

Review

Life cycle assessment of reusable food and beverage packaging systems: A proposal of good practice

Namy Espinoza-Orias^{*} , Lars Lundquist

Nestlé Research, Rue du Jorat 57, Vers-Chez-Les-Blanc, 1000 Lausanne 26, Switzerland

ARTICLE INFO

Handling Editor: Yutao Wang

Keywords:

Life cycle assessment
Food
Beverage
Reusable packaging
Good practice

ABSTRACT

Re-use and refill are attracting increased attention to increase packaging circularity. At the same time a large part of industry, including the food and beverage sector, is simultaneously setting goals towards net-zero and environmental protection. Reuse is relatively common within the beverage sector and for secondary and tertiary packaging. However, although the latest version of the European Union Packaging and Packaging Waste Regulation legislation maintains the focus of reuse obligations to beverage packaging and transport packaging it leaves member states the freedom to expand the scope of reuse obligations to potentially more challenging primary packaging applications in terms of cleaning and refurbishing requirements. To ensure that the increased circularity of re-use systems is not achieved at the expense of environmental impacts, it is becoming highly critical to introduce more rigor into how re-use systems are compared with single-use systems, not only in terms of life cycle assessment (LCA) methodology, but also in terms of the nomenclature used, default reuse parameters evaluated, and how the single-use reference system is chosen. The present work examines a selection of LCA studies performed over the past decade on reusable packaging in direct contact with food and critically reviews their quality regarding LCA methodology. Based on the observations, we propose a framework for good practice aiming to provide more clarity and consistency in the preparation of LCAs comparing reusable packaging systems to single-use packaging.

1. Introduction

The Ellen MacArthur Foundation (EMF) promotes recyclable packaging, recycled content, and reuse as key means to address plastic packaging landfill and littering issues (EMF, 2017). In Europe, 39% of the 54.1 million tons converted in 2022 (Plastics Europe, 2024) were used in packaging applications. Eventually, this ended as 19.4% of the total packaging waste generated (Eurostat, 2024). Therefore, many companies in the fast-moving consumer goods sector and in particular the food sector have committed to better managing used plastic packaging to avoid packaging waste ending up in landfill or as litter. At first, EMF (2017) ventured that the re-use potential for plastic packaging exceeded 20% by weight of the plastics currently placed on the market. For the food and beverage industry, EMF's hypothesized that there was a re-use potential of 2% for plastic beverage bottles, 7% for pallet wraps and 3% for large rigid plastic packaging, as well as a yet unknown potential related to e-commerce packaging. More recently, EMF (2023a) modeled scenarios for beverages, fresh food and food cupboard categories with increasing volumes of plastic packaging switching to reuse

and overall systemic integration (fragmented effort, 2%; collaborative approach, 10%; and system change with 40% of market share, respectively). It showed meaningful reductions in greenhouse gas emissions (ranging between 12% and 69%) and water use (ranging between 16% and 70%) of reuse systems when compared to single-use packaging. However, the mentioned study presents some limitations, such as the fact that the logistics model does not represent any specific supply chain; only "single-use plastic to reusable plastic" applications are covered; reuse rates are largely hypothetical and were not varied to check their sensitivity. All these limitations cast some questions about the conclusions arrived at. In any case, even reporting at industry level on reuse systems for plastic packaging faces data collection challenges (Plastics Europe, 2024).

The reuse principle, which refers to the repeated use of products and components for the same purpose for which they were conceived, is considered in the waste management hierarchy promoted by the European Union in Directive 2008/98/EC (EU, 2008) as the second most preferable option just below waste prevention. This directive allowed a flexible approach to the waste hierarchy where deviations were

^{*} Corresponding author.E-mail address: namydaniela.espinozaorias@rdls.nestle.com (N. Espinoza-Orias).

accepted based on technical, environmental, and economic feasibility. The subsequent Amendment to the Directive (2018/851/EC) (EU, 2018) seemed to follow the original directive's approach. However, more recently, the European Commission (EC, 2022) approved a proposal for ambitious, mandatory targets by 2030 and 2040 on reuse and refill of packaging in selected sectors, including food manufacture and food service (takeaway and home delivery food service packaging). It is still unclear whether these specific targets would be consistent with the flexible approach of the waste hierarchy or deliver superior environmental sustainability performance compared to single-use alternatives, as pointed out in the feedback of key packaging industry stakeholders to the proposal (EPRS, 2023) and by researchers questioning the impacts of circular economy approaches such as the use of reusable packaging (Megale Coelho et al., 2020; Gonçalves Castro et al., 2022; Corvellec et al., 2022; Zink and Geyer, 2017). For the time being, the adopted text seems to focus on reuse targets for alcoholic and non-alcoholic beverage packaging as well as transport and grouped packaging (European Parliament, 2024). However, the adopted text leaves member states free to expand the scope of reuse obligations to a wider range of products.

Reuse is defined as the "operation by which packaging is refilled or used for the same purpose for which it was conceived, with or without the support of auxiliary products present on the market enabling the packaging to be refilled" (ISO, 2013). In turn, reusable packaging "has been designed to accomplish or proves its ability to accomplish a minimum number of trips or rotations in a system of reuse" (ISO, 2013). EMF defines four business-to-consumer reuse models (EMF, 2019): refill at home, refill on the go, return from home, and return on the go. Users refill their packaging in refill models, whereas in return models the packaging is returned to an operator that takes care of refilling it. In their Global Commitment (EMF, 2023b), EMF sets moving from single-use towards reuse models, where relevant, as one of its key targets.

Reuse is relatively common within the beverage sector, although reusable bottles have given way to single-use packaging in recent years (Parker, 2019). Equally common is the reuse of secondary and tertiary packaging (crates and pallets) where packaging is not in direct contact with food and beverages. Although there is certainly potential for increased reuse in such applications, if reuse is to become a force to be reckoned with it will have to expand beyond the realm of these applications and enter direct food contact applications. The major questions remaining are to what extent and under which conditions reuse will be environmentally competitive with single-use business models to distribute food and beverages.

Wood and Sturges (2010) performed a structured and detailed review of life cycle assessment (LCA) studies of reusable and single-use packaging in product distribution systems, identifying key factors influencing their environmental performance when compared. The factors were divided into two categories: primary factors, those which consistently had a significant influence on the results of most impact categories assessed; and secondary factors, those typically affecting the results to a lesser degree or for selected impact categories only. Cotta-fava et al. (2024) address the requirements that comparisons of single-use and reusable packaging shall satisfy to inform decision and policy makers in a reliable, impartial, and scientifically robust manner. Their observations of partial compliance of requirements are based on four studies that compared packaging used in the informal eating out sector.

To draw reliable conclusions and support decision and policy making, reuse systems must be compared to single-use systems in a comprehensive and consistent manner according to good practice in LCA. The aim of this article is to: a) critically review the quality of selected assessments performed over the past decade on the comparison of single-use and reuse packaging systems in direct contact with food with respect to LCA methodology, and b) based on the resulting observations and building on the work of Wood and Sturges (2010), propose a framework for how to assess reuse systems in comparison to single-use

distribution systems for food and beverage applications.

2. Research design

The research design followed in this review article is displayed in Fig. 1 and it consists of 3 phases. Phase 1 establishes concepts and good practice in the environmental assessment of reusable packaging systems. In Phase 2, the gaps or lack thereof between good practice and selected, published LCA studies are systematically identified. Finally, Phase 3 presents the results of the review and recommendations for future LCA studies on this topic.

3. Definitions and good practice

3.1. Goal

When defining the goal of an LCA study, ISO 14040:2006 (ISO, 2006a) and 14044:2006 (ISO, 2006b) require clearly stating four key aspects: its intended application, why the study is being performed, the intended audience, and whether the results will be used in a comparative assertion disclosed to the public or not.

Typically, the goal of LCA studies evaluating single-use packaging and reusable packaging tends to be the identification of which packaging system performs better in terms of environmental sustainability. However, as Loiseau et al. (2020) ascertain, in terms of LCA studies supporting decision making, the goal should rather be to "establish the extent to which and the conditions under which one system" exhibits superior environmental performance to the other. Measures which are applicable to both systems should be equally considered to avoid artificial bias. This approach acknowledges the influence of multiple parameters to which the systems (single-use and reusable) are sensitive to in actual scenarios, not just theoretical, ideal, or optimized ones. Accordingly, an additional goal of an LCA study would be the systematic evaluation of these conditions as part of a sensitivity assessment to identify potential levers of improvement.

In the papers reviewed, the goal should have clearly stated the questions investigated along with the intended application of the study. Even though this is the first and obvious requirement of any LCA study, we evaluated if indeed all selected papers diligently observed it or not. In the context of this review article, we were interested in the goals of assessment of a reusable packaging system on its own or in comparison to a single-use system.

3.2. Functional unit

ISO 14044:2006 (ISO, 2006b) defines the functional unit in an LCA as the "quantified performance of a product system" which serves as the unit of reference throughout the study. The Product Environmental Footprint (PEF) Guide (EC JRC, 2012), the Product Environmental Footprint Category Rules Guidance (EC, 2017), and the subsequent recommendations for the update of the PEF method (Zampori and Pant, 2019) further specify the qualitative and quantitative description of the function a product delivers in the following terms: a) what is the function provided, b) how much of that function is provided, c) how well the function is provided in terms of quality requirements, and d) for how long the function is provided. Additional specifications are provided in the case of food products, whereby the functional unit shall be measured in terms of a quantity (mass or volume) at "product consumption level" and throughout its shelf-life if indicated on its packaging (EC, 2017). It is recognized that the quality requirements are not always sufficiently considered in functional units applicable to food and beverage products and more specific guidance would need to be developed.

In line with prevailing standards and good practice, we propose a functional unit for packed food and beverage products, consisting of the following requirements applicable in the context of a comparison between reusable and single-use packaging systems. The definition of the

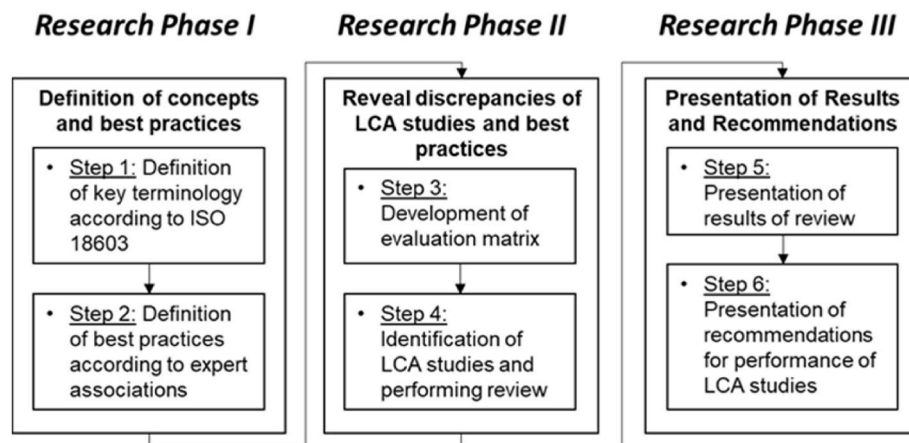


Fig. 1. Research design followed in this review article.

functional unit also applies to bulk/refill delivery systems which can have a mix of reusable packaging components and single-use packaging systems. The functional unit declared in the papers under review was checked against the following definition:

- **What?** Food product/beverage delivered to and consumed at the point of consumption.
- **How much?** Mass/volume delivered by the packaging system (includes any food loss and waste characteristic of the considered packaging system).
- **How long?** Representative period of operation of the reusable packaging system considered for analysis assuming that it is generally longer than that of a single-use distribution system.

The expected level of quality, addressed by the question “how well?”, is left out of the definition of functional unit applicable to packaged food products due to the lack of consensus across different food attributes—such as nutritional value and sensory characteristics—and linking these to the environmental performance of a food product. These supplementary quality characteristics (thoroughly reviewed in Hauschild et al., 2017.) do not necessarily add elements that merit analysis in the context of the assessment of reusable packaging. However, “how well is the product consumed?” and “how well is the product protected?” are relevant questions in assessing potential food loss and waste arising from different formats of packaging (single-use or reusable) and how the packaging systems fare when compared to each other. Examples of functional units are provided in Appendix A.

A study with a functional unit defined according to these criteria was considered satisfactory.

3.3. Scope

The scope of an LCA study defines which processes within the life cycle of the packaging system will be included and which will be excluded (system boundary) and provides an explanation or justification for the methodological choices made (allocation criteria, data and data quality requirements, and assumptions among others (ISO, 2006b)).

According to section 4.2.3 of ISO 14044:2006 (ISO, 2006b), the scope of assessment should cover all potentially significant contributions. For reusable packaging applications, this would comprise the following operations:

- Manufacture of packaging materials: resource extraction/production and processing.
- Manufacture of packaging solutions: conversion processes.
- Manufacture of bulk delivery systems and ancillary equipment.
- Filling of containers.

- Storage processes (at warehouses, retail locations, cleaning locations, reconditioning locations, points of consumption).
- Operation of bulk/refill delivery systems.
- Transportation between processes (transfer of materials between processes; forward and reverse logistics of packaging).
- Sorting processes.
- Reconditioning of packaging solutions (quality inspection, cleaning, refurbishing, repair, maintenance).
- Food loss and waste due to the use of the packaging solutions.
- End of life of packaging solutions and bulk/refill delivery systems.

Nevertheless, the relevant operations and life cycle stages will be determined by the functional unit chosen for the study. In our review, a study excluding any of the above-mentioned elements without an acceptable justification was deemed unsatisfactory. Although not covered in ISO 14044:2006 (ISO, 2006b), it would be considered good practice to state if the assessed system operates in real life already or if it is a hypothetical one. A hypothetical study contains data that does not represent a system operating at steady state; this ranges from only assumptions and hypotheses to partial primary data complemented with assumptions.

3.4. Consistency between functional unit, goal, and scope of the study

The first phase in an LCA study is the definition of its goal and scope – including the functional unit – upon which the study will be designed and prepared. The iterative nature of an LCA may require a review or refinement of the initially stated goal and scope. As stipulated in ISO 14044:2006 (ISO, 2006b), consistency between the declared goal and scope and the functional unit chosen should be maintained. In this case, the review focused on checking whether choices made when setting up the study with regards to these 3 elements could answer the initially formulated questions or not. For example, if a study aims to determine which distribution system – single-use or reusable – has better environmental performance, then the review would examine the choice of functional unit (which one was chosen, which one should have been chosen). Moreover, in this type of comparative assessment, dissociating packaging from its main functions (i.e., protecting and delivering food products) would be erroneous. Then, the review would verify if the food product was included in the assessment or not.

3.5. Number or reuses/rotations by design and in practice

ISO 18063:2013 (ISO, 2013) defines a rotation as the “cycle undergone by reusable packaging from filling/loading to filling/loading” (Fig. 2 expands the concept to the processes a reusable packaging rotation entails: filling, emptying, collection, sorting, and

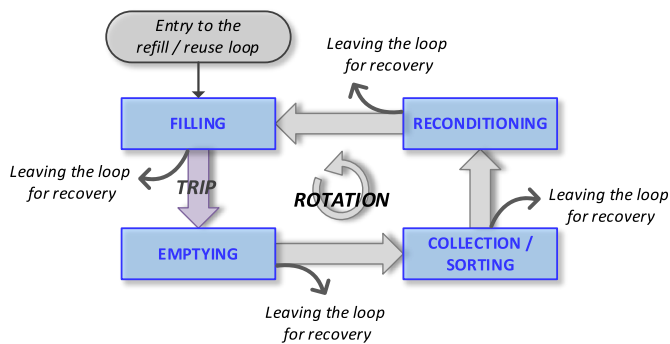


Fig. 2. Diagram explaining the refill/reuse loops. Adapted from ISO 18603:2013.

reconditioning. Food enters the system at the filling stage and leaves it at the emptying stage; food loss and waste can leave a rotation at any of the stages therein). This avoids the unnecessary and confusing distinction between calling the first rotation in the life cycle of a reusable packaging as “use” and only the subsequent ones as “reuse”: the first use is the first rotation. In this paper this definition is also applied to the synonyms “reuses”, “reuse cycle” or “refill cycle”.

Despite the wide variety of vocabulary for reuse parameters found in literature (e.g. loss rates, damage rates, breakage rates, attrition rates, number of trips, top-up rates, useful life, trippage, number of rotations, number of uses), few definitions are provided. These terms allude to the moment when a packaging item is retired from use.

By design, reusable packaging is placed in the market with the purpose of being used for a certain number of rotations before it is retired from use. The number of rotations attained in practice will not necessarily be the same.

The number of rotations in practice or reuse rate can be calculated for a pool of containers in service following guidance provided by Bojkow (1991) or more recently, the Packaging Working Group (2016). Both references estimate an average number of reuses in practice (R = Reuse rate) in terms of the number of containers filled during the lifetime of the pool of containers (C_f) and the total number of containers put into circulation since the launch of the pool of containers (S) (Equation (1)).

$$R = \frac{C_f}{S} \quad (1)$$

In this review, articles that explain how the number of reuses used in the calculations was derived (assumption by design or actually measured) are deemed satisfactory.

3.6. Life cycle impact assessment (LCIA) indicators

The choice of life cycle impact indicators evaluated in a study will depend on its goal and scope. Good practice calls for multi-indicator evaluation, including those indicators capturing environmental issues relevant to the system(s) under analysis. Moreover, this allows for the identification of burden shifting, if occurring. Additional operations in a reusable system could have significant impacts in environmental impact indicators not observed in single-use systems (for example, water consumption during reusable packaging cleaning).

ISO (ISO, 2006b) recommends a “representative set of environmental indicators”. For simplicity we chose to distinguish only between single- and multi-indicator studies, considering the first as unsatisfactory and the second as satisfactory. A more detailed discussion as to the “representativity” of the chosen indicators in a multi-indicator study would be warranted but was deemed out of scope of this publication as it refers more to common LCA practice than to the specifics of how to assess reuse systems vs. single-use systems.

3.7. Break-even point

The break-even point is the point at which the environmental impacts of reusable packaging are comparable to those of single-use packaging when delivering the same functional unit. One break-even point is calculated per environmental impact indicator evaluated. In the experience of the authors, the break-even point can be determined as a specific number of rotations or as a specific sales rate. In existing reuse systems calculating a break-even point is not necessary unless the goal is to improve its operation. For hypothetical systems, a study which did not attempt to calculate a break-even point was considered unsatisfactory if the goal of the study involved a comparison of a single-use distribution system to a reuse system.

3.8. Packaging system

ISO 18601:2013 (ISO, 2013) defines a packaging system as the complete set of packaging for a packaged good, and consists of primary, secondary, and tertiary packaging. Primary packaging comes in direct contact with the food and beverage product; secondary packaging (also called group packaging) groups units of primary packaging into convenient units at point of sale (TCGF, 2011); and finally, tertiary packaging (also called distribution or transport packaging) groups units of primary/secondary packaging for safe handling and transportation. A comprehensive LCA study accounts for all levels within the packaging system and covers key characteristics of packaging such as the materials chosen, recycled content, mass of the containers, their capacity, and the packaging conversion processes required in their manufacture. A study not considering the full packaging system without an acceptable justification in terms of the relative importance of its contribution was deemed unsatisfactory.

3.9. Refurbishing/reconditioning processes

Reconditioning, as defined by ISO 18063:2016 (ISO, 2013), comprises the operations necessary to restore reusable packaging to a functional state for further reuse. These include:

- inspection and assessment of the condition/fitness-for-purpose of the packaging,
- removal of damaged or non-reusable components,
- replacement of damaged or non-reusable components,
- cleaning or washing according to relevant conditions,
- repairing of packaging, when required, and
- re-entry into the reuse system.

A study partially or entirely omitting these operations without justification was deemed unsatisfactory.

3.10. Transport

Transport of reusable packaging materials throughout their life cycle comprises the distances travelled connecting processes as well as the mode of transportation chosen. Varying the transport distances and/or transportation mode should be done as part of the sensitivity assessment in cases where the locations of the processes are not yet fixed, or optimization of the operational set-up is explored. The study was deemed unsatisfactory if this was not done. Conversely, assessing an existing system with set transport distances would be considered satisfactory without a sensitivity study on transport distances.

3.11. Pool size

The pool size is a function of the loss rate and lag-time (inventory build-up at different points in the system due to inefficiencies in collection, storage, refurbishing processes, or transportation) in the

supply chain. Additional factors affecting the pool size are the diversity and dispersal of the supply chain, average length of a rotation cycle, average and degree of kurtosis of the distribution of distances travelled in the supply chain, efficiency of the collection systems and reverse logistics, asset visibility, sales volumes, and seasonality (Wood and Sturges, 2010). Accounting for these parameters allows the calculation of a minimum pool size required for continuous operation of the reuse system. Generally, it would be expected that the real pool size exceeds the minimum pool size to account for supply uncertainty (safety or buffer stock). This “safety factor” can be evaluated as an additional parameter in sensitivity assessments. Pool size is a parameter that reflects the initial capital investment required to launch the system; once it reaches steady state operation, its environmental performance will be determined by the inputs required to maintain business continuity, *i.e.*, substituting losses and obsolescence. For this reason, we did not consider it as a key parameter to describe the environmental performance of a reuse system.

3.12. Losses of containers

Losses of containers can be divided into two categories:

- a) Deliberate retirement: packaging is retired from use typically after a quality inspection prior to reconditioning and refilling. The reasons to do so can be technical (*e.g.*, because it can no longer perform to the expected level of quality; due to food or packaging safety issues) or not (cosmetic reasons such as external scratching of packaging, bumps, or faded labelling).
- b) Packaging lost in distribution: packaging disappearing at various points within the reuse cycle for reasons outside of the control of the reuse system operator regardless of its physical state. It is not necessarily possible to know where packaging disappears nor its potential end-of-life fate.

Losses need to be replaced (topped-up) to maintain the operational performance of the reuse system. They need to be attributed to the delivery of the functional unit either on an individual rotation basis or be related to the delivery of a specific quantity of food or beverage products over a definite period (*e.g.* total annual sales). Knowing the losses also permits to calculate the number of trips/rotations a packaging item completes before exiting the reuse system. In this sense, losses in the way the term is defined here or number of trips a packaging item undergoes are mutually equivalent, provided that the latter accounts not only for packaging deliberately retired from use, but also for packaging items lost at various stages in the reuse system. This information is a necessary, but not sufficient criterion for the calculation of the reusable packaging minimum pool size. Studies which did not fully account for the two aspects of losses were deemed unsatisfactory.

3.13. Losses of product

Having described the functional unit of the assessments in terms of the food or beverage product being consumed, neglecting any food loss and waste incurred throughout its life cycle would go against the systematic approach that characterizes LCA. Upstream food loss and waste (from farm to factory gate) can be assumed similar for products packed in single-use or reusable packaging and hence not considered in the assessments. However, downstream food loss and waste (from factory gate to end of life) can be different depending on the packaging system chosen for the product. Whereas it is unlikely that food losses and waste will differ between single-use and returnable packaging systems, hybrid or refillable packaging systems making use of dispensing systems or with manual refill from a refill container may imply differences in food losses and waste which should then be included in the study to ensure robust conclusions.

The inclusion of food loss and waste in the assessment can follow

existing standards and protocols for its measurement and reporting (*e.g.* the Food Loss and Waste Accounting and Reporting Standard (WRI, 2016)). Studies where food losses may be relevant (particularly refill systems) and did not address them were judged unsatisfactory.

3.14. Sensitivity assessments

When carrying out sensitivity assessments, the goal is to test the robustness of the model created, enabling the identification and quantification of the influence of certain parameters onto the environmental impact of the whole system. Of all the parameters that can potentially be varied in the assessment of reusable packaging and its comparison to single-use packaging, only a few would lead to significant changes in the results and decisions taken accordingly. The following parameters may be significant contributors to overall impacts of reuse systems and should be addressed: container (weight/volume, material type), transportation, refurbishing operations, reusable packaging losses, and product losses. Certainly, variations in other parameters may also affect the outcome of a study. If that were the case, they should also be included in the sensitivity assessment. For systems already in operation where primary data is available for the previously mentioned factors, sensitivity studies are not warranted unless the goal of the study is to identify improvement potential.

In this review, the degree to which studies are deemed satisfactory depends on which of the parameters identified as potentially significant were tested or not.

3.15. Consistency of conclusions with goal and scope

The conclusions of the study shall be consistent with the initially stated goal and scope. They should certainly answer the questions initially posed, identify significant issues, and acknowledge any limitations of the study. Consistency is only judged on the defined goal and scope, not on the appropriateness of the goal and scope, which is dealt with elsewhere. Generalizations beyond the scope of the study or conclusions addressing topics not initially posed would not correspond to good practice.

4. Literature review methodology

This review article follows the principles of a systematic literature review according to Tranfield et al. (2003). First, the objective and scope of the review were defined. Secondly, relevant literature was screened in search engines (Scopus and Science Direct) or repositories of specialized journals (*e.g.* International Journal of Life Cycle Assessment and Journal of Cleaner Production). Three categories of keywords were employed in the search: reuse (“reusable” OR “returnable”), subject (“packaging” OR “container” AND “food” OR “beverage”), and assessment (“environmental impact” OR “environmental assessment” OR “life cycle assessment”). Criteria for inclusion or exclusion of papers are detailed in Table 1.

5. Results

5.1. Results of the literature review

A total of 20 articles were selected for review. Table 2 and Fig. 3 present the references and key aspects of the studies. Four general observations can be made: LCA studies in literature have largely been conducted on 1) food products with low manufacturing and distribution complexity (*i.e.* fresh produce), 2) beverages for which reuse/returnable packaging is well established for decades in some geographies, 3) portioned take-away food prepared at small scale (restaurants, fast-food outlets), and 4) using empirical data representing key aspects of the system (existing systems) or assumptions (hypothetical systems). However, LCA studies on reusable primary packaging for other products in

Table 1
Criteria for inclusion and exclusion of articles.

Aspect	Inclusion criterion	Exclusion criterion	Rationale
Quality	Peer-reviewed articles	Not peer-reviewed articles	Ensures relevance to academic and practitioner community
Methodology	Life cycle assessment	Other types of assessments	Scope and objective of this review
Focus	Reuse of primary packaging in direct contact with food and/or beverages	Reuse of secondary/tertiary packaging unless deemed relevant for this review	Scope and objective of this review
Timespan	2015–2023	Prior to 2015. Earlier articles included if referenced by articles in the review sample	Relevant articles emerged mostly after 2015
Language	English	Any other language	Internationally recognized literature written in English

Table 2
LCA studies on reuse of primary packaging for food and beverages considered for review.

Primary sample					
Reference	Comparison	Type of system	Status of system	Packaging type	Product
Franklin Associates (2016)	Display-ready and non-display-ready corrugated fiber containers vs. Reusable plastic containers	Return from shop	Existing	Primary	Fresh produce
Simon et al. (2016)	Aluminium cans, PET bottles, beverage cartons, PLA bottles, glass bottles vs. Refillable PET and glass bottles	Return on the go	Existing	Primary	Beverages
Gallego-Schmid et al. (2018)	Reusable plastic vs. Reusable glass food savers	Refill from home	Hypothetical	Primary	Take-away food
Pereira et al. (2018)	Single-use plastic bottles in supermarket vs. Reusable glass or plastic bottles in a vending machine	Refill on the go	Existing	Primary	Pasteurized milk
Corrugated Packaging Alliance (2019)	Corrugated container vs. Reusable plastic container	Return from shop	Existing	Primary	Fresh produce
Ponstein et al. (2019)	Disposable vs. Reusable glass bottles	Return on the go	Existing	Primary	Wine
Tua et al. (2019)	Single-use vs. Reusable plastic crates	Return from shop	Existing	Primary	Fruits and vegetables
Abejón et al. (2020)	Cardboard boxes vs. Reusable plastic crates	Return from shop	Existing	Primary	Fruits and vegetables
Blanca-Alcubilla et al. (2020)	Single-use vs. Reusable tableware	Return from plane	Existing	Primary	Food served in-flight
Zhou et al. (2020)	Single-use vs. Reusable take-away packaging	Return on the go	Hypothetical	Primary	Diverse fast-food for take-away
Blaziejewski et al. (2021)	Single-use HDPE bottles vs. Reusable metal churns and reusable glass bottles	Return from cafeteria	Existing	Primary	Milk
Cottafava et al. (2021)	Single-use cups made of PP, PLA, PET, and cardboard with PE coating vs. Reusable cups made of PP, PLA, PET, and glass	Return on the go	Hypothetical	Primary	Draught beverages
Greenwood et al. (2021)	Single-use containers made of EPS, PP, Aluminium, and bagasse vs. Returnable and refillable containers made of PBT/PE, PP, steel.	Return and refill on the go	Hypothetical	Primary	Take-away food
Stefanini et al. (2021)	Single-use virgin PET, Recycled PET, glass bottles vs. Returnable glass bottles.	Return on the go	Hypothetical	Primary	Pasteurized milk
Accorsi et al. (2022)	Single-use corrugated cardboard boxes and PP crates vs. Reusable PP crates.	Return from shop	Existing	Secondary	Fresh produce
Hitt et al. (2023)	Single-use PLA, PP, Aluminium, and bagasse containers vs. Reusable PP containers	Return on the go	Hypothetical	Primary	Take-away food
Articles obtained through cross-references from primary sample					
Van Doorselaer and Lox (1999)	One-way vs. Multi-way glass bottles	Return on the go	Hypothetical	Primary	Beer
Levi et al. (2011)	One-way corrugated boxes vs. Reusable plastic containers	Return from shop	Existing	Primary	Fresh produce
Albrecht et al. (2013)	Single-use wooden and cardboard boxes vs. Reusable plastic crates	Return from shop	Existing	Primary	Fresh fruits & vegetables
Accorsi et al. (2014)	Single-use wooden and cardboard boxes and plastic crates vs. Reusable plastic containers	Return from shop	Existing	Primary	Organic, fresh fruit & vegetables

the wide-ranging portfolio of the food and beverages sector are absent.

5.2. Results from review of good practice in life cycle assessment

Table 3 presents the results of the analysis of the quality parameters described in Section 3 and summarized in nine categories (Appendix A provides an extended overview of the analysis). The articles received a pass score for each of the applicable quality parameters they met satisfactorily as explained in Section 3. An article's quality index is the aggregation of pass scores (expressed in percentage). On average, the quality index achieved a value of 71%. Furthermore, conformity scores were calculated for each quality parameter, showing how many articles in the sample met them. The conformity score averaged 75%.

Overall, the analysis shows that:

- The studies reviewed are not fully aligned with good practice proposed by the authors. Additionally, several cases of non-compliance with prevailing ISO standards for LCA were observed.
- Noticeable differences in the quality of the studies assessed were observed over the period reviewed, even though in principle the standards have not changed and all elements to perform a good LCA study were in place all this time; then, the bias would come from discipline in executing the studies, data availability, compliance with standards, and implementation of good practice.
- Understanding of definitions is not homogeneous across all studies.

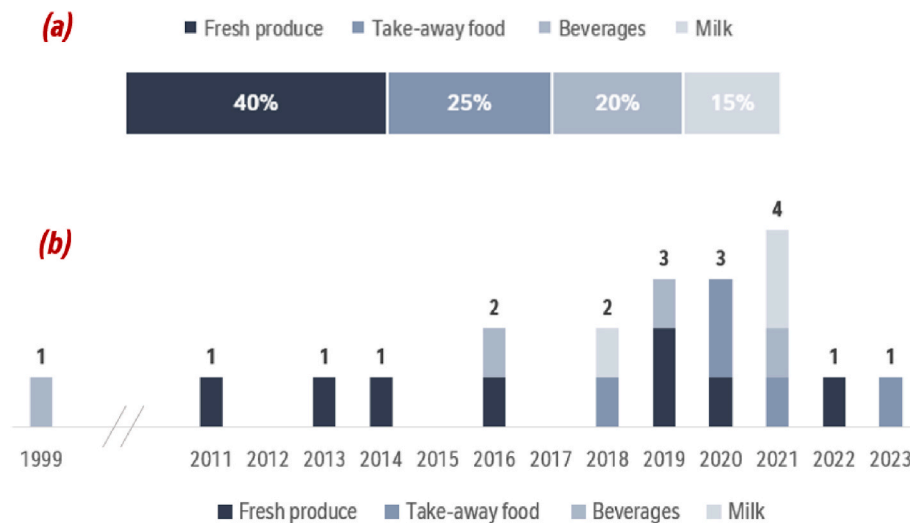


Fig. 3. Studies addressing (a) proportion of food categories in the review sample and (b) number of studies over the period reviewed.

- The quality of the assessments has not necessarily improved substantially over the period reviewed.
- Average quality indexes per food category do not vary markedly (beverages, 67%; fruits and vegetables, 68%; take-away food, 76%; milk, 74%).
- Only [Cottafava et al. \(2021\)](#) met fully the requirements of the applicable, key sensitivity assessments identified earlier; the sensitivity assessments performed in the remaining studies were partial and unsatisfactory.
- Food losses in the refillable systems – where they are pertinent – were omitted.

6. Discussion

6.1. Functional unit

Even though functional units were declared, only 75% of them were consistent with the goal and scope of the study. Almost all functional units answered the question of what is being provided and how much of it; however, it is still not general practice to state them in sharp and unambiguous terms as described in section 3.2 (see [Appendix A](#) for a detailed analysis). Of the papers reviewed, only [Blanca-Alcubilla et al. \(2020\)](#) and [Zhou et al. \(2020\)](#) stand out with sufficiently clear and explicit explanations of the functional unit in terms of what, how much, and for how long it is delivered. Failing to declare unambiguously the functional unit of the assessment can lead to confusion between the reference flows and what is actually evaluated (the product being delivered, or the reusable packaging per se); consequently, the planning and structuring of the assessment is affected.

6.2. Reuse cycles

Although the number of reuse cycles was considered in 70% of the studies, only 25% of the values come from reusable packaging systems in operation; the rest are assumptions or design values. Assessments done at concept stage will obviously require the use of design values, but they should be accompanied by a sensitivity assessment where variations of reuse cycles incorporate informed rates of losses and retirement and reflect if it is conceivable and technically possible that under its current design the reusable packaging could reach certain number of reuse cycles. Such values should be replaced with primary data representing the steady state operation of the reuse system if it is implemented. Secondary data could be used instead of hypothetical data, but it can also be scarce, outdated, nor representative ([Rigamonti et al., 2019](#)). Although

not covered in the studies reviewed here, consumer behavior and preferences determine the number of reuses of the containers in refill systems managed by consumers.

6.3. Scope of the assessment

Similarly to the statement of functional units, all studies explicitly mentioned the scope of the study. 70% of the studies met good practice in scope definition by not excluding relevant processes defined in sections 3.3 and 3.9. In particular, setting boundaries from cradle to factory-gate or excluding elements of return logistic are not considered acceptable practice.

6.4. Life cycle impact assessment indicators

It is well acknowledged that considering multiple and relevant impact indicators allows for a more comprehensive assessment and identifies trade-offs. Still, 25% of the studies chose a single indicator. This choice affects the determination of when a reusable packaging system is competitive to a single-use system by potentially basing the conclusions on the indicator that yields the least conservative break-even point. Impacts associated with operations intrinsic to reusable packaging systems (e.g. refurbishing) may be neglected if a narrow set of indicators is selected.

6.5. Sensitivity assessments

Considering the complexity of reusable packaging systems, the fact that 42% of potential variations in key parameters were addressed to a certain degree in sensitivity assessments emphasizes the need for improvement in LCA practice.

The variation of the mass or material of the containers is relevant only for studies still at design phase, not for systems already in place unless they undergo some optimization in this regard. 25% of the studies considered varying the mass or material of the containers.

40% of the studies assessed variations in transportation distances. This is only relevant for exploratory or hypothetical studies. Systems already running would have fixed distances between processes. [Accorsi et al. \(2022\)](#) developed a tailored digital twin model to represent an existing reusable packaging network; however, although their study insisted on the importance of using primary data, it did not demonstrate its significance by contrasting the results of the study with the same case without access to such data.

Refurbishing conditions were varied in 40% of the studies, mostly

Table 3

Summary of evaluation of quality parameters.

References	Functional Unit (FU)	FU compliant and consistent with goal & scope	Number of reuse cycles by design (in practice)	Scope explicitly mentioned	Good practice in scope definition	LCIA indicators	Sensitivity assessment of key parameters (4 or 5) ^a	Break-even point calculated	Conclusions consistent with goal & scope	Article quality index
Van Doorselaer and Lox (1999)	Yes	Yes	No	Yes	Yes	Single	2	Yes	Yes	67%
Levi et al. (2011)	Yes	Yes	Yes, 200	Yes	Yes	Multiple	3	No	Yes	78%
Albrecht et al. (2013)	Yes	Yes	Yes	Yes	Yes	Multiple	1	Yes	Yes	89%
Accorsi et al. (2014)	Yes	Yes	No	Yes	Yes	Single	3	Yes	Yes	67%
Franklin Associates (2016)	Yes	Yes	Yes (39.3)	Yes	Yes	Multiple	2	No	Yes	78%
Simon et al. (2016)	Yes	Yes	Yes, 20	Yes	No	Multiple	1	Yes	Yes	78%
Gallego-Schmid et al. (2018)	Yes	Yes	Yes	Yes	Yes	Multiple	2	Yes	Yes	89%
Pereira et al. (2018)	Yes	Yes	No	Yes	No	Multiple	2	No	Yes	56%
CPA (2019)	Yes	Yes	No	Yes	No	Multiple	0	No	Yes	56%
Ponstein et al. (2019)	Yes	No	Yes, 5	Yes	No	Single	1	No	No	33%
Tua et al. (2019)	Yes	No	Yes, 1-125	Yes	No	Multiple	1	Yes	Yes	67%
Abejón et al. (2020)	Yes	No	Yes, ≥100	Yes	No	Multiple	1	No	No	44%
Blanca-Alcubilla et al. (2020)	Yes	Yes	Yes (10)	Yes	Yes	Single	3	No	Yes	67%
Zhou et al. (2020)	Yes	Yes	No	Yes	Yes	Single	2	Yes	No	56%
Błazejewski et al. (2021)	Yes	Yes	Yes (1012 for metal churns, 283 for glass bottles)	Yes	Yes	Multiple	2	Yes	Yes	89%
Cottafava et al. (2021)	Yes	Yes	Not mentioned	Yes	Yes	Multiple	4	Yes	Yes	89%
Greenwood et al. (2021)	Yes	Yes	Yes, 50 for plastic containers, 100 or 200 for steel containers	Yes	Yes	Multiple	1	Yes	Yes	89%
Stefanini et al. (2021)	Yes	Yes	Yes, 30 (8)	Yes	Yes	Multiple	1	No	Yes	78%
Accorsi et al. (2022)	Yes	No	Yes (10)	Yes	Yes	Multiple	1	Yes	No	67%
Hitt et al. (2023)	Yes	No	Yes, 20	Yes	Yes	Multiple	2	Yes	Yes	78%
Conformity of sample reviewed to the parameter assessed	100%	75%	70%	100%	70%	75%	42%	60%	80%	

^a 4 parameters applicable to returnable systems; 5 parameters applicable to refillable systems.

focusing on frequency of cleaning, type of energy used, and amount of water and other ancillary materials. In ascending order of cleaning intensity, food categories can be ordered as fresh produce, beverages, milk, and prepared meals. Then, sensitivity assessments would be warranted for prepared meals and potentially beverages and milk. Five out of twelve applicable studies (42%) and three out of eight (38%) that did not need them performed said assessments. Different technologies for cleaning were not explored. Other refurbishing operations such as re-labelling or repairing containers were not considered in the reviewed studies.

At steady state operating conditions, systems in place can calculate the return rate (percentage of containers returned by consumers relative to containers placed in the market), the replacement rate (percentage of containers that need to be replaced due to obsolescence or because they are lost), and the number of reuses per container (calculated as the inverse of the replacement rate). Deloitte Développement Durable (2018) presents examples of these calculations for existing systems. Knowledge of these rates for existing reusable packaging systems or reasoned assumptions for hypothetical ones can guide whether a sensitivity

assessment of number of reuse cycles is a useful exercise or not. If no losses of reusable packaging existed then the reuse rate would depend only on obsolescence, which in turn can be affected by packaging (re-) design. Understanding of how incompressible loss rates are can inform strategies to affect it, such as introduction of deposit schemes. Only 20% of the studies varied the replacement rate based on a loss or breakage rate.

Food losses are consistently excluded by the three studies in the sample evaluating refill systems and for which they are a relevant parameter (Gallego-Schmid et al., 2018; Pereira et al., 2018; and Błazejewski et al., 2021); they were not addressed anyway by the remaining systems studied in the review sample. Food losses and waste, particularly for products with relatively high environmental impacts such as dairy products, may constitute a significant contribution to overall results (Erlöv et al., 2000; Burek et al., 2017). Błazejewski et al. (2021) do acknowledge milk losses can depend on the type of vessel but assumed them negligible and thus omitted them; additionally, the study excludes the dispensing system and implicitly any potential losses in the form of spillage in dispensing. Franklin Associates (2016) describe container

losses both in terms of breakage rate, *i.e.* voluntary retirement of containers due to breakage or wear, and losses in the supply chain. Blazewski et al. (2021) add 15% containers to the pool required for delivery to account for losses, breakage, and demand fluctuations. Since all other studies deal partially with losses or disregard them, their conclusions are potentially biased.

6.6. Break-even point

Break-even points were calculated in 60% of the studies but not always for all impact indicators evaluated. Only 8 studies (40%) calculated all the respective break-even points and presented them either in the text or in supplementary material. 10% of the reviewed assessments evaluated break-even points for the single environmental indicator considered, which does not allow understanding whether other relevant environmental indicators for the system would have produced higher break-even points or not. Moreover, 20% of the reviewed studies calculated break-even points for some of the indicators evaluated and without a justification regarding the relevance of the chosen indicators.

However, not all studies required this calculation, only the hypothetical systems did. It was deemed that seven of the reviewed studies dealt with hypothetical scenarios. Six of them calculated a break-even point, which demonstrates good practice in this regard. For existing reusable packaging systems, calculating the break-even point provides additional information about their performance. Another important calculation is the combination of a break-even point with the transportation distance beyond which it is not desirable to implement a reusable packaging system (ADEME, 2008). None of the studies reviewed covered this point.

6.7. Conclusions consistent with goal and scope

80% of the studies state conclusions that are consistent with the initially defined goal and scope. However, not all conclusions are automatically valid since the goals and scopes were not necessarily following good practice in all cases (75% did). Typical deviations would be drawing conclusions outside the scope of the study or failing to address key parameters determining the environmental performance of reusable systems such as number of reuses, packaging losses or the distribution stage. For example, Simon et al. (2016) did not demonstrate that reusable glass bottles with similar weight to single-use ones would withstand the number of reuses they propose. Accorsi et al. (2022) failed to provide answers to the questions posed in the goal of the study, meaning that the importance of using primary data representing logistics was not compared to secondary sources. Ponstein et al. (2019) drew a generic conclusion on reusable glass bottles being preferable without addressing distribution distances. Tua et al. (2019) show an inconsistency between goal and scope and the conclusions arrived at because they excluded the distribution stage. Abejón et al. (2020) extend their conclusions beyond the scope of the study. Zhou et al. (2020) did formulate a conclusion, but a goal cannot be extracted to compare it with due to the format of the article, which is atypical for LCA studies.

20% of the studies conclude on the preferability of reusable packaging based on the break-even points calculated for all indicators assessed. On the other hand, 35% of the assessments draw conclusions on environmental preferability of a system based on limited number of break-even points, which may hide environmental trade-offs.

7. Recommendations and conclusions

Beyond the fact that basic rules related to LCA are not consistently respected, the key shortcomings directly related to reuse are related to sensitivity assessments on key parameters and the calculation of break-even points for a single indicator rather than for a meaningful set of impact categories.

The most common generic LCA shortcomings observed were:

- inconsistency between goal and scope and the functional unit,
- failure to declare the reference flow associated to the functional unit,
- failure to use a representative set of environmental impact indicators for the packaging systems under study, and
- inconsistency between goal and scope and conclusions (particularly critical for the 35% of reviewed studies with a clear intention to support policy making).

Based on the reviewed studies, a three-step procedure is proposed when multiple indicators are assessed and break-even points calculated: first, normalize the results to obtain a more-contextualized view; second, select the priority indicators resulting from the normalization step; and third, calculate the break-even point only for those priority indicators. The conclusions – albeit conservative – of a study should be based on the highest break-even point thus calculated.

Whereas the likelihood of observing differences in food losses between reusable packaging and single-use packaging distributed through the same channels is relatively low, this cannot be said for bulk delivery/refill systems. In the latter case there are several additional sources of potential food losses such as product expiry in dispensing and spillage in the operation of dispensing systems which should be considered in comparative assessments.

Another point of concern related to bulk delivery/refill systems is the extent to which reuse is practiced either upstream by the operator or down-stream by the consumer. Upstream reuse would follow the same principle as conventional reuse systems, whereas down-stream re-use practices can be partially imposed by the operator through standardizing the dispensing system to accept only one container format. However, there is no guarantee that the consumer is always in possession of a reusable container at the point of purchase. This forces the consumer to acquire another container to complete a purchase, consequently increasing the impacts associated with delivering the functional unit in question. In cases where the consumer is entirely free to choose the container and how it is managed the uncertainty is even higher and should be accounted for through sensitivity studies.

Re-use and refill are attracting increased attention as a means to increase packaging circularity while at the same time a large part of industry is setting strategies and goals towards net-zero and environmental protection. In order to ensure that the increased circularity of re-use systems is not achieved at the expense of environmental impacts, it is becoming increasingly important to introduce more rigor into how re-use systems are compared with single-use systems, not only in terms of LCA methodology, but also in terms of the nomenclature used, default reuse parameters evaluated, and how the single-use reference system is chosen. The framework for good practice proposed in this paper aims to provide more clarity in the preparation of LCAs of reusable packaging systems and complement operational guidance (CITEO, 2021; WRAP, 2023).

CRediT authorship contribution statement

Namy Espinoza-Orias: Writing – original draft, Methodology, Investigation, Formal analysis. **Lars Lundquist:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Dennis Niedenzu for the support provided in the preparation of the literature review methodology and productive discussions while initiating the review of relevant published literature on the topic.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2025.145207>.

Data availability

No data was used for the research described in the article.

References

- Abejón, R., Bala, A., Vázquez-Rowe, I., Aldaco, R., Fullana-i-Palmer, P., 2020. When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. *Resour. Conserv. Recycl.* 155, 104666. <https://doi.org/10.1016/j.resconrec.2019.104666>.
- Accorsi, R., Cascini, A., Cholette, S., Manzini, R., Mora, C., 2014. Economic and environmental assessment of reusable plastic containers: a food catering supply chain case study. *Int. J. Prod. Econ.* 152, 88–101. <https://doi.org/10.1016/j.ijpe.2013.12.014>.
- Accorsi, R., Battarra, L., Guidani, B., Manzini, R., Ronzoni, M., Volpe, L., 2022. Augmented spatial LCA for comparing reusable and recyclable food packaging containers networks. *J. Clean. Prod.* 375, 134027. <https://doi.org/10.1016/j.jclepro.2022.134027>.
- Agence de l'Environnement et de la Maitrise de l'Energie (ADEME), 2008. Report on the economic and environmental impact of a deposit system for beverage packaging and the recycling of plastic packaging. <https://www.asser.nl/upload/eel-webroot/www/documents/sectors/waste/ademe.pdf>. November 2023.
- Albrecht, S., Brandstetter, P., Beck, T., Fullana-i-Palmer, P., Grönman, K., Baitz, M., Deimling, S., Sandilands, J., Fischer, M., 2013. An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe. *Int. J. Life Cycle Assess.* 18, 1549–1567. <https://doi.org/10.1007/s11367-013-0590-4>.
- Blanca-Alcubilla, G., Bala, A., de Castro, N., Colomé, R., Fullana-i-Palmer, P., 2020. Is the reusable tableware the best option? Analysis of the aviation catering sector with a life cycle approach. *Sci. Total Environ.* 708, 135121. <https://doi.org/10.1016/j.scitotenv.2019.135121>.
- Blażejowski, T., Walker, S.R.J., Muazu, R.I., Rothman, R.H., 2021. Reimagining the milk supply chain: reusable vessels for bulk delivery. *Sustain. Prod. Consum.* 27, 1030–1046. <https://doi.org/10.1016/j.spc.2021.02.030>.
- Bojkow, E., 1991. Basic considerations on the calculation of the trippage number for returnable containers. *Packag. Technol. Sci.* 4, 315–331.
- Burek, J., Kim, D., Nutter, D., Selke, S., Auras, R., Cashman, S., Sauer, B., Thoma, G., 2017. Environmental sustainability of fluid milk delivery systems in the United States. *J. Ind. Ecol.* 22 (1), 180–195. <https://doi.org/10.1111/jiec.12531> [online].
- CITEO, 2021. Vers une définition des games standards réemployables. Available at: 20211201_Citeo_Vers_une_definition_de_games_standards.pdf (dev-dropteam.com). Accessed in November 2023.
- Corrugated Packaging Alliance (CPA), 2019. Life cycle assessment of corrugated containers and reusable plastic containers for produce transport and display. Summary. https://www.packagingstrategies.com/ext/resources/Resources/White-Papers/CPA_Comparative_LCA_White_Paper_2019.pdf. October 2023.
- Corvellec, H., Stowell, A.F., Johansson, N., 2022. Critiques of the circular economy. *J. Ind. Ecol.* 26, 421–432. <https://doi.org/10.1111/jiec.13187>.
- Cottafava, D., Costamagna, M., Baricco, M., Corazza, L., Miceli, D., Riccardo, L.E., 2021. Assessment of the environmental break-even point for deposit return systems through an LCA analysis of single-use and reusable cups. *Sustain. Prod. Consum.* 27, 228–241. <https://doi.org/10.1016/j.spc.2020.11.002>.
- Cottafava, D., Brussa, G., Cavenago, G., Cespi, D., Rigamonti, L., Bala, A., Beigbeder, J., Refalo, P., Szadovskii, I., 2024. Requirements for comparative life cycle assessment studies for single-use and reusable packaging and products: recommendation for decision and policy-makers. *Int. J. Life Cycle Assess.* 29, 909–911. <https://doi.org/10.1007/s11367-024-02291-0>, 2024.
- Deloitte Développement Durable, 2018. Analyse du cycle de vie de dispositifs de réemploi ou réutilisation (BtoC) d'emballages ménagers en verre. <https://bibliaire.ademe.fr/consommer-autrement/1676-systèmes-de-collecte-des-emballages-ménagers-pour-reemploi-ou-reutilisation.html>. November 2023.
- Ellen MacArthur Foundation (EMF), 2017. The New Plastics Economy: Catalysing Action. Available at: the New Plastics Economy: Catalysing action.Pdf (thirdlight.com). October 2023.
- Ellen MacArthur Foundation (EMF), 2019. Reuse. Rethinking Packaging. Available at: emf.thirdlight.com/file/24/A-BkCs_aXeX02_Am1z_J7vzLt/Reuse - rethinking packaging.pdf Accessed in October 2023.
- Ellen MacArthur Foundation (EMF), 2023a. Unlocking a reuse revolution: scaling returnable packaging. Available at: Unlocking a reuse revolution - scaling returnable packaging.pdf (thirdlight.com). March 2024. https://emf.thirdlight.com/file/24/sjZ_pROsjk8VSKPjXVEszMGHY/Unlocking%20a%20reuse%20revolution%20-%20scaling%20returnable%20packaging.pdf.
- Ellen MacArthur Foundation (EMF), 2023b. The Global Commitment five years in: learnings to accelerate towards a future without plastic waste or pollution. <https://emf.thirdlight.com/file/24/SWAXKg3SWOeL4OSWZn0SWsy8Dw/The%20Global%20Commitment%20Five%20Years%20In%20a%20Learnings%20to%20Accelerate%20towards%20a%20Future%20without%20Plastic%20Waste%20or%20Pollution.pdf>. January 2025.
- Erlöv, L., Löfgren, C., Sörås, A., 2000. Packaging – a Tool for the Prevention of Environmental Impact. Packforsk Report No. 194, June 2000.
- European Parliamentary Research Service (EPRS), 2023. Revision of the Packaging and Packaging Waste Directive. Available at: Revision of the Packaging and Packaging Waste Directive (europa.eu). Accessed in October 2023.
- Eurostat, 2024. Packaging Waste Statistics. Available at: Packaging Waste Statistics - Statistics Explained. Accessed in January 2025.
- European Union (EU), 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. Available at: EUR-Lex - 32008L0098 - EN - EUR-Lex (europa.eu). Accessed in October 2023.
- European Union (EU), 2018. DIRECTIVE (EU) 2018/851 of the EUROPEAN PARLIAMENT and of the COUNCIL of 30 May 2018 Amending Directive 2008/98/EC on Waste. Available at Directive (EU) 2018/of the European Parliament and of the Council of 30 May 2018 Amending Directive 2008/98/EC on Waste (europa.eu). October 2023.
- European Commission Joint Research Centre (EC JRC), 2012. Product Environmental Footprint (PEF) Guide. Ref. Ares(2012)873782-17/07/2012. <https://dl.icdst.org/pdfs/files3/51fb3fc9befdc585c0a111ec8007e41a.pdf>.
- European Commission (EC), 2017. PEFCR Guidance document - Guidance for the Development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3.
- European Commission (EC), 2022. Proposal for a REGULATION of the EUROPEAN PARLIAMENT and of the COUNCIL on Packaging and Packaging Waste, Amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and Repealing Directive 94/62/EC. Available at: COM.COM(2022)0677_EN.pdf (europa.eu). Accessed in October 2023.
- European Parliament, 2024. European Parliament Legislative Resolution of 24 April 2024 on the Proposal for a Regulation of the European Parliament and of the Council on Packaging and Packaging Waste, Amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and Repealing Directive 94/62/EC (COM(2022)0677 – C9-0400/2022 – 2022/0396(COD)). Available at: Texts Adopted - Packaging and Packaging Waste - Wednesday, 24 April 2024 (europa.eu). Accessed in May 2024.
- Franklin Associates, 2016. Comparative Life Cycle Assessment of Reusable Plastic Containers and Display and Non-display Ready Corrugated Containers Used for Fresh Produce Applications. Peer reviewed report prepared for IFCO Corporation.
- Gallego-Schmid, A., Mendoza, J.M.F., Azapagic, A., 2018. Improving the environmental sustainability of reusable food containers in Europe. *Sci. Total Environ.* 628–629, 979–989. <https://doi.org/10.1016/j.scitotenv.2018.02.128>.
- Gonçalves Castro, C., Hofmann Trevisan, A., Pigozzo, D.C.A., Mascarenhas, J., 2022. The rebound effect of circular economy: definitions, mechanisms and a research agenda. *J. Clean. Prod.* 345, 131136. <https://doi.org/10.1016/j.jclepro.2022.131136>.
- Greenwood, S.C., Walker, S., Baird, H.M., Parsons, R., Mehl, S., Webb, T.L., Slark, A.T., Ryan, A.J., Rothman, R.H., 2021. Many happy returns: combining insights from the environmental and behavioral sciences to understand what is required to make reusable packaging mainstream. *Sustain. Prod. Consum.* 27, 1688–1702. <https://doi.org/10.1016/j.spc.2021.03.022>.
- Hauschild, P.Z., Rosenbaum, R.K., Olsen, S.I., 2017. Life Cycle Assessment, Theory and Practice. Springer. Available at: Life Cycle Assessment: Theory and Practice | SpringerLink.
- Hitt, C., Douglas, J., Keoleian, G., 2023. Parametric life cycle assessment modeling of reusable and single-use restaurant food container systems. *Resour. Conserv. Recycl.* 190, 106862. <https://doi.org/10.1016/j.resconrec.2022.106862>.
- International Organization for Standardization (ISO), 2006a. ISO 14040:2006 Environmental Management – Life Cycle Assessment – Principles and Framework.
- International Organization for Standardization (ISO), 2006b. ISO 14044:2006 Environmental Management – Life Cycle Assessment – Requirements and Guidelines. Geneva, Switzerland.
- International Organization for Standardization (ISO), 2013. ISO 18603:2013. Packaging and the Environment - Reuse. Geneva, Switzerland.
- Levi, M., Cortesi, S., Vezzoli, C., Salvia, G., 2011. A comparative life cycle assessment of disposable and reusable packaging for the distribution of Italian fruit and vegetables. *Packag. Technol. Sci.* 24, 387–400. <https://doi.org/10.1002/pts.946>.
- Megale Coelho, P., Corona, B., ten Klooster, R., Worrell, E., 2020. Sustainability of reusable packaging – current situation and trends. *Resour. Conserv. Recycl.* X 6, 100037. <https://doi.org/10.1016/j.rcrx.2020.100037>.
- Packaging Working Group, 2016. Packaging Working Group Guidance Document, 1.0. European Commission.
- Parker, L., 2019. How the plastic bottle went from miracle container to hated garbage. *Natl. Geogr.* August 23, 2019 <https://www.nationalgeographic.com/environment/article/plastic-bottles>.
- Pereira, A., Villanueva-Rey, P., Vence, X., Moreira, M.T., Feijóo, G., 2018. Fresh milk supply through vending machines: consumption patterns and associated environmental impacts. *Sustain. Prod. Consum.* 15, 119–130. <https://doi.org/10.1016/j.spc.2018.05.003>.
- Plastics Europe, 2024. The circular economy for plastics – a European analysis 2024. <https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/>.

- Ponstein, H.J., Meyer-Aurich, A., Prochnow, A., 2019. Greenhouse gas emissions and mitigation options for German wine production. *J. Clean. Prod.* 212, 800–809. <https://doi.org/10.1016/j.jclepro.2018.11.206>.
- Rigamonti, L., Biganzoli, L., Grosso, M., 2019. Packaging re-use: a starting point for its quantification. *J. Mater. Cycles Waste Manag.* 21, 35–43.
- Simon, B., Ben Amor, M., Földényi, R., 2016. Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. *J. Clean. Prod.* 112, 238–248. <https://doi.org/10.1016/j.jclepro.2015.06.008>.
- Stefanini, R., Borghesi, G., Ronzano, A., Vignali, G., 2021. Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. *Int. J. Life Cycle Assess.* 26, 767–784. <https://doi.org/10.1007/s11367-020-01804-x>.
- The Consumer Goods Forum (TCGF), 2011. Global protocol on packaging sustainability 2.0. https://www.gs1gt.org/productos/sostentibilidad/descargas/protocolo_global.pdf. November 2023.
- Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *Br. J. Manag.* 14 (3), 207–222. <https://doi.org/10.1111/1467-8551.00375>.
- Tua, C., Biganzoli, L., Grosso, M., Rigamonti, L., 2019. Life cycle assessment of reusable plastic crates (RPCs). *Resour.* 8, 110. <https://doi.org/10.3390/resources8020110>.
- Van Doorsselaer, K., Lox, F., 1999. Estimation of the energy needs in the life cycle analysis of one-way and returnable glass packaging. *Packag. Technol. Sci.* 12, 235–239. [https://doi.org/10.1002/\(SICI\)1099-1522\(199909/10\)12:5%3C235::AID-PTS474%3E3.0.CO;2-W](https://doi.org/10.1002/(SICI)1099-1522(199909/10)12:5%3C235::AID-PTS474%3E3.0.CO;2-W).
- Wood, G., Sturges, M., 2010. Single Trip or Reusable Packaging – Considering the Right Choice for the Environment. WRAP, Banbury, UK.
- World Resources Institute (WRI), 2016. Food loss and waste accounting and reporting standard. https://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_final_2016.pdf.
- WRAP, 2023. UK Plastics Pact Reuse Round Tables – Final Project Report. London, UK. Available at: UKPP Reuse Round Tables - Final Project Report Draft v9 FINAL.pdf (wrap.org.uk). Accessed in December 2023.
- Zampori, L., Pant, R., 2019. Suggestions for Updating the Product Environmental Footprint (PEF) Method, EUR 29682 EN. Publications Office of the European Union, Luxembourg. <https://doi.org/10.2760/424613,JRC115959>. ISBN 978-92-76-00654-1.
- Zhou, Y., Shan, Y., Guan, D., Liang, X., Cai, Y., Liu, J., Xie, W., Xue, J., Ma, Z., Yang, Z., 2020. Sharing tableware reduces waste generation, emissions and water consumption in China's takeaway packaging waste dilemma. *Nat. Food* 1, 552–561. <https://www.nature.com/articles/s43016-020-00145-0>.
- Zink, T., Geyer, R., 2017. Circular economy rebound. *J. Ind. Ecol.* 21 (3), 593–602. <https://doi.org/10.1111/jiec.12545>.