

Article

Assessing Reusable Packaging: The Importance of Methodological Choices in Carbon Footprint Calculation

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Abstract: The reliability and clarity of environmental assessments represent an important prerequisite for measures towards the sustainable transformation of our economic system. Studies examining the environmental performance of reusables are often used to derive arguments for and against their use. Accordingly, it is important to have clarity about the influence of methodological decisions on the results of such studies. This paper analyses possible approaches to the allocation of environmental impacts of transport processes to reusable shipping packaging in the context of parcel deliveries. A model was developed to conduct comparative analyses of carbon emissions (carbon footprint) from the use of single-use vs. reusable shipping packaging and was subsequently applied to two reusable shipping packaging systems currently available on the market. The results showed that using different allocation models led to significant variations in the results for the carbon footprint of the analysed packaging (single-use and reusable), while at the same time, the calculated environmental break-even point in the comparison between the single-use and reusable options remained rather stable. The results highlight the importance of a clear and standardized methodological framework for the communication of footprint information for reusable shipping packaging. Moreover, for determining the environmental break-even point, the results suggest that aspects like the comparison scenario (i.e., the selection of the single-use packaging) are more important than the methodological choice of the allocation model for transportation processes.



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1. Introduction

Until 2021, e-commerce in Germany and Europe has been showing continuous growth for years—with growth rates well above ten percent between 2017 and 2021, which was partly fuelled by the Corona pandemic [1–3]. In Germany, in 2021, the turnover in e-commerce was EUR 99.1 billion [4]. In 2022 and 2023, the turnover in e-commerce dropped, but it still remains above the pre-pandemic level, and a continuously strong market position can be assumed for the future [4].

In line with the growth in e-commerce, there has been a significant increase in the number of items sent by courier, express, and parcel (CEP) services; from 2014 to 2018, the number of items sent in Germany increased by 740 million, which corresponds to a growth rate of 27%. In 2021, the total number of items sent by CEP providers exceeded 4 billion [5,6].

Products sold in e-commerce are mostly packed in single-use shipping packaging, which is disposed of upon receipt of the goods. This linear packaging system leads to a high consumption of resources and corresponding amounts of waste: as described by Reitz [7], in 2020, more than 900 kt of packaging waste was generated in e-commerce in Germany, 90% of which was cartons and boxes made of corrugated board. By 2030, forecasts assume that packaging consumption will increase to just under 1500 kt [8].

If the trend of steadily increasing resource consumption and corresponding amounts of waste in this area is to be broken, innovative solutions at the logistics system level and adjustments to business models will be required. A significant reduction in resource consumption and waste as well as a reduction in greenhouse gas emissions can be achieved by using reusable packaging instead of disposable (single-use) packaging [8–10]. To contribute to the sustainable transformation of economic systems through the use of reusable shipping packaging, studies are needed to assess their environmental performance—also in comparison to single-use packaging—and thus provide a valid basis for targeted measures.

In addition to the analyses of the fundamental potential of reusable packaging that demonstrate the environmental benefits of using reusable packaging in lieu of disposable packaging, environmental assessments (particularly carbon footprint studies) of shipping packaging are also carried out for the purpose of comparing packaging with each other and communicating environmental product information. Comparative assessments of reusable (and disposable) shipping packaging have been carried out frequently in recent times (see, e.g., [9,11–15]).

Despite some methodological differences between the studies, there are some common findings, such as the following:

- The number of cycles achieved by reusable packaging is crucial for its environmental performance.
- Transport contributes significantly to the total environmental impact of reusable packaging and should be optimized to maximise environmental benefits.
- The impact of packaging production is relevant, but it is not the decisive factor, particularly when a high number of use cycles is achieved.

The results of life cycle assessments (LCAs), carbon footprint studies, etc., are, however, influenced by methodological choices. This needs to be considered when interpreting the results, especially if these are used for communicating environmental information or claims publicly. A comparison of absolute numbers, e.g., for the carbon footprint per use cycle for a reusable packaging solution, is, however, hardly ever possible—even more so if the communication suggests environmental preference over other products regarding certain environmental aspects. Several standards in the 14,000 series of the International Standardisation Organization (ISO) provide guidance in this regard [16–19].

ISO 14026 provides principles, requirements, and guidelines for communicating the environmental footprint information of products. Besides referring to ISO 14044, ISO 14026 requires that footprint communications are based on studies conducted following Product Category Rules (PCRs) in accordance with ISO/TS 14027 (development of product category rules) [20]. Among other aspects, ISO/TS 14027 requires PCRs to include a definition of the functional unit as well as of allocation rules which shall be applied.

While there are different methodological choices to be made that impact the results, for shipping packaging, such category rules do not exist so far. And, while there is a common understanding concerning the functional unit in LCA and carbon footprint studies of shipping packaging—typically defined as one (or multiple) use cycles of the packaging required to deliver a defined shipment ordered online to the final customer including return of the packaging if applicable—regarding the allocation of the transport emissions to the single parcel as well as allocation of environmental burdens between packaging and product, there appears to be no common understanding. With the relatively new prEN 17837:2022 [21] “Postal Services-Parcel Delivery Environmental Footprint-Methodology for calculation and declaration of GHG emissions and air pollutants of parcel logistics delivery services”, first steps into the direction of standardizing environmental assessments for parcel delivery are made, and conclusions for assessing packaging can be drawn. However, this standard also allows for choosing between different allocation methods and does not guarantee a comparability of calculations.

Against this background, in this paper, we investigate possible approaches to allocation and assess the effect of the choice of allocation rules for single studies as well as for

comparing studies and using footprint information for communication. The following questions will be addressed:

- What allocation approaches can be derived from existing related standards and guidelines?
- How do different methods of allocating the environmental impacts (CO₂ emissions) of transportation processes influence the environmental performance of reusable shipping packaging?
- How does the choice of the allocation method influence the results of comparative studies of single-use vs. reusable shipping packaging?
- What recommendations can be derived based on the results for the communication of footprint information?

2. The Role of Transport and Possible Allocation Approaches

A relevant share of the total environmental impacts of reusable shipping packaging results from transportation processes (see, e.g., refs. [8,9,11,22,23]). From the warehouse in which the product is stored until it is ordered and shipped to the customer, different means of transportation might be used. While the exact design of the transportation processes might differ from case to case, in many cases, the transport can be divided into long-distance transport, which typically uses 16/28/40 t lorries, and the last mile, which uses 3.5 t trucks.

The emissions from the transport processes comprise well-to-wheel emissions from the use (and combustion) of fuel as well as pro rata consideration of vehicle manufacturing and end-of-life and infrastructure use, with the latter being negligible in many cases.

In LCA and carbon footprint studies of shipping packaging, two subsequent steps of allocation are required for the transportation processes: First, the total environmental impacts (resulting from fuel consumption and emissions) of the transport processes need to be assigned to the individual parcel (i.e., the packaging and the product). This is necessary since irrespective of the transportation being long-distance or last mile, usually more than one parcel is transported on the same vehicle. Second, transports represent co-processes in which two services are provided, namely

1. Transport of the product;
2. Transport of the packaging.

To conduct LCAs/carbon footprint studies of the packaging, it is therefore necessary to further allocate the environmental impacts (fuel consumption and emissions) of the transport processes that have been assigned to the individual parcel in the first step between the packaging and the product. The necessary allocation procedures are illustrated in Figure 1:

In some studies [9,24,25] that assess reusable packaging, datasets from LCA databases are used to model transport emissions, which quantify the emissions based on ton kilometres (tkm), i.e., on the transported mass and the distance. However, such datasets often assume a capacity utilization that is higher than is typically the case for parcel delivery [26,27] and allocate the emissions based on mass. In fact, the emissions from transport are a combination of constant emissions which are independent from the load and emissions which depend on (and increase with) the load [28,29].

In parcel delivery, particularly on the last mile, the capacity utilization is typically significantly lower than the maximum load. The limiting factor here is not the mass of the transported parcels but their volume and practical requirements of the delivery. Therefore, a more differentiated modelling approach to calculate the total transport emissions seems favourable.

To then allocate the total emissions to the single parcels and then between the product and the packaging, different approaches can be considered.

General guidance on possible approaches is provided by the standards mentioned above (e.g., ISO 14040/44). More specific guidance regarding the allocation of environmental impacts of transportation processes between parcels (i.e., step one of the allocation

procedure is described above) can be found in a recently published draft European Norm: (prEN 17837:2022) “Methodology for calculation and declaration of GHG emissions and air pollutants of parcel logistics delivery services” [21]. Regarding the second level of allocation, a respective methodology has been developed in the context of LCAs of beverage packaging in Germany [28,29]. These approaches will be described in the following sections.

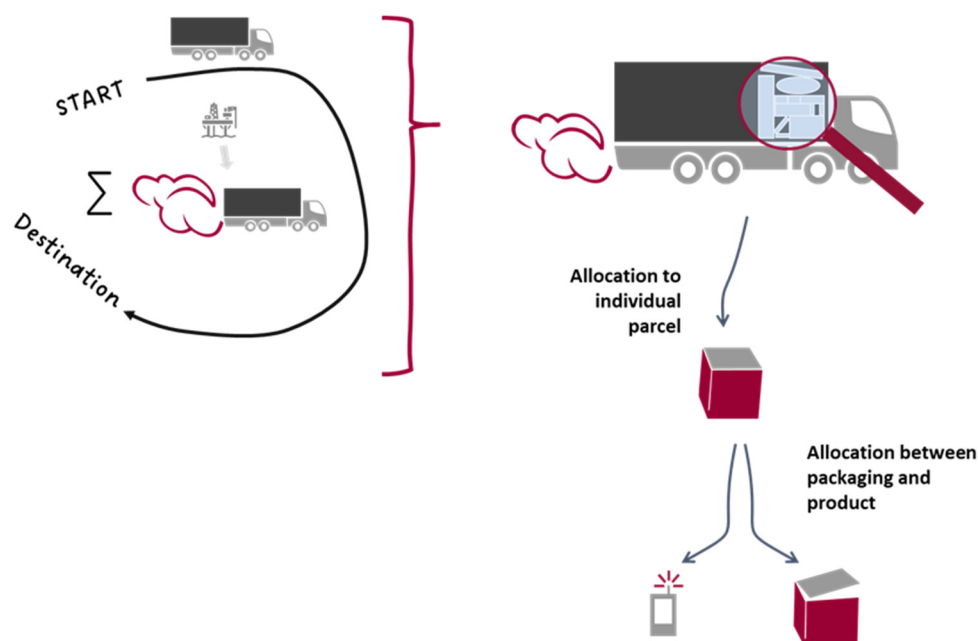


Figure 1. Two-step allocation procedure for assigning environmental impacts of the transport processes to the packing.

3. Calculating GHG Emissions from Transportation Processes

3.1. Allocating Environmental Impacts between Parcels: prEN 17837:2022

The standard “Methodology for calculation and declaration of GHG emissions and air pollutants of parcel logistics delivery services” (prEN 17837:2022) provides principles and rules for the quantification, allocation, and reporting of environmental impacts related to parcel logistics delivery services.

According to prEN 17837:2022 [21],

“The emissions shall be allocated to the parcels according to the clearly stated and justified allocation procedure. The allocation of emissions from an operation towards the parcel delivery service shall be representative and carried out in a manner that it reflects the underlying physical relationships between them. Finally, the sum of the allocated emissions to a parcel for a set of operation shall be equal to the emissions from the operation before allocation.”

Different allocation procedures are proposed for operation processes and transportation processes. In the following, with regard to the research questions of this article, we focus on the transport processes.

For transport processes, five approaches are proposed, of which two are “preferred approaches”: one for long-distance (“trunking”) and one for last mile/first mile delivery. These approaches are summarized in Table 1.

Table 1. Allocation approaches outlined in prEN 17837.

Simplified Approaches	Preferred Approaches
By number of packages	Last mile: based on the number of stops on a tour
By volume	
By mass	Long distances: based on volume and mass

Different preferred allocation procedures are provided for long-distance and last-mile/first-mile deliveries because it is recognized that the limiting factors impacting the vehicles' fuel consumption are different: It is argued that, for long-distance transportation, weight and volume are the pertinent factors influencing fuel consumption and thereby the environmental impacts because the volume of the parcel influences the loading limit of the vehicle and the latter has a direct impact on fuel consumption. For pick-up/delivery on the first/last mile, the number of stops is assumed to be the main factor influencing fuel consumption. This could be a suitable approach for (possibly comparative) carbon footprint calculations of delivery services, but for the focus of this study, which is on the assessment of (single-use and reusable) packaging (which should be independent from the number of stops), this approach is not suitable.

Furthermore, for long-haul transportation, an approach to allocate emissions between parcels and other cargo as well as combined passenger and cargo transportation is proposed based on the share of mass of parcel to the other cargo transported. However, this is not relevant in this study as it is assumed that only parcels are transported.

3.2. Allocation between Packaging and Product: Learnings from Beverage Packaging

Transportation is a co-process, since the product under investigation is transported together with another product, the packaged good. Against this background, the minimum requirements for LCAs of beverage packaging developed by the German Federal Environment Agency stipulate that only the share of the environmental impacts of the packaging, but not the share of the packaged good are to be taken into account in LCAs that focus on the packaging [28]. Accordingly, including the impacts of the packaged good would be an expansion of system boundaries that is not in line with an attributive approach to the LCA of a packaging system [28].

Following this logic, only the environmental impacts caused by the presence of the packaging should be considered in the context of a LCA that focusses on the environmental impacts of transport packaging.

It is further important that a corresponding allocation procedure considers that there is no linear relationship between the transportation of the packaging and the environmental impacts resulting from the transport process. Due to its individual nature (e.g., volume, shape), a package can result in the same number of goods having to be transported on more vehicles. However, such an effect is not considered when the results are scaled up or down based on ton kilometres (tkm).

One example for an allocation method that meets these requirements and at the same time considers the packaging-related degree of capacity utilization of the means of transport (e.g., truck, container, etc.) is the method used in the study "Life Cycle Assessment for Beverage Packaging II" [29]:

Within the scope of the method, the individual degree of utilization of the vehicle as well as the share of the transported product and the packaging system are determined. In the case of a packaging-related underutilization, mathematically, more vehicles are driving to transport the same number of products. As a result, the environmental impact attributed to the packaging system is higher. This approach tends to result in a larger proportion of the transport loads being transferred to the transported goods in the case of light packaging systems, while a higher proportion of the loads is assigned to the packaging in the case of heavier and small-volume systems.

The starting point for the method is the division of the environmental impacts (fuel consumption and emissions) into the constant, load-independent share for the transport of the empty vehicle and the load-dependent share for the transport of the vehicle's payload (which is equal to the additional load caused by loading of the vehicle) (cf. Figure 2).

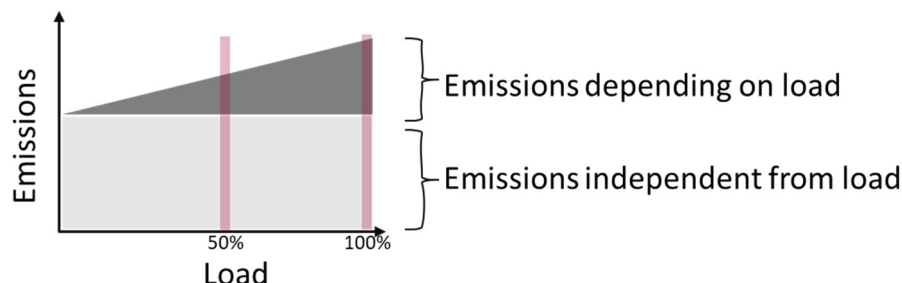


Figure 2. Load-dependent and load-independent emissions.

Whereas the allocation between the packaging and the transported good of the load-dependent portion is “simply” carried out based on mass proportions, since the additional load is caused by the mass of the payload, the allocation of the environmental impacts of the load-independent share is performed based on causality. This means that it is calculated according to which proportion of the load-independent share is caused by the presence of the packaging.

In this regard, hypothetical optimal packaging is assumed as an alternative, under the use of which the payload of the transporting vehicle is fully utilized with the product. The environmental load to be assigned to the packaging system is then calculated based on the difference between the environmental load of the actual system (i.e., transport with load) and the hypothetical ideal case. The environmental impact of the ideal case, on the other hand, is attributed to the product (for a detailed description of the allocation process, see [29]).

4. Approach

In order to assess the impact of different allocation approaches on the environmental impacts of shipping packaging, a model was developed to conduct comparative analyses of carbon emissions (carbon footprint) from the use of single-use and reusable packaging.

For this purpose, different single-use shipping packaging was compared with suitable reusable alternatives. The modelling of reusable packaging is based on two currently available systems that are already in use on a small scale:

- A flexible reusable plastic bag (“hey circle bag”);
- A reusable plastic box (“hey circle box”).

Within the definition of the product system to be analysed, the methodological requirements of pr:EN 17837 were slightly adapted in line with the defined goals of this study:

Only direct and indirect emissions from transportation processes are included (well-to-wheel). Location operation processes (“Location Operation Categories (LOCs)”) and other indirect emissions are outside of the scope.

The following transport operation categories are considered:

- Transport of (reusable or single-use) packaging from production (of packaging) to central hub / e-commerce retailer.
Mode: ship and lorry.
- Transport of parcel from central logistic hub to (regional/processing) hub (“trunking”).
Mode: large lorry.
- Transport of parcel from (regional/processing) hub to delivery depot (“processing”).
Mode: medium size lorry.

- Transport of parcel from delivery depot to consumer/parcel station, etc. (“last mile”). Mode: small size lorry.
- Transport of empty (reusable) packaging back to central hub/e-commerce retailer.

To model emissions from transport, process parameters need to be defined, including the

- Mode of transport;
- Type of vehicle (lorry);
- Type and consumption of fuel(s) per trip;
- Distance travelled per trip;
- Number, weight, and volume of parcels transported in a leg (trunking);
- Number of parcels delivered and number of stops during a round trip (last-mile delivery);
- Weight and volume of parcels catered during a round trip (last mile-delivery);
- Load factors of vehicles;
- Vehicle capacity (volume, weight);
- Empty distances.

Different parameters that were needed for allocating emissions between parcels were approximated based on other studies [5,8,23,30–34]. This includes, for example, vehicle capacity in terms of volume and weight. Load factors were approximated based on publicly available statistics by the German Federal Motor Transport Authority (KBA) [26,35]. The average number of stops during last-mile delivery tours was calculated based on case studies by the German Association of Courier, Express, and Package Service Providers (BIEK) [5,30–34].

The reusable packaging analysed in the model was provided by hey circle. The hey circle parcel delivery system deviates from the archetypal process flow described in prEN 17837:2022, so far as the parcel circulates between the consumer and e-commerce. Therefore, considered transport processes only include processes starting from “trunking” to the “last mile”.

Two packaging solutions from hey circle (bag and box) are compared to different single-use packaging options. Table 2 provides an overview of the packaging options under investigation:

Table 2. Packaging under investigation.

Packaging	Type	Mass	Materials
Hey circle box	Reusable	990 g	>95% PP
Hey circle bag	Reusable	82 g	>95% PP
Single-use bag	Single use	35 g	PP, 50% recycled material
Single-use bag	Single use	44 g	Paper (Kraftliner)
Single-use box	Single use	353 g	Cardboard, 80% recycled material

The primary data used in the study were provided by hey circle and their suppliers, respectively. In addition, market data for parcel delivery from previously published research were used [8,23]. The emissions from transportation were modelled using fuel consumption data for the different means of transport under consideration in a designated transport model. Background processes were modelled using datasets from ecoinvent v3.

The emissions from the manufacturing and end-of-life stages of the examined packaging were calculated in a carbon footprint model, which incorporated background processes from ecoinvent v3. Regarding the consideration of recycled content and recycling at end-of-life, the guidelines of the Product Environmental Footprint (PEF) were followed [36,37].

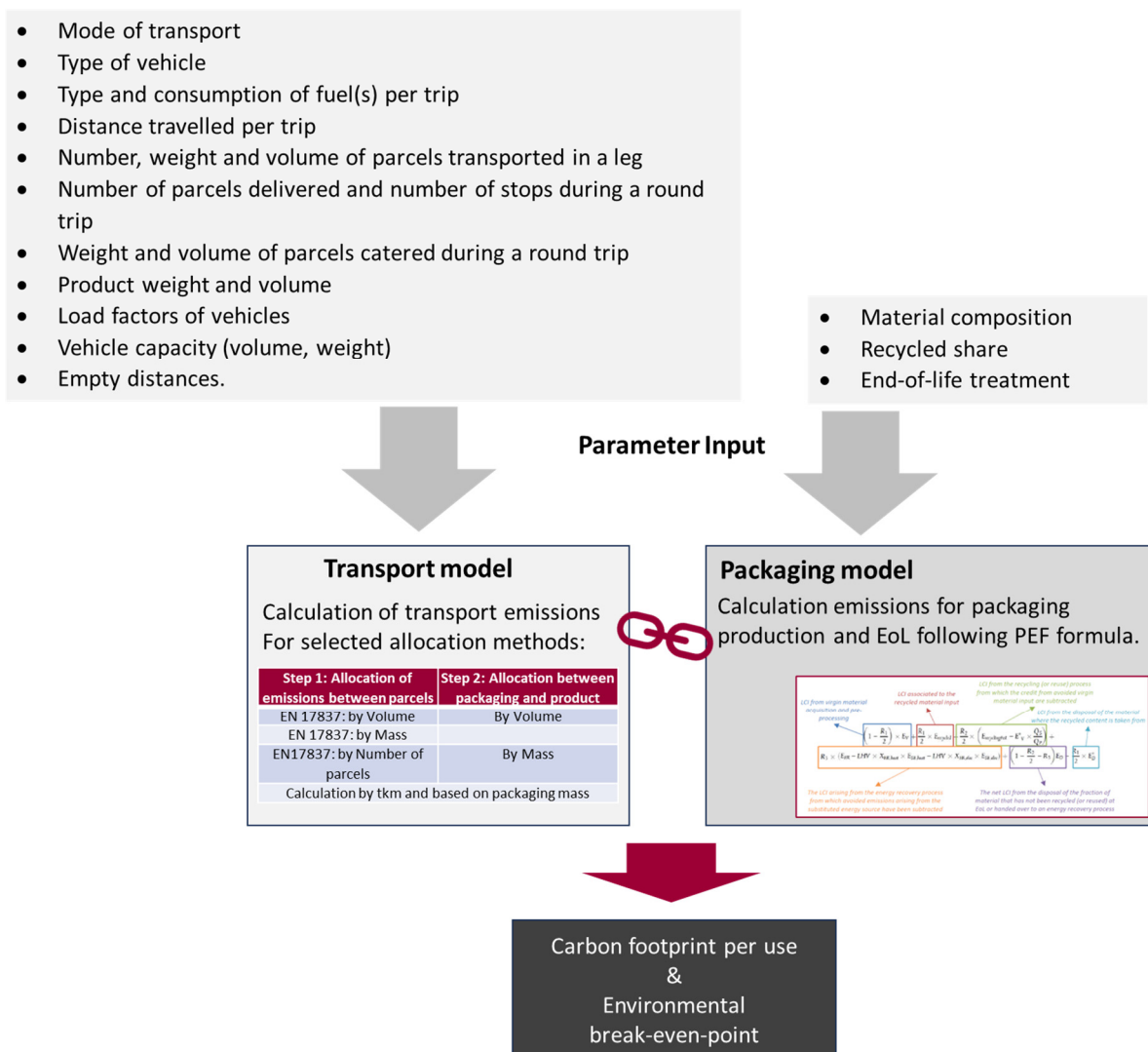
This model was coupled with a specific transportation model, in which the transport emissions for the depicted transport chain were calculated. Various approaches could be chosen for allocating the emissions to the individual shipment and, ultimately, the packaging. Table 3 summarizes the allocation models integrated in the model.

Table 3. Allocation methods integrated in the model.

Step 1: Allocation of Emissions between Parcels	Step 2: Allocation between Packaging and Product
EN 17837: by volume	By volume
EN 17837: by mass	
EN 17837: by number of parcels	By mass
Calculation by tkm and based on packaging mass	

The model provides the carbon footprint per use cycle and the environmental break-even points for the reusable packaging under investigation for the selected allocation method and the specific parameters defining the transport and the parcel.

Figure 3 provides an overview of the combination of the transport and packaging model and lists the required parameter input(s).

**Figure 3.** Model structure and parameter input.

5. Results

5.1. Carbon Footprint of Reusable Packaging Solutions

The carbon footprint for reusable packaging depends on the number of use cycles. The carbon footprint consists of emissions that occur per use cycle and emissions from packaging production and end-of-life stages, which are distributed over the number of

use cycles. Relevant emissions per use cycle result from the transport processes to the customers, and back to the e-commerce retailer or the reuse system, respectively.

The carbon footprint for the two assessed reusable packaging solutions depending on the different number of use cycles is shown in the following table for the different allocation methods and the calculation based on tkm, respectively.

Allocation of the emissions based on the number of parcels (i.e., each parcel is allocated an equal share of the emissions) does not lead to meaningful results. Firstly, the differences between the different parcels are neglected, which is not in line with the goals of this study. Secondly, for the return trip (i.e., the transport of the now empty packaging), the high emissions from allocation step 1 (equal distribution of emissions based on the number of parcels) are 100% percent allocated to the packaging in step 2, as there are no more products in the packaging. This is the reason for the high emissions shown in Table 4. Therefore, the results from allocating based on the number of parcels are not included in the following description of the results.

Table 4. Carbon footprint results. Results in CO₂ equivalents.

Packaging	Number of Use Cycles	Step 1: Volume Step 2: Volume	Step 1: Volume Step 2: Mass	Step 1: Mass Step 2: Volume	Step 1: Mass Step 2: Mass	Step 1: Number Step 2: Volume	Step 1: Number Step 2: Mass	tkm Approach
Hey circle box	15	361 g	414 g	408 g	477 g	566 g	647 g	455 g
	20	280 g	333 g	326 g	396 g	484 g	566 g	373 g
	30	198 g	251 g	245 g	314 g	403 g	484 g	292 g
Hey circle bag	5	85 g	77 g	84 g	76 g	303 g	290 g	75 g
	10	54 g	46 g	52 g	45 g	271 g	259 g	43 g
	15	43 g	35 g	41 g	34 g	260 g	248 g	32 g

For the hey circle box, the results between the different allocation and calculation methods differ between 30 and 60 percent, depending on the allocation/calculation method and the number of cycles. For the hey circle bag, results differ between 10 and 20 percent.

The improvements of the carbon footprint, which can be achieved by increasing the number of use cycles from 15 to 30 in case of the box, range from 34 to 45 percent. The carbon footprint improvements resulting from increasing the number of use cycles from 5 to 15 in case of the bag range from 49 to 57 percent.

The calculation based on ecoinvent datasets for tkm (which is essentially a mass-based approach) results in similar results as the other mass-based allocation approaches (in both steps). For the latter, the emissions are slightly higher as the capacity utilization was modified (i.e., decreased) to better reflect parcel delivery.

5.2. Environmental Break-Even Points

A key question for reusable packaging is how many cycles need to be reached to have a better environmental performance—measured here as the carbon footprint—than the replaced single-use packaging.

As the allocation based on the number of parcels does not lead to meaningful results in this regard, this allocation method is not included in the following. Table 5 gives an overview of the calculated break-even points for the different allocation methods.

Table 5. Break-even point results.

Packaging	Compared to	Step 1: Volume Step 2: Volume	Step 1: Volume Step 2: Mass	Step 1: Mass Step 2: Volume	Step 1: Mass Step 2: Mass	tkm Approach
Hey circle box	Plastic bag	49	-	-	-	-
	Paper bag	-	-	-	-	-
	Cardboard box	10	11	11	12	12
Hey circle bag	Plastic bag	3	3	3	3	3
	Paper bag	8	9	8	9	9
	Cardboard box	1	1	1	1	1

The hey circle box aims at substituting cardboard boxes; however, plastic and paper bags are included for completeness. Within the considered range, the reusable box is not environmentally advantageous compared to the paper bag. In comparison to the plastic bag, an environmental break-even point is only observed with one allocation approach—allocation based solely on volume. Here, the reusable box becomes environmentally advantageous after 49 cycles.

In comparison to the cardboard box, the various allocation approaches yield ecological break-even points of 10 (based solely on volume), 11 (based on volume/mass, mass/volume), and 12 (based solely on mass as well as on tkm).

For the comparison between the reusable bag and the disposable plastic bag, all considered approaches result in a break-even point of 3. Compared to the paper bag, the required number of cycles ranges from 8 to 9; in comparison to the cardboard box, the reusable bag is environmentally advantageous—already after the first cycle—regardless of the chosen methodological approach.

6. Discussion and Conclusions

Based on existing standards, different allocation methods were identified and applied for allocating transport emissions to individual parcels as well as between the packaging and the product. This was carried out in two steps, as outlined in Table 3. In addition, a calculation using a process calculating emissions based on the transport performance in tkm was performed. Hereby, it could be demonstrated which types of conclusions regarding the environmental performance of reusable shipping packaging strongly depend on the choice of allocation methods and which statements are largely unaffected by allocation methodology. Thus, a contribution was made to further develop the environmental assessments of shipping packaging, aiming to provide an even more valid basis for making decisions regarding the promotion of reusable packaging in the context of the sustainable transformation of our economic system.

As described above, allocation based on the number of parcels (i.e., each parcel is allocated an equal share of emissions) does not lead to meaningful results—at least not if all transported shipments are not identical—which will not be the case in reality, especially regarding the return transport of emptied packaging. Firstly, in this allocation approach, the differences between the different parcels are neglected, which is not in line with the goals of this study. Secondly, for the return trip (i.e., the transport of the now empty packaging), the relatively high emissions allocated to the empty packaging in allocation step 1 (equal distribution of emissions based on the number of parcels) are 100% percent allocated to the packaging in step 2, as there is no more products.

Regarding the other allocation approaches under investigation, the packaging carbon footprint calculated for different numbers of use cycles differs significantly. This shows that the results calculated using different approaches for allocating transport emissions are

not comparable. As the carbon footprint is a figure frequently used in communications by providers of reusable shipping packaging [38–40], either to be reported directly as a product carbon footprint or to calculate potential greenhouse gas savings for the packaging user, this underlines the necessity for a clear and standardized methodological framework for the communication of footprint information for reusable shipping packaging or—at least—for transparency when reporting environmental information such as the carbon footprint. The necessary transparency must include relevant process parameters that influence the carbon footprint. These include, in particular, the transport parameters such as distances, means of transport, and capacity utilization. Further relevant factors are the diversity and type of other parcels in the delivery, the transported product (weight, volume), and the potential opportunity for reusable packaging to reduce its volume for return shipping (foldable packaging).

During the delivery of identical parcels, all assessed allocation methods lead to the same results. However, in reality, a variety of different parcels are transported together. If a study aims at, for example, comparing different means of transport, ignoring these differences and assuming identical parcels can be justified. If studies aim at analysing and comparing the carbon footprint (or environmental performance) of different packaging types, these differences cannot be neglected as parameters such as weight and volume are crucial in this kind of assessment.

The assumption of a lightweight product can lead to higher emissions for the packaging in the allocation. Conversely, a heavy product will be assigned more emissions in allocation by mass. The same applies to large and small product volumes in allocation by volume. At the same time, it is important to consider that (reusable) shipping packages are generally intended for the transport of roughly defined products (in terms of weight, volume, and protection requirements), which should be considered in the calculation.

For all examined approaches (except the allocation based on the number of shipments), arguments can be found; the explanations in Section 2 should be considered. For example, allocation by volume can be justified by the fact that volume is the limiting factor in delivery traffic, and packaging that is volume-reduced or reducible for return shipping will perform better in allocation by volume. Allocation by mass could be justified, among other reasons, by the fact that a shipping package is primarily a means to an end and ideally should be made as light as possible, which pays off in allocation by mass.

At this point, a specific recommendation for a particular allocation approach is intentionally omitted. Instead, the differences should be highlighted, and it should be emphasized that clear guidelines are needed for communicating footprint information. Ideally, a process for developing product category rules should be initiated. These rules would need to provide clear guidelines on the methodological framework, including the allocation rules to be applied, and take into account the relevant standards [18–20] to achieve a better comparability of calculations from different stakeholders. An unrestricted comparability of carbon footprint results cannot be guaranteed even with detailed standards, as the influence of specific parameters, data uncertainties, database choice, etc., is too significant. However, methodologically induced deviations under otherwise identical assumptions and settings, as investigated here using various possible allocation methods, can be eliminated through appropriate rules. At a minimum, increased transparency regarding the methodological background of carbon footprint results for shipping packaging should be established promptly. Such an increase in transparency could help to avoid misleading communication of the relevant information in the short term.

When comparing single-use and reusable packaging, the influence of the chosen allocation approach on the results is significantly smaller. The differences in terms of the break-even point required for environmental advantage are relatively small, with a maximum of 1–2 use cycles. Overall, all considered approaches tend to yield the same results, indicating a consensus on the range of the required number of use cycles. This suggests that both for an internal company analysis aiming at environmental process optimization and for external communication, the choice between the examined allocation methods—

each applied to reusable and single-use packaging—is not crucial. The extent to which and when reusable packaging becomes environmentally advantageous can be quantified with only slight deviations when using all the examined approaches. For determining the environmental break-even point, it is more important to choose the comparison scenario (selection of the single-use packaging considered in comparison) well, and to gather the other parameters such as transport distance as accurately as possible, as these can indeed have an influence [9,22]. Transparency regarding these key assumptions (distances; replaced single-use packaging) would also contribute to improving the comprehensibility of communicated carbon footprint information in this context.

Considering the scientific discourse on the environmental advantages of reusable shipping packaging, as well as reusable packaging in other fields of application, it can be observed that the influence of methodological settings, such as allocation procedures, is sometimes insufficiently considered. While assessments of the fundamental environmental advantages, relevant parameters, and ecological break-even points, e.g., [20,24,25,41–43], are less affected by the methodological choices examined in this study, statements about absolute emissions or potential absolute emission savings, e.g., [24,25,41,43–45], need to be critically reflected upon regarding the methodological settings. In future studies, it seems necessary to pay more attention to the choice of the allocation method, be aware of its influence on the absolute carbon footprint results, and ensure transparency in the methodological descriptions.

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References

1. BEVH. *Interaktiver Handel in Deutschland: Ergebnisse 2018*; Bundesverband E-Commerce und Versandhandel Deutschland e.V. (bevh): Berlin, Germany, 2019.
2. EY; WI. *Zwischenbilanz COVID-19: Umweltpolitik und Digitalisierung*, Ernst & Young Wirtschaftsprüfungsgesellschaft (EY); Wuppertal Institut für Klima, Umwelt, Energie gGmbH (WI): Wuppertal, Germany, 2020.
3. McKinsey. *The Great Consumer Shift: Ten Charts That Show How US Shopping Behavior Is Changing*; McKinsey: Boston, MA, USA, 2020.
4. BEVH. E-Commerce in Krisenzeiten, Berlin. 2024. Available online: https://bevh.org/fileadmin/content/05_presse/Pressemitteilungen_2024/bevh_PK_2024.pdf (accessed on 17 April 2024).
5. BIEK. *Clever verpackt—Effizient zugestellt: KEP-Studie 2019—Analyse des Marktes in Deutschland*; Bundesverband Paket und Expresslogistik (BIEK): Berlin, Germany, 2019.
6. Reitz, A. *Versandverpackungen: Bestandsaufnahme von Mengen und Materialdaten*. Werkstattpapier, Projekt praxPACK. 2020. Available online: https://www.praxpack.de/fileadmin/user_upload/materialien/praxPACK_Werkstattpapier_Bestandsaufnahme_Versandverpackungen_Mengen.pdf (accessed on 23 September 2020).
7. Reitz, A. Verbrauch von Versandverpackungen in Deutschland. *Müll Abfall* **2021**, *4*, 191–195. [CrossRef]
8. Zimmermann, T.; Hauschke, F.; Memelink, R.; Reitz, A.; Pelke, N.; John, R.; Eberle, U.; Ninnemann, J. *Die Ökologisierung des Onlinehandels: Neue Herausforderungen für die umweltpolitische Förderung eines nachhaltigen Konsums*; Teilbericht II; TEXTE 142/2021; Umweltbundesamt: Dessau-Roßlau, Hamburg, 2021.
9. Zimmermann, T.; Bliklen, R. Single-use vs. reusable packaging in e-commerce: Comparing carbon footprints and identifying break-even points. *GAIA—Ecol. Perspect. Sci. Soc.* **2020**, *29*, 176–183. [CrossRef]

10. Zimmermann, T. Herausforderungen und Potenziale im Einsatz von Mehrwegverpackungen im Onlinehandel. *Müll Abfall* **2022**, *54*, 358–364.
11. Heckel, F. *CO₂-Optimierte Kreislauflogistik eines Mehrwegversandsystems im B2C E-Commerce*; Hochschule Pforzheim: Pforzheim, Germany, 2022.
12. rhinopaq. Whitepaper Mehrwegverpackungen. 2022. Available online: <https://www.rhinopaq.com/whitepaper/> (accessed on 31 March 2022).
13. RePack. Net Impact of RePack. 2020. Available online: <https://f.hubspotusercontent00.net/hubfs/2630758/Net%20Impact%20of%20RePack%20-%20Net%20Positive%20Nordics%20workshop%2015.9.2020%20-%20UPDATED.pdf> (accessed on 11 July 2023).
14. Park, J.; Waqar, Z. Life cycle assessment of returnable mailers used for apparel electronic commerce: A case study in Canada. *Packag. Technol. Sci.* **2022**, *35*, 651–662. [CrossRef]
15. Zimmermann, T.; Bliklen, R. Vergleichende ökologische Betrachtung von Mehrweg- und Einweg-Versandverpackungen. Werkstattpapier. Projekt praxpack. Hamburg. 2020. Available online: https://www.praxpack.de/fileadmin/user_upload/Werkstattpapier_OEkologische_Bewertung_von_MWVP_REV2.pdf (accessed on 17 August 2021).
16. DIN EN ISO 14044; Umweltmanagement—Ökobilanz—Anforderungen und Anleitungen. Beuth: Berlin, Germany, 2006.
17. DIN EN ISO 14040; Umweltmanagement, Ökobilanz, Grundsätze und Rahmenbedingungen. Beuth: Berlin, Germany, 2006.
18. ISO 14026:2017; Umweltkennzeichnungen und -deklarationen—Grundsätze, Anforderungen und Richtlinien für die Kommunikation von Fußabdruckinformationen. DIN: Berlin, Germany, 2018.
19. ISO 14067:2008; Treibhausgase—Carbon Footprint von Produkten—Anforderungen und Leitlinien für Quantifizierung. Beuth: Berlin, Germany, 2019.
20. ISO/TS 14027; Environmental Labels and Declarations—Development of Product Category Rules. Beuth: Berlin, Germany, 2018.
21. EN 17837; Postal Services—Parcel Delivery Environmental Footprint—Methodology for Calculation and Declaration of GHG Emissions and Air Pollutants of Parcel Logistics Delivery Services. Beuth: Berlin, Germany, 2022.
22. Zimmermann, T.; Rödig, L. *praxpack: Nutzerintegrierte Entwicklung und Erprobung von Geschäftsmodellen für praxistaugliche Mehrwegverpackungslösungen im Onlinehandel*; Schlussbericht; Ökopool: Hamburg, Germany, 2023.
23. Zimmermann, T.; Memelink, R.; Rödig, L.; Reitz, A.; Pelke, N.; John, R.; Eberle, U. Die Ökologisierung des Onlinehandels: Neue Herausforderungen für die umweltpolitische Förderung eines nachhaltigen Konsums. Teilbericht I; UBA-Texte 227/2020, Umweltbundesamt, Dessau-Roßlau, Hamburg. 2020. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2020_12_03_texte_227-2020_online-handel.pdf (accessed on 22 March 2021).
24. Pålsson, H.; Olsson, J. Current state and research directions for disposable versus reusable packaging: A systematic literature review of comparative studies. *Packag. Technol. Sci.* **2023**, *36*, 391–409. [CrossRef]
25. Bradley, C.G.; Corsini, L. A literature review and analytical framework of the sustainability of reusable packaging. *Sustain. Prod. Consum.* **2023**, *37*, 126–141. [CrossRef]
26. DCTI. *Klimafreundlich einkaufen—Eine vergleichende Betrachtung von Onlinehandel und stationärem Einzelhandel*; Deutsches CleanTech Institut: Bonn, Germany, 2015.
27. KBA. *Verkehr deutscher Lastkraftfahrzeuge (VD): Gesamtverkehr*; Kraftfahrtbundesamt: Flensburg, Germany, 2018.
28. Detzel, A.; Kauertz, B.; Grahl, B.; Heinisch, J. Prüfung und Aktualisierung der Ökobilanzen für Getränkeverpackungen; TEXTE 19/2016, Dessau. 2016. Available online: https://www.ifeu.de/fileadmin/uploads/uba_texte_19_2016_pruefung_und_aktualisierung_der_oekobilanzen_fuer_getraenkeverpackungen.pdf (accessed on 8 March 2021).
29. Plinke, E.; Schonert, M.; Meckel, H.; Detzel, A.; Giegrich, J.; Fehrenbach, H.; Ostermayer, A.; Schorb, A.; Heinisch, J.; Luxenhofer, K.; et al. Ökobilanz für Getränkeverpackungen II; TEXTE 37/00, Dessau. 2000. Available online: <https://www.umweltbundesamt.de/publikationen/oekobilanz-fuer-getraenkeverpackungen-ii> (accessed on 9 November 2021).
30. BIEK. *Fahrzeugbestand nach Emissionsklassen und nach Antriebs- und Kraftstoffarten*; BIEK Kompendium, Bundesverband Paket und Expresslogistik: Bonn, Germany, 2018.
31. BIEK. *Marktanteile der Zustellkonzepte im B2C Segment*; BIEK Kompendium, Bundesverband Paket und Expresslogistik: Bonn, Germany, 2018.
32. BIEK. Innovationen auf der Letzten Meile—Kurier-, Express- und Paketdienste: Bewertung der Chancen für die nachhaltige Stadtlogistik von morgen Nachhaltigkeitsstudie 2017 im Auftrag des Bundesverbandes Paket und Expresslogistik e. V. (BIEK). 2017. Available online: <https://www.biek.de/publikationen/studien.html> (accessed on 1 August 2022).
33. BIEK. KEP-Studie 2022—Analyse des Marktes in Deutschland: Impulsgeber mit Innovationskraft. Eine Untersuchung im Auftrag des Bundesverbandes Paket und Expresslogistik e. V. (BIEK), Berlin. 2022. Available online: <https://www.biek.de/publikationen/studien.html> (accessed on 29 July 2022).
34. BIEK. KEP-Studie 2021—Analyse des Marktes in Deutschland: Möglichmacher in bewegten Zeiten. Eine Untersuchung im Auftrag des Bundesverbandes Paket und Expresslogistik e. V. (BIEK), Berlin. 2021. Available online: <https://www.biek.de/publikationen/studien.html> (accessed on 29 July 2022).
35. KBA. CO₂-Emissions- und Kraftstoffverbrauchs-Typprüfwerte von Kraftfahrzeugen zur Personenbeförderung mit höchstens neun Sitzplätzen und Wohnmobilen, Flensburg. 2020. Available online: https://www.kba.de/SharedDocs/Publikationen/DE/Fahrzeugtechnik/SV/sv222_m1_kraft.pdf.pdf?__blob=publicationFile&v=6 (accessed on 13 October 2020).
36. Russo, C.; Tuomisto, H.; Michalopoulos, G.; Pattara, C.; Polo, P.J.A. *PEF Screening Report in the Context of the EU Product Environmental Footprint Category Rules (PEFCR) Olive Oil Pilot*; European Commission: Brussels, Belgium, 2015.

37. COM. *Understanding Product Environmental Footprint and Organisation Environmental Footprint Methods*; European Commission: Brussels, Belgium, 2021.
38. Hey Circle. Impact: Die Mehrweg Lösung für Onlinehändler. Available online: <https://www.heycircle.de/impact> (accessed on 22 April 2024).
39. Ravioli. Der Ravioli Impact—Ravioli. Available online: <https://getravioli.de/impact> (accessed on 22 April 2024).
40. rhinopaq. Paketrechner für CO₂-Einsparungen • rhinopaq. Available online: <https://www.rhinopaq.com/paketrechner/> (accessed on 22 April 2024).
41. Coelho, P.M.; Corona, B.; Worrell, E. *Reusable vs. Single-Use Packaging: A Review of Environmental Impacts*; Zero Waste Europe: Brussels, Belgium, 2020.
42. Coelho, P.M.; Corona, B.; ten Klooster, R.; Worrell, E. Sustainability of reusable packaging—Current situation and trends. *Resour. Conserv. Recycl. X* **2020**, *6*, 100037. [[CrossRef](#)]
43. Albrecht, S.; Bertling, J.; Fischer, M.; Gehring, F.; Kabasci, S.; Prescher, T.; Schulte, A. Reusable Plastic Crates vs. Single-Use Cardboard Boxes, Oberhausen. 2022. Available online: <https://publica-rest.fraunhofer.de/server/api/core/bitstreams/20b3024c-f4b0-42a5-b7b6-a59a337287f6/content> (accessed on 7 May 2024).
44. Bertling, J.; Dobers, K.; Kabasci, S.; Schulte, A. *Kunststoffbasierte Mehrwegsysteme in der Circular Economy*; Fraunhofer UMSICHT: Oberhausen, Germany, 2022.
45. Krieg, H.; Gehring, F.; Fischer, M.; Albrecht, S. Carbon Footprint von Verpackungssystemen für Obst- und Gemüse Transporte in Europa, Stuttgart. 2018. Available online: https://www.stiftung-mehrweg.de/fileadmin/user_upload/SIM_CF_Bericht_De.pdf (accessed on 7 May 2024).

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