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Two packaging systems in competition

Reusable plastic crates vs. single-use cardboard boxes

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REUSABLE PLASTIC CRATES vs. SINGLE-USE CARDBOARD BOXES

- two packaging systems in competition

Authors: Stefan Albrecht, Jürgen Bertling*, Matthias Fischer, Florian Gehring**, Stephan Kabasci, Tim Prescher, Anna Schulte

Contacts:

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
Osterfelder Straße 3, 46047 Oberhausen, Germany
www.umsicht.fraunhofer.de

***Jürgen** Bertling
juergen.bertling@umsicht.fraunhofer.de

Fraunhofer Institute for Building Physics IBP
Wankelstrasse 5, 70563 Stuttgart, Germany
www.ibp.fraunhofer.de

****Florian** Gehring
florian.gehring@ibp.fraunhofer.de

Client:

STIFTUNG INITIATIVE MEHRWEG
Taubenstrasse 26, 10117 Berlin

Contact person:
Dr. Jens Oldenburg
j.oldenburg@stiftung-mehrweg.de

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Statement on funding, responsibilities and terms of use

The preparation of this report was commissioned by the Stiftung-Initiative-Mehrweg (SIM). For this purpose, literature and statistical data were evaluated and two interviews were conducted. Furthermore, two studies commissioned by the European Federation of Corrugated Board Manufacturers (FEFCO) form the basis for the work. The present report is to be understood as a response to these studies in order to initiate an overarching discourse on the two central solution approaches for packaging tasks – single-use and reuse.

This response represents a scientific expression of opinion, which is based on available data, but also has a normative character in the interpretation. Experiments or own data collection were not carried out but are included in parts of the cited literature. The statements in this report relate to life cycle assessments carried out in accordance with the ISO 14040 standard. However, the report itself is not subject to the requirements of ISO 14040. The statements in the FEFCO studies were not always comprehensible without further background data, resulting in uncertainties in the assessment.

The authors were free to formulate the report; there was no influence from the client, the experts consulted or other third parties. Nevertheless, the client had the opportunity to critically comment on preliminary versions of the report once. The results of the report do not always represent the view of the commissioning organizations or the Fraunhofer institutes UMSICHT and IBP, but primarily the view of the authors involved. An internal review process took place at both institutes.

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1 Executive Summary

The European Federation of Corrugated Board Manufacturers (FEFCO), based on the results of scientific studies, conducted by Ramboll and VTT, recently claimed that

- corrugated cardboard boxes were advantageous over plastic-based reusable crates for vegetable packaging and that
- a modification of the waste hierarchy in favor of decision-making based on life-cycle analyses was needed.

Our own previous studies and the following response to two of the studies commissioned by FEFCO show, however, that central statements in favor of cardboard single-use systems are not plausible in our view. We see the following reasons for this:

- A high reutilization rate (above 95 percent) is the central prerequisite for a circular economy. Due to the currently recognizable limits of material recycling, this can only be achieved with reuse systems. At the same time, reuse systems also reduce dependence on imports and strengthen Europe's technological sovereignty.
- Reusable packaging, not single-use packaging, seems superior in terms of "fit-for-purpose". Their higher material input, which can be apportioned to several uses, in particular allows a better product protection, and they are more suitable for modern digitalization solutions.
- The results of the life cycle assessment study commissioned by FEFCO are based on a base scenario that is very unfavorable for the reuse systems. With parameters such as those reported for European B2B reuse systems, which we consider to be more realistic, the reuse system performs significantly better.

As a result, we come to the following recommendations:

1. The waste hierarchy should be maintained, strengthened and implemented.
2. Deviations from the order of priority specified by the waste hierarchy, as represented by the direct recycling of single-use packaging, should be justified by proof of the ecological advantage over competing reuse systems as indicated by life cycle assessment and other criteria (e. g. littering, product safety or technological sovereignty).
3. Reuse systems should be supported and promoted through appropriate regulatory and policy measures.
4. Comparative life cycle analyses should be carried out on the basis of transparent, realistic parameters to be agreed upon in a multi-stakeholder process.
5. Single-use packaging contributes significantly more to littering than reusable packaging and this fact must be adequately taken into account when assessing environmental impacts.

6. Transparent monitoring should be introduced for the key parameters of reuse systems – circulation figures, breakage and leakage rates, and end-of-life recycling rates.
7. Single-use systems are short-lived goods, and their recyclability should be measured in terms of reutilization rates in new products rather than in recycling rates based on collected waste.

2 Preliminary remark and reason for this statement

The decision between the packaging systems single-use and multi-use is, strictly speaking, a decision between the two most important options for a circular economy: "recycling" or "reuse". As a premise, it seems obvious to use everything as long and often as possible. Only when this is no longer possible or reasonable due to damage, loss of performance or ecologically superior innovations, the components and/or materials used should be recycled. This idea has already been anchored in the German Kreislaufwirtschaftsgesetz (Closed Substance Cycle Waste Management Act) and the European Waste Framework Directive with the concept of the "waste hierarchy".

The top priority in the waste hierarchy is the avoidance of waste, which includes reuse as the most important measure in addition to generally abandon the use of materials or products. On the second level are measures that enable reuse, such as cleaning and repair. Only when these two options have been exhausted, waste should be sent for material recycling. If this is also no longer possible, energy recovery is to be considered. The purpose of a waste hierarchy is that, until proven otherwise, it is assumed that a higher hierarchy level is ecologically advantageous compared to the subsequent ones. The European Waste Framework Directive therefore requires for any deviation from the waste hierarchy, that a lower level achieves a better overall result with respect to environmental protection, calculated on a life-cycle basis (EU RL 2008/98).

In the course of current discussions on a Circular Economy, the hierarchical stages have been further differentiated under the term "R-strategies". Measures such as repair, refurbish, and remanufacture, which are also generally considered more sustainable than recycling, have been added. Recycling is generally considered to be the final R-strategy to be applied at a later stage, see e.g. (Reike et al. 2018) or (Potting et al. 2017).

Despite the legal anchoring of the waste hierarchy and the associated prioritization of reuse systems, they can still be found in a few sectors of the economy only. Even in beverage packaging, where they dominated in the past, their share has been declining for a long time. In Germany, for example, it is currently far below the legally stipulated reuse quota of 70 percent. (Federal Environment Agency 2020). At the same time, per capita packaging consumption is rising steadily, and the overall low recycling rate has so far hardly led to a reduction in the use of resources or reduced environmental impacts. (Federal Environment Agency 2022b).

The situation described leads to studies being presented time and again by both the stakeholders of the reuse and the single-use side, which are supposed to prove the fundamental advantageousness of the respective system. On the one hand, to avoid the application of the waste hierarchy, on the other hand, to demand its consistent implementation. Corresponding studies have recently been commissioned and published by the European Federation of Corrugated

Board Manufacturers (FEFCO) to compare reuse (here in particular plastic-based reusable crates) and single-use (here in particular cardboard boxes):

- "A critical view on packaging recycling and reuse in the European Circular Economy." (Pajula and Sundqvist-Andberg 2022).
- "Comparative Life Cycle Assessment (LCA) - Packaging Solutions for the Food Segment." (Castellani et al. 2022)

Based on the results obtained by the contractors (VTT, Ramboll), a basic superiority of single-use systems was derived by FEFCO in a summary statement.

- "Recycling vs. Reuse for Packaging - Bringing the science to the packaging debate." (FEFCO 2022)

The studies mentioned and conclusions made therein are partly contradictory to the results from two studies by Fraunhofer institutes from 2018 and 2022:

- "Carbon footprint of packaging systems for fruit and vegetable transport in Europe." (Krieg et al. 2018a)
- "Kunststoffbasierte Mehrwegsysteme in der Circular Economy." (Bertling et al. 2022)

The different results and conclusions in the above-mentioned studies are the motive for our statement presented here, in which we try to explain the reasons for the different results and our different view. At the same time, we want to point out ways to reach a robust knowledge base for future political decision-making processes.

3 A generic look at reuse and single-use systems

The comments in this chapter should be understood as a response to VTT's white paper, "A critical view on packaging recycling and reuse in the European Circular Economy." (Pajula and Sundqvist-Andberg 2022).

3.1 The waste hierarchy is a reasonable, but so far insufficiently implemented component of the circular economy.

Although the waste hierarchy has been discussed since the 1970s[1], it was not included in the European Waste Framework Directive until 2008. According to the waste hierarchy, the top priority is the prevention of waste, which includes the reuse of products as the most important measure, in addition to generally abandon the use of materials or products (Figure 1). At the second level of the hierarchy are measures that enable reuse, such as cleaning and repair. Only when these two options have been exhausted, waste should be sent for material recycling. If this is also no longer possible, energy recovery is to be considered. Disposal (landfilling) represents the final stage of the waste hierarchy. The statements in the legal acts repeatedly point out that all waste management measures must be carried out in accordance with the waste hierarchy.

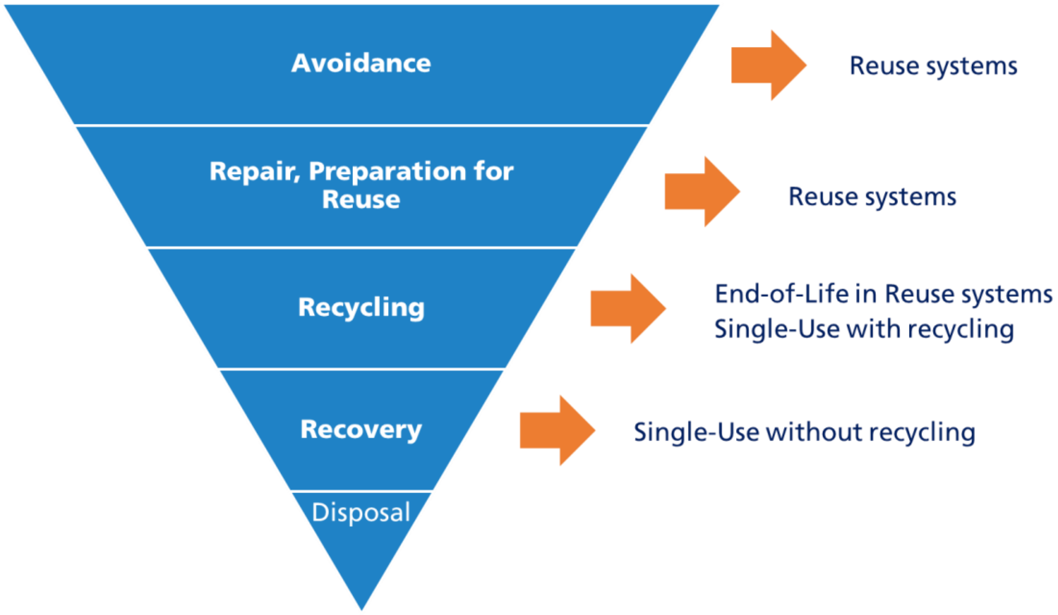

Figure 1: Placement of single-use and reuse systems in the European waste hierarchy (Bertling 2021).

To date, there is no theoretical or empirical foundation for the waste hierarchy. However, its usefulness can be justified by the fact that each level contains the subsequent ones, but not the preceding ones, as additional options. For example, a product that has been reused several times can be recycled later, and if

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[1] Cf. "Lansink's Ladder"; https://www.adlansink.nl/voorbeeld-pagina/

this is no longer possible, it can be recovered energetically. Conversely, a product that has been burnt for energy recovery can no longer be recycled, and a recycled product (after the usual mechanical comminution) can no longer be reused. Keeping the options open thus requires the primacy of the waste hierarchy to be taken seriously and to be implemented.

The European Waste Framework Directive (Waste Directive (EU RL 2008/98)) requires for any deviation from the ranking of the waste hierarchy, that a lower level achieves a better overall result from a life-cycle perspective in terms of environmental protection (cf. §4 (2) in Table 1). An assessment from a life-cycle perspective is usually understood as a complete environmental performance analysis (European Commission 2010). A further restriction of the waste hierarchy can be found in the Packaging and Packaging Waste Directive (94/62/EC) including the amending directive (2018/852/EU), which additionally requires taking food hygiene and consumer protection into account.

However, the legal acts do not prescribe how to compare exactly single-use and reuse systems in order to justify a deviation from the waste hierarchy on this basis. Lazarevic et al. (2010) point out that this situation has led to the waste hierarchy being increasingly questioned and undermined. At the same time, the authors emphasize that the results of life cycle assessments and other environmental performance analyses are only valid in relation to the individual case and the assumptions made (cf. chapters 3.4 and 0).

The current German Packaging Act (VerpackG) addresses the requirements for the waste hierarchy only very weakly and sporadically. For example, a reuse quota of at least 70 percent for beverage bottles is mentioned among the general objectives, without this requirement being specified in more detail in terms of time or the deviation being linked to proof of ecological advantages of the single-use systems in the sense of the European Waste Framework Directive.

From 2023, offering a reusable alternative for service packaging in the catering sector at the same price will be mandatory. However, also in this case, no proof of ecological advantage or at least equivalence is required for maintaining the single-use offer. The German Packaging Act does not contain any mechanisms for promoting reusable packaging in the sense of the waste hierarchy for any other packaging applications. For packaging that is subject to mandatory participation in the dual systems (i.e., packaging that is disposed of at the end consumer), fees are levied, the amount of which is supposed to be based on the degree of recyclability. However, there are no requirements regarding the ecological benefits in comparison to reusable packaging.

Table 1: References to the waste hierarchy in European legal regulations

Legal act	Reference to the waste hierarchy
Directive **2008/98/EC** on waste (WD: Waste Directive)	**§ 4 (1)** The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: • (a) prevention; • (b) preparing for re-use; • (c) recycling; • (d) other recovery, e.g. energy recovery; and • disposal **§ 4 (2).** When applying the waste hierarchy referred to in paragraph 1, Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste. [….] **§ 4 (3)** Member States shall make use of economic instruments and other measures to provide incentives for the application of the waste hierarchy, [...]. **§ 8 (2)** Member States may take appropriate measures to encourage the design of products and components of products in order to reduce their environmental impact […] Such measures may encourage, inter alia, the development, production and marketing of products and components of products that are suitable for multiple use, that contain recycled materials, that are technically durable and easily reparable and that are, after having become waste, suitable for preparing for re-use and recycling in order to facilitate proper implementation of the waste hierarchy. The measures shall take into account the impact of products throughout their life cycle, the waste hierarchy and, where appropriate, the potential for multiple recycling
Directive **94/62/EC** on packaging and packaging waste incl. the amending Directive **2018/852/EC** (PPWD: Packaging and Packaging Waste Directive).	**§ 5 (1)** In line with the waste hierarchy laid down in Article 4 of Directive 2008/98/EC, Member States shall take measures to encourage the increase in the share of reusable packaging placed on the market and of systems to reuse packaging in an environmentally sound manner and in conformity with the Treaty, without compromising food hygiene or the safety of consumers. Such measures may include, inter alia: • the use of deposit-return schemes; • the setting of qualitative or quantitative targets; • the use of economic incentives; • the setting up of a minimum percentage of reusable packaging placed on the market every year for each packaging stream. **Annex II (1)** Packaging shall be designed, produced and commercialised in such a way as to permit its reuse or recovery, including recycling, in line with the waste hierarchy, and to minimise its impact on the environment when packaging waste or residues from packaging waste management operations are disposed of. **Annex IV (4)** The implementation plan to be submitted […] shall contain […] [...] including appropriate economic instruments and other measures to provide incentives for the application of the waste hierarchy [...].

Pajula and Sundqvist-Andberg (2022) write against this background in relation to the situation of recent years of an "improved waste hierarchy approach". This appears questionable at least because ultimately in practice it is often a non-legitimized disregard for the concept of the waste hierarchy, regardless of whether one wants to understand it as a fixed "basic principle" or as a "guideline" having the character of a recommendation.

Since the structure of the waste hierarchy represents a plausible and easily understandable order of priority and, as R-strategies, also plays a key role in modern concepts for the circular economy, we advocate retaining it. Those actors who want to deviate from it should present a viable justification based on life cycle analyses which, in addition to ecological impact categories, should also include other sustainability effects (e.g., littering, product protection or technological sovereignty). Such life cycle analyses cannot be of generic nature but must concern the concrete individual case and are only valid for this case. The system boundaries, the setting of parameters and the correct choice of methodology should be defined in a fair and transparent multi-stakeholder process that brings together the various interests and leads to a consolidated starting point for the comparisons in order to enable a rational decision-making process (cf. chapter 3.4).

3.2 High reutilization rates, not recycling rates, are the basis for a circular economy.

Pajula and Sundqvist-Andberg (2022) state in their white paper that the essential basis for the circular economy is recycling and subsequently justify the advantageousness of corrugated cardboard with its high recycling rate. In 2019, this was 82.0 percent (paper, paperboard and cardboard). However, the figures have been falling since 2017, when the recycling rate was 85.4 percent.

Albeit it is true that a high recycling rate has a favorable effect on the circular economy, this alone is not enough. The fundamental objective in a circular economy is that as much as possible of the material originally used for any application is reused for the same purpose. Only then a Circular Economy reliably succeeds in reducing the use of primary raw materials. This goal can be achieved both by non-destructive reuse and by recycling into the same application or into an equivalent material stream. The recycling rate is related to the amount of waste collected - which is usually less than the amount produced due to losses or growth effects. The reutilization rate, which describes the amount of secondary raw material input in relation to the quantity of material in the cycle, would be the more important parameter for the comparative evaluation of single-use and reuse systems. In the case of single-use systems, it corresponds to the secondary raw material input in relation to the quantity produced; in the case of reuse systems, it is calculated from the quantity of products in circulation minus the leakage rate.

Overall, production and consumption in the paper and cardboard sector in Europe (EU-28) have decreased slightly since 2012. For plastics, the production volume has also decreased, while consumption has increased a bit. At the same time, the reutilization rate for paper and cardboard has risen from 50.8 to 56.0 percent and for plastics from 14.9 to 18.5 percent, so that the primary raw material demand in both material groups, considered over all their applications, has decreased somewhat (cf. Table 2), source data also there).

In the packaging sector, on the other hand, paper and cardboard have shown a significant increase in production and consumption over the last decade. However, the reutilization rate has remained almost unchanged, albeit at a high level of around 75 percent. This has led to an increase in the use of primary raw materials for packaging production in the European paper and cardboard sector since 2012. The production of plastic packaging has increased less significantly over the same period, and the reutilization rate of 31.5 percent is still at a very low level.

Table 2: Reutilization rates for paper/cardboard and plastics

Branch	**Life cycle stage**	**Paper and cardboard**		**Plastics**[I]	
		2012	**2021**	**2012**	**2020**
total	Production (in 1000 tons per year)	92 081	90 583	57 000	55 000
	Consumption[II] (in 1000 tons per year)	77 364	72 219	45 900	49 100
	Utilization rate[III]	50,8 %	56,0 %	14,9 %	18,5 %
	Net reutilization rate (recycled content)[IV]	-	42,5 %		
Packing	Production (in 1000 tons per year)	40 787	53 545	18 085	19 900
	Consumption (in 1000 tons per year)	35 352	44 934	n. d.	n. d.
	Reutilization rate	75,6 %	74,8 %	26,1 %	31,5 %
	Net reutilization rate (recycled content)	-	56,8 %		

Data sources: (CEPI 2013, 2022; Plastics Europe 2013, 2021; EUROSTAT 2022).

Notes:

I Reuse systems are not explicitly considered in the statistics and tables used. In the area of paper, this is not problematic, as there are in fact no reusable applications. In the area of plastics, this can lead to certain distortions, since reusable packaging is taken into account on the production side, but not on the waste side.

II The quantities of plastics consumed correspond to the European demand for processing.

III For the reutilization rate, the recycled quantities were related to the produced quantity.

IV For paper and cardboard, the difference between raw material input and production volume was used to calculate the net reutilization rate. For packaging, the paper and cardboard industry average was also used.

V Data for plastics from 2019 (instead of 2020).

However, the reutilization rate does not yet represent the actual recycled content (net reutilization rate) in the product. Degraded fiber content, labels, colorants and adhesives, coatings, foreign substances and discards reduce the recyclable content. From a comparison of raw material input and production volume, assuming that the non-recyclable fractions are mainly in the recovered paper but not in the primary raw materials, an average recyclable fraction of 75.9 percent can be calculated for the recovered paper fraction. A recycled content of 42.5 percent is calculated for paper and cardboard as a whole and 56.8 percent for paper and cardboard in packaging. In some applications with lower quality requirements, higher recyclate percentages are possible. At the same time, however, the packaging sector uses high-quality materials (kraftliner, semichemical fluting), for which the recyclate content is significantly lower. These are also used, for example, for fruit and vegetable crates (cf. chapter 4.2.1). One reason for the low recyclate content is that the recyclability requirements for products are not very demanding. For example, in the paper industry, according to the RESY standard, which is used to assess recyclability, recovered paper is considered recyclable above a recyclable content of 50 percent (as an example (PTS 2021)).

For a comparison of single-use and reusable packaging, it does not make sense to use the EoL recycling rate for reusable packaging, but rather to balance the proportion of packaging that remains in the multi-use cycle and is thus reused. This corresponds to the net reutilization rate. In the area of reuse systems, the net reutilization rate results primarily from the leakage rate in the case of a stationary state, i.e., a constant number of containers in circulation.

Net reutilization rate = 100 % - Leakage rate

Leakage is mainly caused by the removal of packaging from the cycle for non-intended uses (e.g., the use of boxes for moving or of returnable cups as collection objects). The leakage rate and thus the net reutilization rate therefore depend primarily on the incentive system for return (deposit, rental fee) and on how attractive the packaging system is for non-intended use. Defective reusable packaging, on the other hand, does not automatically contribute to the leakage rate, as it can be recycled and is thus not lost to the material cycle.

Leakage rates are usually high when a new reuse system is introduced and then drop significantly over time. Typical leakage rates for established reuse systems are in the range of less than one percent (cf. chapter 3.3). To date, however, there is no established higher-level monitoring system that records and makes available circulation figures, leakage rates and breakage rates. These data, which are important for calculating the ecological performance of reuse systems, should be presented openly and transparently in the future in order to be able to assess the performance of a reuse system more accurately.

In principle, however, it can be expected that in reuse systems there is a high level of interest in recycling among all participants along the supply chain due to the incentive systems used. A track-and-trace over many circulations is easily possible due to the non-destructive circulation. The opportunity exists to create digital twins that record all information about transported goods, circulation figures, weather influences, etc. over the entire life cycle. In the case of single-use systems, on the other hand, there are only limited incentives for closed-loop recycling (cf. also the plastic litter issue in Section 3.6). At the same time, the returned material is a mixture of wastes with an unknown history. Various research projects are attempting to find solutions to this problem through complex marking of the packaging and complex plant technology for sorting (Holy Grail 2.0 (Schröer 2020)). However, the information attributed to the single-use packaging can ultimately no longer be clearly assigned beyond the destructive recycling process, so that traceability is only possible to a limited extent here.

If reusable packaging is discarded for aesthetic reasons, or if it is worn out or broken, it can still be repaired or recycled. Accordingly, recycling merely represents the tertiary option of closed-loop recycling. Transferring the recycling rate of single-use plastic packaging (41 percent (EUROSTAT 2022)) to reuse systems, as (Pajula and Sundqvist-Andberg 2022) did in their study, is not justified in our opinion. Such a comparison of overall recycling rates is unsuitable for comparing concrete systems (reusable crates versus single-use boxes). Plastic reusable packaging, unlike the single-use plastic packaging essentially represented in the recycling rate of 41%, consists of high-quality, single-grade polyolefins (PP or HDPE). They are mostly contained in closed B2B loops or are endowed with a deposit in the B2C sector, so that an almost complete return is guaranteed[2] . The history of the packaging and the material is also often known. If performance deteriorates due to wear or breakage, the packaging can be regranulated according to type and thus used for high-quality recycling for the same application. The recycling rate for these plastic products (reusable packaging) is therefore close to 100 percent. (Bekuplast 2015).

3.3 Circulations, breakage and leakage rates are the most important performance parameters for reuse systems.

The circulation numbers of a reuse system are determined by leakage and rejection (due to breakage, defects, aesthetic or functional reasons). These quantities are related in a stationary system as follows:

1/circulations * 100 % = leakage rate + rejection rate

Broken boxes can be sorted out partially if they can be repaired by spare parts. This means that, in principle, the losses of reusable packaging are fully recorded in the number of circulations. An additional consideration of leakage or also breakage rates to the circulation figure leads to a double counting of the losses and distorts the result of balancing and ecological evaluation. The rejection rate can be used to determine the proportion that is recycled. The leakage rate, on the other hand, determines definite material losses (see chapter 3.2).

As part of a meta-study, Fraunhofer UMSICHT and Fraunhofer IML examined the circulation figures for fruit and vegetable multi-use crates given in various LCA studies and values named by industry experts (cf.

Table 3). The comparison of circulation numbers and service life shows that approx. 10 uses per year are typical. Based on the literature researched, a practical circulation number of up to 100 and a service life of approx. 10 years appear to be realistic for plastic-based reusable crates. A circulation number of 100 means a cumulative loss rate (leakage, and rejection) of 1 percent.

The leakage rate is reported by experts to be about 0.8 percent (Muske 2021). For breakage, data could be obtained from the study of (Lange and Pelka 2013) of 0.12 percent, and from an internal company study by IFCO and EPS values of 0.53 percent were determined (Krieg et al. 2018b). This gives a range for total losses of 0.8 to 1.33 percent. This results in circulation figures of 125

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[2] Losses are already taken into account in the leakage rate in particular.

and 75, respectively, which are very much in line with the assumption of around 100 circulations (see also Box 1). An exception could be extensive rejection for aesthetic or functional reasons or the abandonment of entire pools. However, no data are available on the relevance and frequency of such cases.

Table 3Circulation figures and service life from life cycle assessment studies and expert statements for reusable crates (Bertling 2021)

Circulation number	Lifetime (years)	Source/Expert
Life Cycle Assessments		
1-150		(ADEME 2000)
50 -100	10	(Albrecht et al. 2009)
200	20	(Levi et al. 2011)
50 - 200	20	(Albrecht et al. 2013)
30 - 70		(Accorsi et al. 2014)
700	13,75	(Koskela et al. 2014)
20 - 200		(Battini et al. 2016)
23,4 - 72,9		(Franklin Associates 2016)
100	10	(Baruffaldi et al. 2019)
100 - 150	10	(Abejón et al. 2020).
	7	(Accorsi et al. 2020)
150	1,5	(Antala et al. 2020)
50	5	(Del Borghi et al. 2020).
150		(López-Gálvez et al. 2021)
1 - 125		(Tua et al. 2019)
50		(Hofmeister et al. 2021)
Expert interviews		
250		(Haidlmair 2021)
50 - 100	7-10	(Muske 2021)
	10-15	(Kellerer 2021)
100 --200	5-20	(Robbert 2021)

The rates described above represent values for fruit and vegetable crates. For the future, it is important that the circulation numbers from various applications are monitored and the results are presented transparently. It is also particularly interesting to see how the circulations develop when new systems are introduced.

Box 1:
"It is in the company's own interest to reduce leakage, damage and rejection of reusable crates as far as possible. Defective crates are repaired and less than 0.5 percent are rejected as non-repairable. The rejects are regranulated and this material is used for producing new crates. The number of returnable crates is consistently recorded by all those involved in the process chain, so that the leakage rate is less than 1 percent. Average lifetimes of 12 years are common and circulation rates of 80 to 120 are easily achievable for well-positioned companies."
Alexander Markow
(Managing Director National Logistics, ALDI Süd Dienstleistung-SE & Co. oHG)

3.4 Comparison with life cycle assessments is laborious, sometimes uncertain, but ultimately unavoidable.

Life cycle assessments are based on ISO standards 14040 and 14044 and are one of the most important tools for determining the environmental impacts of products, services and processes. Using them, both product comparisons and the contributions of individual practices to the overall environmental impact can be estimated.

There are numerous comparative life cycle assessment studies on reusable and single-use items. Sometimes they arrive at different results even for the same task. The reasons for this are different assumptions in the study framework or diverging background data, and the modeling approaches can also vary. As soon as fundamental assumptions differ, the direct comparison of two studies is inconsistent. However, consistency, defined as freedom from logical contradictions, is a mandatory requirement for comparative life cycle assessments (Weidema 2019). Two studies can each be internally consistent, but at the same time inconsistent with another, so that direct comparability is not possible. These inconsistencies can lead to contradictory conclusions being derived from two (or more) LCAs in comparison.

It is important that when comparing different LCAs with different assumptions, system boundaries or data, either a separate LCA calculation with the same boundary conditions is carried out or a well-grounded interpretation is made – if possible with reference to the underlying documents (e.g. negotiation minutes of a standardization body taking into account expert assessments of all comparison alternatives) or due to the hierarchical ranking of standards (e.g. the requirements of ISO 14044 have priority over other standards such as the Product Environmental Footprint, PEF). This also implies that for different comparison options, experts from all parties should jointly define framework conditions and assumptions in order to perform a comparison that is as consistent and robust as possible.

A meta-analysis by Fraunhofer UMSICHT and Fraunhofer IML for fruit and vegetable crates, plant trays and coffee-to-go cups has shown advantages of the reusable systems for greenhouse gas emissions (GHG) in all three applications (Bertling et al. 2022). The medians of the results are each in favor of the reuse systems (cf. Figure 2; note the inversely scaled x-axis, on the right are the systems with the lowest GHG emissions). Nevertheless, it is noticeable in the chosen boxplot representation that the range and overlap of the result areas are considerable. Additionally, the results hardly seem to become more robust with an increasing number of studies carried out.

The reasons for the different results lie primarily in the base scenarios selected in each case and the associated parameters for the life cycle assessments. Circulation numbers, breakage and leakage rates, recyclate quantities used in production, and recycling rates at the end of life are important parameters influencing the results. Many LCAs test the influence of these parameters in sensitivity analyses. In most studies, however, this is done only as a variation of individual parameters whose effects are examined as a consequence of a deviation from a selected baseline scenario. Despite sensitivity analysis, therefore, coupled and nonlinear effects that occur when several parameters are varied simultaneously and may significantly change the outcome of the comparison may remain undetected. A complement to single-factor variation would be the consideration of uncertainties in parameters used, for example in Monte Carlo simulations. In this case, the entire definition range of the parameters and their simultaneous variation is taken into account. A detailed comparison of the life cycle assessments of reusable plastic crates and single-use cardboard boxes for fruit and vegetables, carried out by Ramboll on behalf of FEFCO and by Fraunhofer IBP on behalf of SIM, can be found in chapter 0 of this position paper.

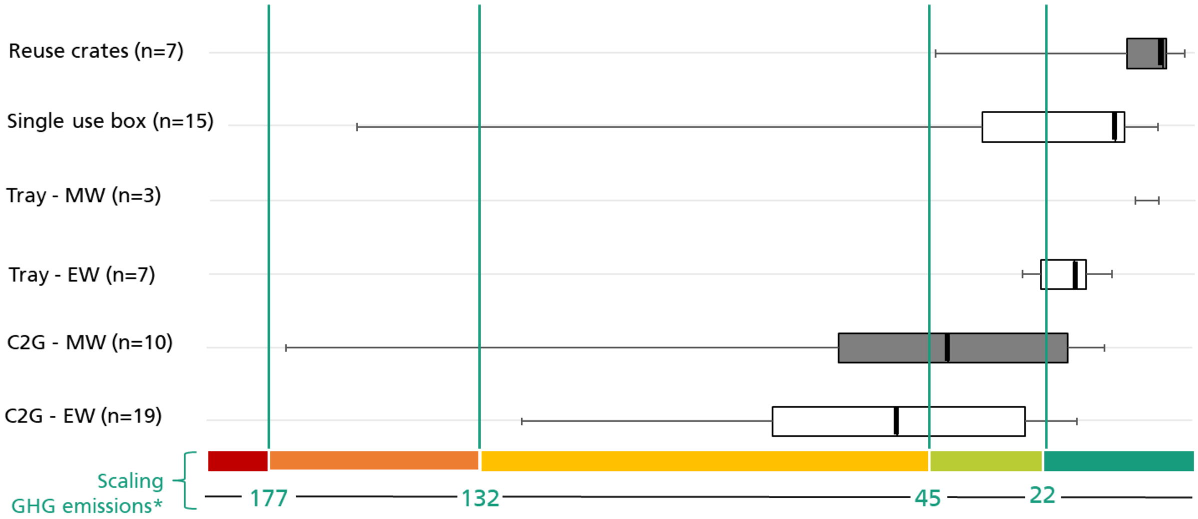

Figure 2: Results of a meta-analysis on greenhouse gas emissions from reuse and single-use systems
(* In kg CO_2 -eq per circulation and 1000 L packed volume. The volume of the plant trays refers to the calculated volume of all plant pots that fit into the respective tray. The data are presented as a boxplot. Here, the value on the far left is the maximum value and the one on the far right is the minimum value. The vertical line in the middle represents the median and the box around the median includes the 25 percent of the data that are above and below the median. A detailed explanation of the boxplot can be found here: https://en.wikipedia.org/wiki/Box_plot)

Another aspect that influences the result of a life cycle assessment is the balancing of end-of-life processes and the allocation rules applied. Here, the main focus is on whether credits or debits from downstream processes are credited for recyclate use or production and how these are to be allocated between two product life cycles. Ultimately, the allocation rules reflect environmental policy prioritizations according to which the recyclate content in the product should be increased or the recyclability at the end of life should be improved.

In the present situation, therefore, there may be several LCAs - each consistent and comprehensible in itself - on the same problems, which arrive at different results. If a large number of LCAs are available on a given topic, meta-analyses can be carried out in an attempt to "tease out" the variation in parameter assumptions, system boundaries and allocation rules. In the present case, our own meta-analysis confirmed the advantages for reuse systems. Ultimately, however, this situation remains unsatisfactory and the result uncertain.

So far, LCA comparisons are often commissioned by an industry association or as a single case study of one actor, so that data on the competing comparison system are not available and estimated with sufficient accuracy. As a rule, the parameter sets used are not confirmed by the respective other industry association or actor. Especially, if a deviation from the waste hierarchy is to be legitimized by a life cycle assessment, it seems to us to only make sense if agreement is reached between the actors and stakeholders of all the systems to be compared on the method, the parameters and the selected parameter combinations as well as the scenarios and impact categories investigated. For this, political assistance would be helpful.

3.5 Packaging must also contribute to achieving the climate targets.

Crippa et al. (2021) have presented in a paper that was also cited in the work of Pajula and Sundqvist-Andberg (2022) the greenhouse gas emissions from food production along entire value chains. They conclude that food production as a whole is responsible for 34 percent of global GHG emissions and that of these, emissions associated with packaging account for only 5.4 percent. Overall, these assumptions give food packaging a 1.9 percent share of total global greenhouse gas emissions. Pajula and Sundqvist-Andberg (2022)conclude that it is therefore necessary above all to reduce emissions elsewhere in the food chain, for example by reducing food losses (cf. chapter 3.7) and by increasing the use of packaging.

The European Union's climate targets are ambitious and require not only that particularly relevant aspects be addressed, but that almost all practices of consumption and production be rethought. The aim is to achieve a 55 percent reduction by 2030 compared with 1990 levels, and to achieve climate neutrality by 2050.

Packaging, through its design and weight, influences other life cycle stages in food production, such as transport and storage, and can therefore be a key element in mitigation strategies. However, the direct emissions associated with them also need to be reduced. A continuation of current practices in dealing with packaging would mean that food packaging alone would already account for 2.5 percent of total annual GHG emissions in 2035 and 7.4 percent by 2045 (cf.

Table 4). Consequently, the zero emissions target for 2050 could not be met. From this consideration, it becomes clear that even though packaging is not responsible for the largest share of GHG emissions compared to other sectors, a continuation of current practices is not compatible with climate targets. Therefore, solutions need to be found that allow direct emissions reductions for packaging without implementing new emissions at other stages of the life cycle. The combination of reuse and recycling, where packaging is managed in pool systems, used as often as possible and finally sent for high-quality recycling at the end of its life, could be such a strategy.

Table 4: Greenhouse gas targets of the European Union for the coming decades and development of the share of food packaging in business-as-usual. (Umweltbundesamt 2022a) .

Year	2015	2030	2035	2040	2045	2050
	Current value	**(55 % compared to 1990)**	**interpolated**			**Target: zero emission**
Greenhouse gas emissions in metric tons per capita and year according to EU targets [metric tons per capita and year].	8	6,9	5,17	3,45	1,73	0
Share of packaging for food if current practice is continued	1,6 %	1,9 %	2,5 %	3,8 %	7,4 %	100 % (Target is missed)
Share of transport for food if current practice is continued	1,5 %	1,7 %	2,3 %	3,5 %	6,8 %	100 % (Target is missed)

3.6 Packaging should be "fit-for-purpose."

The primary functions of packaging are protection, storage, loading and transport. Above all, these require robust and standardized packaging (GDV 2022). In contrast to single-use systems, the material input and the costs for the packaging are apportioned to several uses in reuse systems. The higher the number of circulations, the more robust the packaging can be. In reusable packaging, therefore, a homogeneous material is generally used, e.g. HDPE or PP, and the packaging is reinforced by suitable structures where necessary. With single-use systems, on the other hand, economical material use and robustness compete directly with each other. The application is usually very thin-walled for environmental and cost reasons, and functionality is sought through a mix of materials that is difficult to recycle.

The correct handling of packaging requires comprehensive information (GDV 2022). Numerous pictograms and specific application information exist for this purpose. In this respect, reusable packaging has the advantage that the user of this packaging can learn how to handle it, since it is on the market for a long time and standardized.

In an empirical study by Fraunhofer IML and the University of Bonn, breakage rates were investigated over the transport route of cardboard boxes and reusable crates for fruit and vegetables (Lange and Pelka 2013). As a result, packaging breakage occurred in 4.2 percent of the single-use cardboard boxes. For reusable crates, this figure was only 0.12 percent. The proportion of damaged packaging that was also found to have product damage (transported goods: fruit and vegetables) was approx. 24 percent for single-use packaging and approx. 4 percent for reusable packaging. The reasons for the lower proportion of packaging breakage and the lower proportion of product damage in the case of reusable packaging lie in the higher mechanical strength and better handling due to uniform, known packaging formats. In the case of single-use packaging, in addition to the low mechanical strength, the lack of modular coordination and low compatibility with other packaging also led to breakage and product damage, particularly in the retail sector.

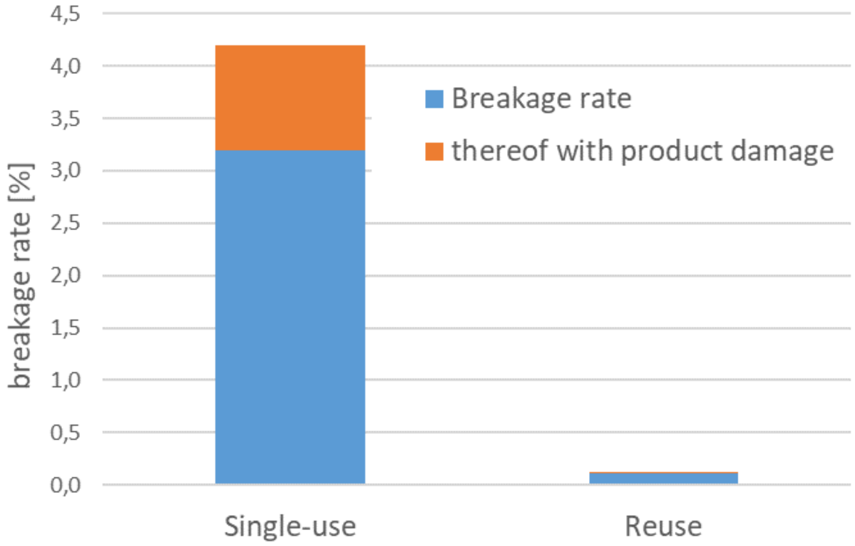

Figure 3: Breakage rate of single-use cardboard crates and multiple-use plastic crates and proportion of damaged products (own representation based on data from (Lange and Pelka 2013) .

In many applications, for example, sea transport, outdoor applications, cold storage or chilled counters, or packaging or transport of moist or cold products, a high wet strength is also required. In the case of cardboard packaging, this usually requires an increased use of virgin fiber (kraftliner), additional additives and treatment steps. Since this is associated with costs and also with restrictions on recycling (RESY 1998), sufficient wet strength is sometimes set aside at the expense of product protection (see Box 2).

Box 2:
“Many single-use packages are inadequately designed. They cannot withstand the mechanical loads during transport and are not really adapted to the requirements during transport, turnover, storage and handling processes. They also often lack the necessary wet strength to save costs. Reuse systems are clearly superior to single-use systems in this respect, they protect the product and also the actors who have to handle them better. The challenge for reuse systems is certainly the return logistics. In this field, there is a need for cooperation and new standards, especially in international trade.”
Uwe Schieder (Loss Prevention and Transport Safety Officer at the German Insurance Association GDV)

3.7 The relationship between food losses and packaging is complicated.

Reducing food losses is a major challenge for sustainable development (Sustainable Development Goal 12.3). Packaging is repeatedly cited as the key to reducing food losses. However, country-specific data on food losses and packaging consumption in Europe (Figure 4), do not show a corresponding correlation. For example, Germany produces almost twice as much packaging waste per person as Finland, yet person-specific food losses are higher in Germany. Thus, other factors seem to be more important than packaging in reducing food waste.

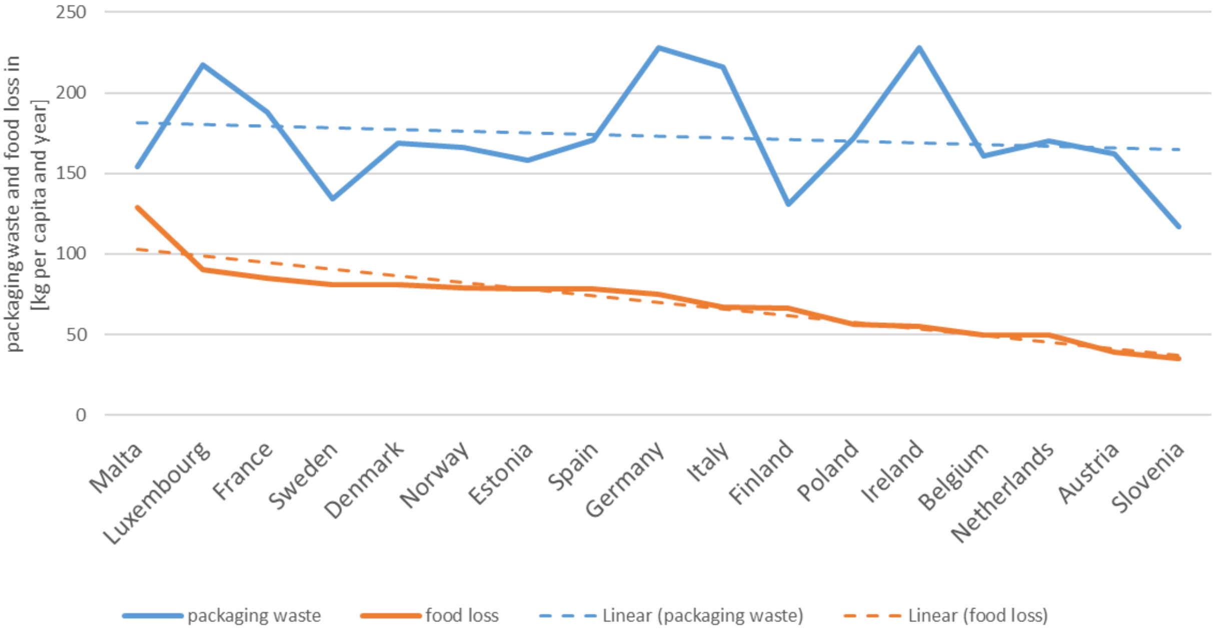

Figure 4: Packaging waste and food losses per capita per year in different countries. (Own representation based on data from: EUROSTAT 2022; United Nations Environmental Programme (UNEP) 2021).

A variety of measures are being discussed to combat food losses. These are primarily the avoidance of overproduction and overconsumption, and the free or lower-cost distribution of products that have exceeded their best-before date. Waiving best-before date imprints or providing differentiated consumer information about the shelf life of products are also frequently proposed. These measures are all independent of the type of packaging.

The role of packaging is also addressed, calling for an integrated consideration of packaging- and food-related environmental impacts (Wikström et al. 2019; Verghese et al. 2015). For example, more robust packaging - i.e., especially reusable packaging (see chap. 3.6) - is cited as an important measure in packaging design against food losses. Another point concerns the correct portioning of the packaged quantity, which is of particular interest to private households that have been shrinking for years in terms of the number of people. Since portion sizes are more likely to change in the long term compared to the presence times of a packaging solution on the market, this requirement can be met equally by single-use and multi-use packaging.

Another aspect that reduces food losses is the re-sealability of the packaging, which can be expected more with reuse systems. The use of barriers that reduce flavor loss or environmental influences and thus reduce spoilage of the product can also be achieved by packaging systems. While in the case of reuse systems it is implemented primarily through correspondingly higher wall thicknesses, in the case of single-use packaging this is done primarily through coatings or multilayer materials. Even though these are very efficient in terms of barrier properties, they often impair recyclability.

The integration of sensor technology, for example to monitor cold chains, into the packaging can also reduce losses. This, too, is more feasible in reusable packaging since the costs of sensor technology can only be allocated to several circulations in reusable packaging. In addition, the sensors in single-use cases would negatively affect recyclability and, depending on the type of sensor, valuable materials would even be lost.

Although there are initial proposals and case studies that consider the environmental impacts of food losses and packaging type in an integrated manner (Yokokawa et al. 2018), studies that address the different options in packaging design across systems for the comparison of reuse and single-use have been lacking.

3.8 Preventing plastic littering requires efficient incentive systems.

Another problem addressed in the context of packaging is plastic emissions in the form of microplastics and littering (careless or illegal disposal of waste) (Bertling et al. 2018; Bertling 2021).

This environmental impact of plastic emissions has not yet been considered in life cycle assessments, even though initial proposals have been made to do so (Maga et al. 2022; Bertling et al. 2018).).

The already implemented directive to ban certain single-use plastic products (EU 2019/904 2019) and the restriction proposal on primary microplastics of the (European Chemicals Agency ECHA 2020) are measures to reduce plastic emissions in line with the application of the precautionary principle. Basically, deposits or rental fees for packaging systems are also suitable for reducing leakage rates and thus littering. For reusable packaging, they are inherent in the system; for sigle-use packaging, they have so far only been implemented for single-use beverage containers, e. g., in Germany with enormous effort and against massive resistance. (Tagesschau 2015).

Paper and cardboard are seen as an alternative to reduce plastic emissions. However, the goal cannot be to replace "plastic littering" with "paper littering". On one hand, paper and cardboard very often contain printing inks (Association of the German Paint and Printing Ink Industry VdL 2018) or additives (Ginebreda et al. 2011), which are not or only difficultly degradable. Their fate and effects in the environment are hardly ever investigated, since littering is understandably not an intended disposal path - but it still takes place. On the other hand, paper and cardboard packaging is increasingly coated with polymers, the degradability of which is also not always given and which at the same time make recycling more difficult (e.g. in the case of coffee-to-go cups). Tapes, adhesive tapes, labels and adhesives are also frequently made of plastic and bonded to the paper.

Ultimately, the reduction of littering will depend on the cycles being almost completely closed. This is only possible if forwarding or returning of the packaging is more attractive than littering at every stage of the value chain, especially for the end user. In this respect, the participation fees that are already levied on single-use packaging when it is placed on the market are to be regarded as less effective than deposits or rental fees. The ongoing discussion about low recycling rates and the low level of confidence of citizens and the media in the realization of a circular economy of single-use packaging by the dual systems also does not help to increase the appreciation of packaging materials in general and plastics in particular. This further encourages littering. The interest of all stakeholders in returning packaging is therefore a clear advantage of the reuse systems in relation to the littering problem.

3.9 Systemic risks are more than just investment risks, as the current commodity crisis shows.

Due to the way they operate across the value cycle, reuse systems are more difficult to set up than single-use systems, which take advantage of existing waste treatment systems for recycling or energy recovery. Reuse systems require cross-company cooperation. Ideally, their introduction would therefore be supported by appropriate regulatory and fiscal measures, as long as there are no legitimate study results for the respective individual case that prove the ecological and social advantages of single-use systems.

The German packaging industry currently employs slightly less than 50,000 people in over 700 companies. At the same time, the number of employees rises slightly, while the number of companies declines (Appenberg & Partner 2022). To date, there are no statistics on the breakdown of companies and employees between reuse and single-use systems. If reuse systems were to be implemented to a greater extent in Germany in the future, they could lead to new jobs. Due to the fact that reuse systems integrate many medium-sized players, it can be expected that the jobs created for logistics and transport in the reuse sector will more than compensate for the jobs lost in production, recycling and disposal for single-use systems.

Reuse systems continue to help build a pool of materials that functions largely independently of imports. Additional raw materials are only required for substituting leakages and ensuring the growth of the system. With today's mostly very low recycling rates, plastic-based single-use cycles still have a great need for virgin material in the form of polyolefinic bulk polymers, which are highly dependent on imports.

In the event of raw material crises, as we have been encountering since 2021, that include commodities such as plastic, wood and paper, which are among the most important materials for the packaging industry (New packaging 2022), reuse systems - if they are already in place - are clearly at an advantage (Bertling et al. 2022).

4 A detailed look at the comparative life cycle assessment of reusable plastic containers and single-use cardboard containers

The following is a critical reflection on the two life cycle assessment studies by Fraunhofer "Carbon Footprint von Verpackungssystemen für Obst- und Gemüsetransporte in Europa" (Krieg et al. 2018a) and Ramboll "Comparative Life Cycle Assessment (LCA) - Packaging Solutions for the Food Segment" (Castellani et al. 2022).

4.1 Subject of the life cycle assessments

Fresh fruit and vegetables have become an indispensable part of everyday life. They are supplied via complex logistical processes. Usually, fruit and vegetables are usually transported in containers made of cardboard (single-use system) or plastic (reuse system). The studies "Carbon Footprint of Packaging Systems for Fruit and Vegetable Transport in Europe" (Krieg et al. 2018a), hereinafter referred to as the "SIM study", and "Comparative Life Cycle Assessment (LCA) Packaging Solutions for the Food Segment"(Castellani et al. 2022), hereinafter referred to as the "FEFCO Study", investigate and compare the environmental impacts of single-use and reusable packaging containers. Although both studies compare the same systems, the results vary. In the following, the framework and parameters of both studies are used for comparison, and the impact of differently selected parameter values on the CO_2 footprint is explained. Basic aspects of the layout of the two studies that are similar or comparable are not discussed further.

4.2 Investigation framework and varied parameter values

The above studies compare single-use and reuse packaging systems in terms of their environmental impacts. Both studies were prepared in accordance with current standards and regulations and were critically reviewed, i.e., the underlying models, the selected parameter values and the written elaboration were examined by critical review panels. Nevertheless, differences in the framework of the studies can be found, and the main ones are summarized in Table 5. These are the reference parameter (functional unit), the loading of the containers with the associated demand for containers used to fulfill the functional unit and the impact categories considered.

Reference quantity (functional unit)

The reference quantity of the LCA (functional unit) differs in the studies. While in the SIM study the distribution of 1000 tons of fruit and vegetables was chosen as the reference value, the FEFCO study defined the distribution of 1000 kilograms of vegetables as the reference value. The difference is thus a factor of 1000, related to the transported mass of goods. A conversion of the results for the comparability of the studies is in principle guaranteed, and both works refer to the foodstuffs to be transported.

Loading of the reference containers

Another difference lies in the utilization of the containers. In both studies, the selected reference container is able to transport 15 kilograms of food. While the SIM study assumes a loading of 15 kilograms of transported mass per container, the FEFCO study assumes a transported mass of 10.5 kilograms (corresponding to 70 percent utilization). This results in a difference in the number of containers to fulfill the functional unit. In the SIM study, a total of 66,667 containers are required to fulfill the functional unit, compared to 95.23 containers in the FEFCO study. Thus, considering the factor difference of 1000 in the functional unit, the FEFCO study requires 42.8 percent more containers relative to the SIM study to fulfill the transportation task. Despite the different assumption on utilization in the two studies, these have each been assumed to be equal for single-use and reuse within a study. This results in an inconsistency when comparing results between studies, but not directly within a study.

Impact categories
The environmental impact categories studied also differ. The SIM study focuses on the carbon footprint based on the impact category global warming potential (GWP), while the FEFCO study evaluates the impact categories of the Environmental Footprint EF2.0, which also focuses on the carbon footprint as a single category.

Table 5: Differences in the scope of investigation

Comparison point	SIM study	FEFCO study
Reference value (functional unit)	Distribution of 1000 tons of fruit and vegetables	Distribution of 1000 kilograms of vegetables
Container loading	100%: 15 kilograms	70%: 15*0.7=10.5 kilograms
Number of containers to fulfill the functional unit	66.667	95,23
Impact category	Global Warming Potential (GWP)	Environmental Footprint EF2.0

In the following chapters, some differences of the parameter values of the single-use system made of cardboard (CB, Cardboard Box) and the reuse system made of plastic (RPC, Reusable foldable Plastic Container) are shown. The parameter values given are taken from the respective study mentioned.

4.2.1 Single-use cardboard boxes CB

In this section, the parameter values of the single-use cardboard box CB (Cardboard Box) are listed and summarized in Table 6.

Container mass:
The CB container mass slightly differs in both studies. The SIM study assumes a mass of 0.78 kilograms, the FEFCO study 0.77 kilograms.

Material composition:
The material composition of the reference vessel also differs among the studies. The SIM study assumes a composition of 64 percent semichemical fluting and

36 percent Kraftliner, whereas the FEFCO study assumes 47 percent semi-chemical fluting and 53 percent Kraftliner. The recycled content (RC) in the SIM study amounts to 19 percent and the RC in the FEFCO study is 23 percent.

Transport:
For the single-use containers, some assumptions of the transport distances differ. These are the routes from the CB producers to the food producers with 50 km (SIM study) and 55 km (FEFCO study), respectively, and from the food producers to the distribution warehouse with 406 km (SIM study) and 840 km (FEFCO study).

End of life:
With regard to end-of-life, slightly different values for the recycling rate are given. The FEFCO study assumes a recycling rate (material recovery) of 82.9 percent, the SIM study a rate of 85 percent.

Results:
To compare the carbon footprint results of the studies, the result of the SIM study was divided by a factor of 1000. The result of the FEFCO study of 34.7 kilograms CO_2 equivalents per ton of vegetables transported is slightly below the result of the SIM study of 37.7 kilograms CO_2 equivalents.

Table 6: Parameter values used for the single-use system in the two studies investigated.

Comparison point	SIM study	FEFCO study
Mass per CB	0,78 kg	0,77 kg
Material composition	64 % Fluting 36 % Kraftliner RC: 19 %	47 % Fluting 53 % Kraftliner RC: 23 %
Transport route Manufacturer to food producer	50 km	55 km
Transport route Food producer to distribution warehouse	406 km	840 km
Material recovery	85 %	82,9 %
Result GWP	37.7 kg CO_2 -equiv. per metric ton of food	34.7 kg CO_2 -equiv. per metric ton of food

4.2.2 Reusable plastic containers

In this section, the parameter values of the reusable foldable plastic containers (RPC) are listed and summarized in Table 7.

Material composition:
The reference containers differ from each other in terms of material composition. The SIM study assumes a composition of 50.5 percent HD-PE and 49.5

percent PP, whereas the FEFCO study assumes 58 percent PE and 42 percent PP. The RC in both studies is 10 percent.

Circulations:
Lifetimes and circulation numbers per year differ significantly in the two studies. The SIM study assumes 50 circulations (5 per year with a service life of 10 years), while the FEFCO study assumes only 24 circulations (4 per year with a service life of 6 years).

Breakage rate:
The breakage rate per circulation was also assumed to be significantly different in the two studies. The SIM study assumes a breakage rate of 0.53 percent, the FEFCO study 2.5 percent.

Transport:
Some transport routes in the use phase differ between the studies. These are the route from the manufacturers of the RPC to food producers with 921 km (SIM study) and 370 km (FEFCO study), from the food producers to the distribution warehouse with 406 km (SIM study) and 840 km (FEFCO study), from distribution warehouse to service center with 223 km (SIM study) and 165 km (FEFCO study), from service center to food producer with 409 km (SIM study) and 380 km (FEFCO study), and from service center to recycling with 867 km (SIM study) and 840 km (FEFCO study).

End of life:
With regard to end-of-life, the recycling rates differ. The SIM study assumes a material recycling rate of 77.5 percent, while the FEFCO study assumes 41.8 percent.

Results:
Analogous to the single-use containers, the result of the SIM study was converted to the reference value of the FEFCO study to maintain comparability. In the SIM study, an emission of 14.5 kilograms of CO_2 equivalents per ton of transported goods was calculated, and in the FEFCO study, an emission of 47.9 kilograms of CO_2 equivalents resulted.

Table 7: Parameter values used for the reuse system in the two studies investigated.

Comparison point	SIM study	FEFCO study
Material composition	49.5 % PP 50.5 % HDPE RC proportion: 10 %	42 % PP 58 % HDPE RC proportion: 10
Circulations	50	24
Breakage rate	0,53 %	2,50 %
Transport route Manufacturer to food producer	921 km	370 km
Transport route Food producer to distribution warehouse	409 km	840 km
Transport route Distribution warehouse to service center	223 km	165 km
Transport route Service center to food producer	409 km	380 km
Transport route Service center for material recycling	867 km	840 km
End of life Material recovery	77,5 %	41,8 %
Result	14.5 kg CO_2 -equiv. per metric ton of food	47.9 kg CO_2 -equiv. per metric ton of food

4.3 Influence of selected parameter values

The results of the carbon footprint of the single-use containers differ only slightly in the studies, whereas those of the reusable containers differ greatly. For this reason, the selected parameters of the reuse system and their influence on the results are examined in more detail below.

In order to identify the influence of the parameters on the result, sensitivity analyses were carried out in both studies. Parameters were changed in the baseline scenario so that the effects of this change on the carbon footprint result are shown. It should be noted that only one parameter of the baseline scenario was changed at a time.

Of the parameters determined above, which differed greatly in both studies, the SIM study examined the circulation number and recycling rate in the sensitivity analysis. The circulations were varied in the sensitivity analysis with 25 and 100 circulations, and the recycling rate between 0 and 100 percent. In the sensitivity analysis, the largest change in emissions from the reusable containers was caused by reducing the recycling to 0 percent, followed shortly by reducing the circulations to 25. This shows that both parameters have a significant impact on the result.

In the sensitivity analysis of the FEFCO study, the influence of the breakage rate and the proportion of material recycling were investigated. The breakage rate was varied between 0.5 and 5 percent. The lower breakage rate leads to the largest reduction in CO_2 emissions in the sensitivity analysis. The percentage of material recycling was set to 70 percent in the sensitivity analysis, which leads to the second highest reduction in carbon footprint. Similar to the SIM study, the sensitivity analysis of the FEFCO study also indicates that these two parameters have a significant impact on the result. Both studies thus react very sensitively to the parameter values of recirculation, breakage rate and the recycling rate at the end of the life of the plastic containers.

However, several parameter values differ between the baseline scenarios of the studies, and their individual and combined effects on the results are discussed below.

To begin with, there is the loading (degree of utilization) of the containers, which results in a greater number being required to fulfill the functional unit. In relative terms, the FEFCO study requires 42.8 percent more containers. Based on their number to meet the functional unit, the required replacement is calculated. This includes the number of circulations to end of life and the breakage rate. Approximately three times as many containers are replaced over their lifetime in the FEFCO study than in the SIM study. This difference is caused by the assumed number of circulations in each study and amplified by the reduced utilization. To be replaced additionally are the containers that break per circulation. Due to the different breakage rates, approx. 6.7 times as many containers are replaced per circulation in the FEFCO study. This difference is also amplified by the lower utilization of the containers. Due to the parameters chosen, not only are more containers needed to fulfill the functional unit in the FEFCO study, but in addition a larger number must be manufactured and accordingly disposed of. Along with a higher number of containers, the relevance of the transport effort increases.

4.4 Consideration circulations

In the SIM study, 50 circulations of the reusable containers are assumed. This is primary data from the Euro-Pool system and IFCO-Systems GmbH, who name circulation numbers of reusable containers of 5 per year, with an average life expectancy of 10 years (Fraunhofer IBP 2017a, 2017b).

In the FEFCO study, 24 circulations of the reusable containers are assumed. The source is a study by Thorbecke et al. (2019). This is an LCA study from the North American market, which also compares single-use containers made of cardboard and reusable containers made of plastic. The study was commissioned by the Corrugated Packaging Alliance (CPA). The assumption of 24 cycles of use is calculated in the study with an average of 4 uses per year over a service life of 6 years.

4.5 Consideration breakage rate

The SIM study is based on a breakage rate of 0.53 percent. This is primary data from the Euro Pool System and IFCO Systems GmbH (Fraunhofer IBP 2017a, 2017b).

The FEFCO study assumes a brakage rate of 2.5 percent, formed as the average of the minimum breakage rate (no breakage rate = 0 percent) and the maximum breakage rate (5 percent) found in the literature. A breakage rate of 5 percent is mentioned by Thorbecke et al. (2019) where they talk about a combined breakage and leakage rate.

4.6 Consideration of material recycling

The SIM study assumes a recycling rate of 77.5 percent. This arises from the assumption that almost 100 percent is recycled, but that the recycling leads to a loss of quality of the granulate due to the shortening of the polymer chains. This loss is estimated at 22.5 percent via the market price of secondary granules. Recycling, which is only affected via chain shortening, was assumed to occur because reusable transport containers are a pooling system with containers made of high-quality mono-materials that are managed in a B2B system (Bekuplast 2015).

The FEFCO study assumes a lower recycling rate of 41.8 percent for the B2B reuse system. This is an EU-wide average for post-consumer recycling of packaging waste, is derived from (EUROSTAT 2022) and is in our opinion not suitable for the transfer to reusable packaging (cf. chap. 3.2).

4.7 Conclusion on the comparison of the two life cycle assessment studies

The studies "Carbon Footprint of Packaging Systems for Fruit and Vegetable Distribution in Europe" (Krieg et al. 2018a), in short "SIM Study" and "Comparative Life Cycle Assessment (LCA) Packaging Solutions for the Food Segment" (Castellani et al. 2022), in short "FEFCO Study" are life cycle assessment studies in which single-use cardboard containers and reusable plastic containers for the distribution of fruit and vegetables (SIM Study) or only vegetables (FEFCO Study) are examined and compared with regard to their environmental impacts.

The results of the carbon footprint of the two studies differ. While in the SIM study the reusable plastic container has a significantly lower carbon footprint and is to be preferred, the FEFCO study leads to the opposite result. As shown in the above analysis, this difference is mainly caused by the choice of parameter values for the reuse system.

Some of these parameters have a significant influence on the result. In order to work out this influence, sensitivity analyses were carried out in both studies, in which one parameter was changed in each case at the base scenario. It can be seen that the parameters of circulation numbers, breakage rate and material recycling rate have significant influences on the result in addition to more methodological influencing factors, such as the allocation rules used at the EoL, which were not investigated here. For the reusable containers, these parameters differ greatly in the two studies.

The reuse system is a B2B system, i.e., a clearly controllable and self-contained system. As a result, the service life of the individual containers and the breakage rate can be recorded and documented very easily. In addition, the B2B system ensures that rejected and defective containers can be recycled in a controlled manner at the end of their life. The operators of the reuse pools are also interested in the profitability of their system. Reuse systems gain in economic advantage with increasing circulation numbers and lower breakage rates, which also becomes apparent ecologically.

The parameter values used in the SIM study were continuously collected by the partners of the Stiftung Initiative Mehrweg during the pooling operation of the reusable containers. This constant recording and testing of the important parameter values is the basis for the positive evaluation of the distribution of fruit and vegetables in reusable plastic transport packaging.

As a result of the comparison of the two LCAs, it can be seen that the FEFCO study assumes a much less favorable baseline scenario. In the parameter study carried out above, it becomes clear that the result of the SIM study approaches that of the FEFCO study when changing to lower circulation numbers, higher breakage and lower recycling rates. We therefore expect that the calculation model used in the FEFCO study, if the parameters were changed to the values used in the SIM study, would also produce a result in favor of the reusable containers. This would confirm the result of the SIM study and thus prove the advantageousness of the reuse system under the boundary conditions considered. It would be worthwhile to check this out.

The parameter values of circulation numbers, breakage rate and proportion of material recycling play a key role in carrying out comparative life cycle assessments on single-use and reuse systems. In order to obtain realistic values, they should be continuously checked and transparently reported by the reuse industry within the framework of monitoring.

5 Conclusions and recommendations

The waste hierarchy in its current form mainly follows the convincing approach that each higher level keeps the following levels as an option. A product or packaging is therefore initially to be used for a long time and frequently. Cleaning and repair can significantly extend the service life. When these options reached an end, recycling is a viable alternative. If the material is irreversibly damaged after a large number of coupled cycles, it can finally be energetically recovered. By going directly to a lower level of the waste hierarchy - recycling should be explicitly mentioned here - one deprives oneself of the higher-level alternatives - in this case, reuse. In our view, it therefore makes sense to maintain the **waste hierarchy and to implement it more actively than before**.

Against the background that the waste hierarchy is still firmly anchored as a principle in the legal acts of the circular economy, it is not sufficient that the recyclability must be proven for single-use packaging, but not its ecological advantages over reuse systems. A corresponding **obligation to prove the ecological advantageousness for single-use packaging for individual cases** should be anchored in law and methodically standardized.

Although packaging is not the main emitter of greenhouse gases, accounting for an estimated 1.6 percent nowadays, it is nevertheless a relevant source. In the coming years, therefore, single-use and reusable packaging must **significantly reduce** their **direct and indirect carbon footprint**.

Life cycle assessments are an important tool in this context, but they can only be used meaningfully if agreement is reached on the relevant parameter variations and constellations as well as system boundaries within the framework of a moderated multi-stakeholder dialog. However, **ecological aspects that are not yet covered by life cycle assessments** must also be **included in the** decision-making process including**, in particular, plastics emissions** (microplastics and littering). These occur primarily in non-refundable single-use plastic packaging or in paper and cardboard packaging modified with plastic.

The path proposed by VTT and FEFCO **to optimize and investigate packaging in terms of "fit-for-purpose" is explicitly to be welcomed**. It is to be expected that reuse systems, due to their robustness, re-sealability and the fact that the costs and environmental impacts for components of intelligent packaging (sensors, radio labels, etc.) can be apportioned over many cycles, will perform particularly well in many areas of application compared to the single-use system. A demanding definition of "fit for purpose" also includes achieving a long service life, a high number of uses and optimum recyclability at the end of life.

The claimed correlation that food losses and other product damage could be reduced by single-use packaging cannot be sustained in our view. Studies and experience to date show that single-use **packaging in particular is often not sufficiently mechanically stable and wet-strengthened.** Furthermore, there is no discernible systematic correlation between food losses and packaging consumption. If at all, it is more likely that food losses and packaging consumption show the same trend. This rather speaks for overproduction and overconsumption as the main reasons for food losses.

It is a fact that reuse systems are generally associated with higher initial investments. For this reason, they have so far been implemented primarily in the B2B sector between large market players. However, it appears to be realistic to **make reuse more widespread through standardization and an investment securing regulatory framework.** This is especially necessary because single-use systems have so far hardly managed to realize a true circular economy through recycling. Reasons for this include low collection and recycling rates, high material diversion for energetic recovery, and the infrequent use of recyclates in the original applications or products. Policymakers should therefore create the appropriate boundary conditions for the introduction of new reuse systems in order to improve resource efficiency and reduce dependence on raw material imports.

Politicians, associations and industry participants should **agree on a procedure for transparent monitoring of the reuse systems.** In this context, key variables such as the circulation numbers, breakage and leakage rates as well as the recycling rate must be recorded and reported. The data from single-use and reuse systems must be sufficiently granular so that for each application in which both systems are available, any deviation from the waste hierarchy in favor of single-use systems is evidence-based for the individual case and not generically justified.

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