that shape is an attribute that could be subject to change.

By changing the shape from cylindrical to rectangular, the amount of trim can be reduced from 45% to 25%, as verified in the thermoforming process of a major plastic packaging supplier in the Netherlands. Higher efficiency in the thermoforming process means less trim and less extrusion, and therefore lower energy consumption. This optimisation also reflects in the impact on transport, as the packaging can be stacked more easily, resulting in less wasted space in the secondary packaging and during transport. In addition, by maintaining the dimensions in the width of the packaging, a rectangular packaging can be lower in height for the same volume. This results in another advantage in transport, especially when filled, as the stacks of packages are lower. The same applies to capacity and therefore efficiency in refrigerators and consequently energy consumption.

The LCA has been performed again with the rectangular packaging, made from 100% virgin PET. The new rectangular packaging solution resulted in a significant reduction in the environmental impact, relatively even a higher reduction than the difference between the total environmental impact of the initial assessed PET and RPET packaging. This example underpins the importance of not only performing LCA but using LCA throughout the redesign process.

4.1. Re-evaluation of the design phase

The example of the higher recycled content and shape optimisation of the packaging shows that LCA can be a promising tool in design for sustainability.

Shape optimisation is a redesign strategy that may not seem influential and therefore may not be immediately considered when designing for sustainability. In the current practice of design for sustainability in plastic packaging, material reduction is often considered, resulting in a reduced wall thickness of the material (or films instead of rigid packaging). However, using films instead of rigid packaging may reduce the recycling possibilities. This can have a negative effect on the environmental impact at the end-of-life phase and therefore a relatively lower impact over the whole life cycle of the packaging. Other examples can be found in green communication strategies of labelling and advertising or literally adding a green colour [10]. Again, this would lead to additional environmental impacts in the production phase and therefore (especially if no real improvement is made) to a less sustainable packaging. These examples of path dependency should be avoided by industry. In particular, greenwashing by one company can harm the good intentions of others.

The specific case study was chosen to demonstrate the principle of linking theory (LCA results) with practice (consumer acceptance) by providing an example that is widely used in practice. It shows that even the impact of one single process can result in a high overall impact due to the large volumes involved. This principle of identifying impactful processes through LCA, rather than analysing the overall results, is not only applicable to this example, but underlines the potential of using LCA in design. Solutions should be found in the design phase that are not only appreciated by consumers or the marketing department, but are actually supported by the results of the LCA.

4.2. Sustainability in mass production

Within the LCA, only a small but significant difference was found between the environmental impacts of two packaging solutions (PET vs. RPET and rectangular vs. cylindrical). However, it should be noted that the total impact is calculated for only one Stock Keeping Unit (SKU) of 10.000 pieces. In real practice, billions of these plastic packaging containers are produced in Europe. So, even the smallest difference for one single packaging solution can have an impact on the overall environmental impact of a packaging design. In addition, impacts in one process may seem small, but they may affect other processes as well. For example, the impact of the input “material” is reflected in several processes, such as: energy (and labour) increases in PET film extrusion, thermoforming and shredding for the production phase only.

On the other hand, if changes are required for these quantities, the redesign should be consumer acceptable and feasible for manufacturers. A simple but effective redesign that reduces environmental impact and is understandable to the consumer is encouraged.

5. Conclusion

In order to achieve a sustainable packaging that is feasible and suitable for mass production, the most impactful processes in the life cycle of a packaging solution should be identified and considered during redesign. In addition, sustainable packaging design will only be accepted if it is understood and accepted by consumers. Of course, the consumer's wishes have to be taken into account, without being influenced by these potentially counter-intuitive opinions. The packaging should be re-evaluated in the design phase and path dependency should be avoided on the manufacturer's side. This way, product-packaging combinations can be created that are sustainable and understandable to the consumer.

This paper highlights the potential for redesign in packaging, specifically for the fresh food industry. The case study on redesigning a sustainable packaging solution for the fresh produce industry shows a significant reduction in impact through the use of rectangular packaging solutions with an increasing amount of recycled material in plastic packaging. Where small changes, even if unperceived or counterintuitive to consumers, can have a significant impact on the actual sustainability characteristics of a product, it has been demonstrated that further integration of sustainability tools (as evaluation but also as inspiration) in the design process can be instrumental. Especially for mass production, it is essential to adequately articulate the sustainability consequences for the consumer, as technical considerations and consumer perceptions are often poorly aligned or even contradictory.

The aim of this paper is to motivate real action at the design stage by using LCA. The potential of design-oriented approaches has been validated by the case study. A simple but effective redesign that does not interfere with the consumers perception led to a packaging that significantly reduces the environmental impact.

The redesign should be acceptable for consumers, and its impact should be verified in the LCA, all in order to genuinely design for sustainability.

6. Future work

Although the potential of using LCA results in design has been highlighted, the assigned focus on plastic packaging solutions for the fresh food industry limits the possibilities for decisions regarding sustainability through Life Cycle Engineering. Though, the theory discussed can be applied to a broader perspective, highlighting the potential to effectively apply sustainability design in mass production.

Further research will broaden the scope of avoiding path dependence, enabling the evaluation of the design phase in other fields of application. Moreover, it is proposed to embed the Life Cycle Assessment methodology into a framework that supports design, in the broad context of manufacturing systems, complying with the sustainability desires of the consumer.

Acknowledgements

Thanks to the manufacturing companies, in particular Hordijk Verpakkingen Zaandam, other packaging institutions in the Netherlands, and recycling facilities for their cooperation and assistance in providing essential industry information. Their contributions were essential to the completion and validation of this research.

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