NORSUS
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Review of life cycle assessments of reuse systems for bottles

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Illustration of reuse of a plastic and glass bottle © Anna Furberg, 2021.

Summary

There is an increasing interest in reusable bottles as an alternative to single-use packaging from the perspective of assumed reduced littering, waste generation and environmental impacts. In the assessment of a possible shift from single use to reusable bottles, it is important to apply a systems perspective to avoid potential trade-offs between various impacts. Life cycle assessment (LCA) is commonly applied to assess the life cycle impacts of products, typically including the processes of raw material extraction, production, use phase as well as waste management of the products assessed. The goal of this study is to review LCAs of reuse systems for bottles as well as the current European practice in such reuse systems. A recent review of LCAs of reuse systems was applied as the point of departure and complemented by recently published LCA studies. The focus of the review was on methodological aspects and on empirical data for trip rates, i.e., the number of times that the bottle is used during its lifetime. In total, nine LCAs of reuse systems and four European reuse system actors were included in the review as well as some additional highly relevant reports on trip rates.

Several aspects were highlighted as important in the reviewed LCAs of reuse systems. These include the size and composition of beverage packaging, trip rate, transportation distance between retailers and manufacturers, as well as the modelling of end of life of packaging materials, including collection rates. It is important that all these aspects are considered, that the data applied for the compared systems are selected, and that the interpretation of the study results are made, in line with the study goal, which can be to e.g. to compare current or potential future reuse and recycling systems. For example, the collection rate of the packaging in the systems assessed, in turn affected by the type of collection system in place, is one important and sensitive parameter both for single-use and reusable beverage packaging. The reason for this is that the collection rate affects the recycling rate, trip rate and littering rate in the respective single-use and reuse systems. However, detailed discussions on various collection systems, their varying collection rates, or potentials for improving these systems are rarely provided in the reviewed studies. When different collection systems are applied for the compared reuse and single-use bottle systems (e.g. a deposit for reusable bottles and a voluntary system for single-use bottles), different collection rates will typically occur. A direct comparison of the environmental impact for such systems might therefore be misleading unless the difference in collection rates between the systems are described and in line with the study goal. If the goal of a study is to compare potential future bottle systems, the collection systems applied should be carefully selected to ensure a comparison focusing on differences between the bottle systems (e.g. single-use bottles which are collected for material recycling and converted to raw material for new bottles, or reusable bottles which are collected for refilling), rather than on differences reflecting the underlying collection systems. This is especially important when there are no clear arguments for why the selected collection systems should be different for the bottle systems assessed. However, if the goal is to compare the impact of existing bottle systems, the collection systems applied for the respective bottle systems should be used. Nevertheless, important aspects, such as the collection systems applied for the compared systems, their related collection rates as well as their impact on the results should be acknowledged.

Other important aspects such as social and economic ones were also identified in the reviewed studies. Littering, which commonly is highlighted as an issue related to single-use plastic products, were only assessed in one of the reviewed studies. This literature review is non-exhaustive but provides an overview of recently published LCAs of reuse systems for bottles. The results from this study can provide recommendations to LCA practitioners in conducting future LCAs of reuse systems for bottles to be compared to single-used bottles, as well as to beverage packaging actors, such as reuse system actors.

Sammendrag

Det er generelt en økende interesse for ombrukssystemer for emballasje som alternativ til engangsemballasje, og dette ser generelt ut til å være motivert ut fra antatte muligheter for redusert forsøpling, mindre avfallsmengder og lavere miljøpåvirkning. For å vurdere endringer i miljøpåvirkninger ved en overgang fra engangsemballasje til et ombrukssystem, er det viktig å benytte et systemperspektiv for å få frem helheten og inkludere flere typer av miljøpåvirkninger. Livssyklusvurdering (LCA) brukes ofte for å vurdere miljøpåvirkningen til produkter gjennom hele livssyklusen, fra utvinning av råvarer, produksjon, bruksfase samt avfallshåndtering. Målet med denne studien har vært å gjennomgå LCA-studier av ombruksystemer for drikkevareflasker, samt gjeldende europeisk praksis i slike ombrukssystemer. En europeisk rapport som sammenstiller LCA-studier for ombrukssystemer ble brukt som utgangspunkt, og denne ble supplert med nyere, relevante LCA-studier. Gjennomgangen har tatt for seg metodiske aspekter og empiriske data for tripptall, det vil si antall ganger en ombruksflaske brukes i løpet av sin levetid. Totalt ni LCA-studier av ombrukssystemer, vurdering av fire europeiske aktører for ombrukssystemer, samt relevante rapporter om beregning av tripptall ble inkludert i studien.

Følgende aspekter ble fremhevet som de viktigste for vurdering av systemenes miljøeffektivitet: størrelse og sammensetning av drikkevareemballasjen, antall ganger en ombruksflaske blir brukt (tripptall), transportavstand mellom forhandlere og produsenter og modellering av avfallshåndtering av emballasjen, herunder innsamlingsgrader i systemene. Det er viktig at både data, forutsetninger og resultater gjenspeiler studiens mål, som eksempelvis kan være å sammenligne nåværende eller fremtidige systemer for henholdsvis ombruks- og engangsemballasje. Innsamlingsgraden i et emballasjesystem er en viktig og sensitiv parameter, fordi den påvirker både resirkuleringsgrad, tripptall og forsøplingsgrad. Detaljerte diskusjoner om ulike innsamlingssystemer og tilhørende innsamlingsgrader, samt forbedringspotensialer er i liten grad beskrevet i de gjennomgåtte studiene. Ulike innsamlingssystemer for engangs- og ombruksemballasje (f.eks. bruk av pantesystem for ombruksemballasje og ikke-pant for engangsemballasje) medfører ulike innsamlingsgrader. En direkte sammenligning av miljøeffekten i slike systemer kan derfor være misvisende dersom man ikke er klar over hvilke forutsetninger rundt dette som ligger til grunn. Dersom målet med studien er å sammenligne mulige fremtidige systemer, er det viktig at innsamlingssystemet velges slik at studien reflekterer forskjeller i flaskesystemet (f.eks. engangsflaske som innsamles for materialgjenvinning til nytt flaskeråstoff, eller ombrukflaske som innsamles for gjenfylling) og ikke forskjeller i underliggende innsamlingssystemer. Hvis målet med studien derimot er å sammenligne eksisterende systemer, bør de respektive innsamlingssystemer benyttes i studien.

Andre aspekter av sosial og økonomisk art er også identifisert. Forsøpling er inkludert som et aspekt i kun én av de gjennomgåtte studiene. Denne litteraturgjennomgangen er ikke uttømmende, men gir en oversikt over nylig publiserte LCA-studier for ombrukssystemer for flasker. Resultatene fra denne studien kan gi anbefalinger for gjennomføring av fremtidige LCA-studier for sammenligning av ombrukssystemer med engangssystemer for flasker, så vel som til aktører i verdikjeden for gjenvinning og ombruk av emballasje.

Contents

1 Introduction

Historically, the use of reusable, or refillable, beverage containers in Europe has decreased and today only a few prospering reuse systems remain (Reloop, 2021). In 2000, refillable packaging was responsible for 41% of the total European beverage market while this share was only 21% in 2015. More recently, however, there has been a renewed interest in assessing alternatives, such as reusable bottles, to single-used beverage packaging, such as single-use plastic bottles, from the perspective of potentially reduced littering, waste generation and environmental impacts (Briedis et al., 2019; Coelho, Corona, & Worrel, 2020; UNEP, 2020). In a reuse system, used bottles are returned to the manufacturer, washed, refilled, and then returned to the retailer to be sold again. Thus, a bottle is utilized many times with the extra effort of transport/washing in each cycle. For the single-use system, the bottles are discarded after use with subsequent waste treatment, where various shares of the bottles become recycled and potentially used in the production of new bottles, incinerated, or landfilled depending on the specific collection and waste treatment system applied. The introduction of the European Commission Directive on single-use plastics, striving to reduce littering from such products, has probably also contributed to the increased interest in reusable bottles as an alternative to single-use products.

At the same time, there are various factors that affect the environmental performance of beverage packaging, which is why the application of a systems perspective becomes crucial when comparing reusable and single-use bottles. This is important to avoid potential trade-offs between various impacts, for example between littering and climate change impacts. The method of life cycle assessment (LCA) is commonly applied to assess the life cycle impacts of products, i.e. including its raw material extraction, production, transport, use as well as its waste management (Hauschild, Rosenbaum, & Olsen, 2018). The results from an LCA can be used for various purposes, such as comparing different products or services that fulfil the same function, identifying opportunities for improvement in a production system, and for decision support (Baumann & Tillman, 2004).

The goal of this study is to review LCAs of reuse systems for bottles as well as the current European practice in such reuse systems. A recent review of LCAs of reuse systems (Coelho et al., 2020) was applied as the starting point and additional LCAs, with a focus on scientific articles published in 2021, were searched for in a literature database. These studies were scrutinized with a focus on methodological aspects in LCAs of reuse systems and on empirical data for trip rates, i.e., the number of times that the bottle is used during its lifetime, as this parameter typically has a large influence on the LCA results for reuse systems. Note that there exist several expressions for trip rates, including for example number of cycles and number of rotations. This study was commissioned by Infinitum who is the operator of the Norwegian Deposit Return System (DRS) for beverage containers, including single-use plastic bottles and metal cans that become collected after use for recycling.

Although this review is non-exhaustive, it provides an overview of recently published LCAs of reuse systems for bottles and provides recommendations of important aspects to consider in future LCAs of such systems. The intended audience of this study include beverage packaging actors, such as reuse system actors, as well as LCA practitioners.

2 Method

A literature review of LCAs of reuse systems for bottles as well as a review of the current European practice related to such systems were conducted. The scopes of these reviews, as well as important aspects to consider in these reviews, were discussed in meetings between NORSUS (Anna Furberg and Hanne Lerche Raadal) and Infinitum (Ole Faye, Kjell Olav Maldum, Sten Nerland and Tor Guttulsrud). Detailed descriptions of the procedures for the literature reviews of LCAs on reuse systems and European practice in reuse systems are provided in Section 2.1 and 2.2, respectively.

2.1 Literature review of life cycle assessments of reuse systems

The literature review of LCA studies of reuse systems for bottles took its point of departure in the report "*Reusable vs single-use packaging: A review of environmental impacts*", which was recently published by Zero Waste Europe and Reloop (Coelho et al., 2020). In that review, seven relevant LCA studies on reuse systems for bottles are cited and these were reviewed in detail in this study. In addition, relevant scientific peer reviewed LCA studies published after 2020 were searched for using the search string; "TITLE-ABS-KEY("life cycle assessment*" AND "reuse*" AND "bottle*")" in the Scopus database (2021-08-16) and included in the review. Furthermore, two highly relevant reports on trip rates were also included.

The review focused on addressing the following questions:

1. What LCA studies of reuse systems for bottles (polyethylene terephthalate (PET), glass, etc.) exist in literature?
2. Which modelling methods have the studies used to arrive at their conclusions?
3. What aspects have been highlighted as important in these LCA studies?
4. What approaches exist in LCA literature to model reuse?
5. How is the number of rotations for bottles, i.e., the number of times that the bottle is used during its lifetime, modelled in these LCA studies?

In line with this, several important aspects were focused on in the review, namely:

- the type of packaging assessed and its material composition,
- data on number of rotations and stockpiles,
- functional unit(s) applied,
- environmental impacts assessed,
- end-of-life modelling,
- main results in terms of identified hotspots, and
- methodological aspects identified as important by the reviewed studies.

Furthermore, a number of other important and interesting aspects were identified in the discussions between NORSUS and Infinitum, including how the LCA studies model the complexity of reuse systems (different sizes of bottles resulting in various pools of bottles), the geographical boundary of reuse systems (some systems are national while others are limited to specific regions), what data that is used to represent trip rates (average data or best/worst-case values), collection rates versus what is put back on the market (all collected bottles do not re-enter the market due to losses in the system), what type of collection system is used (e.g. if deposit system is used for both reuse systems and single-use systems and whether the same collection rates are applied in comparisons of these systems), various economic incentives associated with reuse systems (e.g. is it the producer or the system operator that earns money from the deposit that is not claimed by the user) and bottles taken out of use due to e.g. changes in design. These other important aspects were not the focus of the review, i.e., not searched for explicitly, but considered if such information were readily available in the reviewed literature.

2.2 Review of the current European practice in reuse systems

The literature review of current European practice in reuse systems for bottles was conducted to supplement Infinitum's current knowledge about European reuse systems. Thus, the review took its point of departure from a list including some European reuse systems actors identified by Infinitum, see Table A1 in Appendix 1. In addition to this, additional reuse system actors in the literature review of LCAs of reuse systems (Section 3) were also included if such actors were identified. The review was limited to consumer packaging, which implies that actors applying smaller, closed, reuse systems, for example used by restaurants, were excluded. The review of current European reuse system actors is non-exhaustive, i.e., the authors do not claim to have identified all European reuse system actors. Rather, the review aimed at the identification of such actors via information provided by Infinitum and in the LCA studies reviewed (Section 3). The actors identified by this procedure were then searched for on the internet to identify company websites for these actors and to gather further information.

The review of the current European practice in reuse systems focused on addressing the following questions:

1. What actors exist on the European market for reuse systems for bottles (e.g., PET, glass)?
2. What technical solutions are currently being used by these actors?
3. What empiric data exist for the number of rotations for reuse bottles over their lifetime?

In line with this, some important aspects were focused on in the review, namely:

- Reuse system actor information: company, country, contact information/website,
- Description of technology applied, including its strengths and weaknesses and,
- Data on the number of cycles/number of rotations/trip rates and stockpile size.

Furthermore, a number of additional important aspects were identified in the discussions between NORSUS and Infinitum, including who is the owner of the reuse system, number of product lines in the reuse system (depends on the number of different bottle types, e.g. various volumes and design, and crate types used), whether the reuse system employs a system where single bottles are reported or the number of crates (in turn including a potentially unknown number of bottles), how reuse system actors calculate trip rates, if a deposit system is applied, if a deposit charge is applied for different bottle types and whether the reuse system employs reverse vending machines or not. These other important aspects were not the focus of the review, i.e., not searched for explicitly, but considered if such information were readily available from reuse system company websites.

3 Reviewed life cycle assessments of reuse systems

In this section, the results from the review of LCAs of reuse systems are described. A short description of the key messages from Coelho et al. (2020) is provided in Section 3.1. Then a more detailed overview of the studies reviewed by Coelho et al. (2020) and additional studies reviewed in this study are provided in Section 3.2. Finally, a description of the approaches applied to model reuse, trip rates and stockpiles in the reviewed LCA studies, a presentation of suggestions for modelling trip rates provided by the recently developed product environmental footprint methodology and a presentation of the study by Deloitte (2013) providing empirical data for trip rates are provided in Section 3.3.1, 3.3.2 and 3.3.3, respectively.

3.1 Key messages from the review by Coelho et al. (2020)

Coelho et al. (2020) reviewed seven LCAs of reuse systems and concluded that the break-even point for reusable glass bottles compared to single-use bottles made of glass, PET or aluminium in terms of environmental impacts in general seems to occur after 2-3 uses. Depending on the specific case scenario applied, at least 10 cycles were stated to be required to reach the break-even point between reusable and single-use packaging. It was also stated that reusable glass bottles reach 25-30 cycles on average. Four key parameters, in addition to the packaging type and material composition, were identified as having a high influence on the LCA results, namely; (i) transport (distances e.g. between bottling plant and the local distributor, backhauling, weight and volume of packaging, mode of transport), (ii) production of primary packaging (reusable packaging typically of higher material quality compared to single-used packaging), (iii) the number of times that bottles are used and (iv) the modelling of end of life (share packaging material that becomes recycled/incinerated/landfilled, recycled content, crediting avoided production from recycling of packaging or not). These aspects as well as some additional aspects will be described in more detail and further discussed in the following sections.

3.2 Detailed review of LCA studies of reuse systems for bottles

This section focuses on addressing the questions: (1) What LCA studies of reuse systems for bottles (PET, glass etc) exist in literature? (2) Which modelling methods have the studies used to arrive at their conclusions? and (3) What aspects have been highlighted as important in these LCA studies? (Section 2.1). The reviewed LCA studies are summarized in Table 1 and short overviews are provided for each study with a focus on the type of comparisons conducted, the type of reuse system data applied in the study, aspects highlighted as important in influencing the study results and the main results of the study.

Table 1. Reviewed LCA studies of reuse systems for bottles listed per reusable bottle type in the order of i) increasing packaging size and ii) recycled content. Note that the functional units have been shortened for clarity and do not necessarily represent the exact statements in the reviewed studies. PET=polyethylene terephthalate, LCIA=life cycle impact assessment

Size(s)	Recycled content	Trip rates: Baseline value (range)	Geo-graphical scope	Functional unit(s)	LCIA method (# impact categories assessed)	End-of-life modelling	Reference
Reusable glass bottles							
0.75 L	35%	1 (1-25)	United Kingdom	i) 1 liter of packaged drink ii) total annual production and consumption of carbonated drinks in the UK	CML 2001 (11)	Credits given for avoided burdens from recycling of packaging. However, no credit was given to packaging including recycled materials to avoid double-counting	Amienyo, Gujba, Stichnothe, and Azapagic (2013)
0.75 L	80%	15	Italy	Bottling and distribution of 3 L of wine	ReCiPe 2016, H, (21)	Avoided impacts from recycling of packaging materials were considered and various substitution ratios were applied	Ferrara et al. (2020)
0.75, 1 L	55-75% (depending on colour)	15 (10-20)	Toronto, Canada	Packaging of 1 L of young, non-sparkling wine and that for 750 ml of spirits	ReCiPe v1.02 (4)	Avoided burden approach to recycling was applied	Cleary (2013)
0.75 L, 1 L	87%	5	Regional, Germany	Production of 0.75 L wine	IPCC, 2013 (1)	End of life not modelled	Ponstein et al (2019)
1 L	62.5%	8 (30)	Italy	Container for 1 L of pasteurized milk	ReCiPe 2016, H (6)	Avoided heat and electricity generation due to municipal waste incineration was considered	Stefanini, Borghesi, Ronzano, and Vignali (2021)
1 L	70%	7	Campania region, Italy	Bottling and distributing 1 L of natural mineral water and 1 L of sparkling mineral water	ReCiPe 2016, H (21)	The avoided virgin glass production from recycling of glass bottles was considered in line with Ferrara and De Feo (2020)	Ferrara, De Feo, and Picone (2021)
1 L	80%	1-30	Italy	100 litres of mineral water in 1 litre glass bottles	Environmental Footprint LCIA method, version 2.0 (14)	Avoided production was considered and a substitution ratio at 1:1.15 was applied for glass	Tua, Grosso, and Rigamonti (2020)

Size(s)	Recycled content	Trip rates: Baseline value (range)	Geo-graphical scope	Functional unit(s)	LCIA method (# impact categories assessed)	End-of-life modelling	Reference
Reusable glass and PET bottles							
Glass: 0.33 and 1 L, PET: 0.5, 1 1.5 and 2 L	Not specified	Glass and PET: 1-21	Hungary	Packing of 1000 L of drinks	CML-IA, 2010 (3)	The use of secondary materials was credited by modelling the avoided production using primary material production datasets from the GaBi database. The recycled content of the packaging materials was not stated	Simon et al (2016)
1 L	Glass: Not specified PET: 0%	Glass: 10 (0-50) PET: 15 (0-25)	Italy	Consumption of 152.1 litres of drinking water by one Italian citizen	CED method and CML 2001 (4)	Avoided burdens method (Finnveden et al., 2009) was applied, involving the use of substitution factors	Nessi et al. (2012)

3.2.1 Reusable glass bottles

Amienyo et al., 2013

Amienyo et al. (2013) conducted a case study of the life cycle impacts of carbonated drinks in the United Kingdom and compared reusable glass bottles with single-use aluminium cans and PET bottles. Primary data for e.g., amounts of packaging materials and energy use in manufacturing, were obtained from a drink manufacturer. Several impact categories were considered in the study, however, climate change was in focus and the primary packaging was concluded to be the main contributor to this impact category. Transport was not identified as a significant contributor to climate change and the reason for this could be the short transport distances applied in the study, e.g., 12 km between retailer and manufacturer (also applied for the return of reusable glass bottles). The study concluded that if the glass bottle was reused three times, then its climate change impacts were comparable to the single-use aluminium can and PET bottle. However, the glass bottle needed to be reused 20 times to be advantageous to a PET bottle with a recycled content of 60%. Furthermore, Amienyo et al. (2013) acknowledged other aspects, not addressed in their study, such as the economics of a reuse system. The economic and practical feasibility of a higher recycled content in single-use PET, where the latter is subject to the law on recycling of food packaging, was also mentioned in this context.

Ferrara et al., 2020

Ferrara and De Feo (2020) compared the cradle-to-grave environmental footprint of different packaging options for wine on the Italian market. The options assessed included traditional single-use glass bottle, reusable glass bottle, bag-in-box, multilayer PET bottle as well as aseptic cartons. All packaging were stated to be suitable for wine, although glass was stated to be preferable for high quality aged wine. Data on e.g., weights of primary, secondary and tertiary packaging as well as their waste management were obtained from packaging companies and Italian wineries. Important aspects in terms of affecting the environmental performance of the assessed packaging options were stated to include the weight of the container, distribution distances and the disposal alternatives of the packaging systems. The bag-in-box and the aseptic cartons were concluded to be environmentally preferable. The single-use glass bottle was stated to have the highest environmental impact, ranking worst in 13 of the assessed impact categories, followed by the single-use PET bottle, ranking worst in terms of eutrophication, ecotoxicity and water consumption impacts. Ferrara and De Feo (2020) stated that this was due to high burdens associated with the distribution phase as well as the secondary-tertiary packaging for the reusable glass bottle while the production process contributed significantly to the life cycle impacts of the multilayer PET bottle. In terms of impact on climate change, three reuses of refillable glass bottles were concluded to be needed to break-even with single-use PET bottles. At a trip rate of 15, the glass bottle scored better than the single-use PET bottle for all impact categories assessed in their study. The modelling of various end-of-life scenarios, e.g., by varying the share of discarded single-use and reusable packaging that becomes collected for recycling between 0-100%, were stated to clearly affect the results for single-use glass and PET bottles. Reusable glass bottles, on the other hand, where most affected by variations in the distribution distance and it was concluded that these bottles are only viable on local markets at distribution distances less than 100 km.

Cleary, 2013

The goal of the study by Cleary (2013) was to examine environmental impacts of different wine/spirits packaging by comparing reusable glass with various single-use packaging alternatives, such as glass and PET. In addition, the impact of a plausible future scenario of different packaging market shares was compared to the existing packaging market in Toronto in 2008. For the future scenario, new market shares were assumed and geographical constraints, customer preference of glass and constraints of PET/aseptic cartons were addressed. The transportation return distance was fixed at 200 km, and no sensitivity analysis was conducted for this parameter. Refillable glass bottle and aseptic carton were proven to have the lowest net endpoint level of environmental impacts with an overlapping standard deviation. It was furthermore stated that if the number of cycles is 20 for the reusable bottle, this alternative would be “superior” to the other alternatives for all the assessed impact categories.

Ponstein et al., 2019

In the cradle-to-gate study by Ponstein, Meyer-Aurich, and Prochnow (2019), wine production applying both single-use and reusable glass bottles was assessed in terms of greenhouse gas emissions. Primary data was obtained from wineries in five specific wine-growing areas in Germany. Scenarios were constructed to explore potential impact reductions from e.g., reducing the bottle weight, the reuse of glass bottles and increasing the packaging volume. It was furthermore stated that reuse is common for local consumption within the wine-growing areas while these glass bottles are not commonly distributed on a larger scale, e.g., nationwide. In line with this, a transportation distance at 50 km between the winery and washing facility was applied based on data from one washing facility. The value for the transportation distance was not tested further in a sensitivity analysis. Based on the study results, Ponstein et al. (2019) emphasize the importance of reuse of glass bottles, potentially in combination with bottle weight reductions, in reducing greenhouse gas emissions. Reuse of glass bottles enabled greenhouse gas emission reductions with more than 35% compared to single-use glass in their study. In addition, Ponstein et al. (2019) stated that there are practical limitations to bottle weight reductions and to reuse systems that also need to be taken into consideration. Technical constraints to weight reduction and consumer perceptions of the bottle design were acknowledged in this context. Furthermore, reuse systems were stated to require an appropriate infrastructure of washing facilities to avoid too long transport distances and it was also stated that actions need to be taken to ensure a high bottle collection rate.

Stefanini et al., 2021

Stefanini et al. (2021) compared environmental and marine littering impacts related to the packaging of milk using single-use PET with various recycled content, single-use glass or reusable glass bottles. A lot of the data in the study were provided by an Italian factory for processing and packaging of milk. Littering impacts were assessed by a proposed marine littering indicator constructed as a function of the number of dispersed containers, incentive for returnable bottles, weight of the packaging material and material degradation time. The glass bottle was concluded to have higher environmental impacts compared to PET and while eight reuses of the glass bottle did lower its life cycle impacts, it was not enough to make the reusable glass bottle environmentally preferable to the PET bottle. The reasons for this were stated to be the energy-intensive glass bottle production and its associated transportation emissions which become larger due to the comparatively higher weight of the glass bottle. In addition, the fact that glass bottles need to be transported in their final form, while plastic can be transported in forms requiring less transportation space, was also mentioned. When the trip rate was changed from 8 to 30, the PET bottle with a recycled content at 50% still turned out as the preferable option from an environmental perspective, while the reusable glass bottle had lower, similar, or higher impacts compared to the PET bottle depending on the environmental impact assessed. Other parameters, such as the transportation distance between production site and retailer, which was set to either 243 km or 391 km in that study, were not varied. According to Stefanini et al. (2021), there might be an opportunity to reduce the weight of the glass bottle, and in that way reduce its environmental impacts, but then additional research would also be needed to ensure a sufficient level of bottle shock resistance. In terms of littering impacts, however, the returnable glass bottle turned out as preferable in comparison to all other alternatives assessed.

Ferrara et al., 2021

Ferrara et al. (2021) compared reusable glass bottles and single-use PET bottles applying data on e.g., bottle production, bottling plant operations and distribution of bottles from an Italian mineral water company. The authors highlighted that the number of reuses of the glass bottle and the distribution distance were the most important parameters in influencing the results in their study. Furthermore, the environmental impacts associated with the glass bottle were stated to be clearly dependent on these parameters as glass production is a very energy-intensive process and the glass bottle weight is comparatively high, which in turn affects the transportation impacts. The ranking of the reusable glass bottle and the single-use PET bottle were clearly affected by e.g., the transportation distance. The PET bottle, made from 100% virgin materials, was concluded to be environmentally preferable for most of the assessed impacts for the packaging of natural water, while the reusable glass and PET bottle performed similar for the packaging of sparkling water. The difference in results of these packaging systems were stated to be mainly due to the larger PET bottle weight (about 3 g more) and shorter transportation distance (about 27 km less) in the packaging system for natural water compared to the packaging system for sparkling water. The influence of the number of uses of the glass bottle on the study results was discussed but not tested quantitatively in their study.

Tua et al., 2020

In the study by Tua et al. (2020), reusable glass bottles were compared to single-use glass bottles from a cradle-to-grave perspective. Primary data were obtained from four reuse system actors in Italy, together representing 25% of the Italian reuse bottle market and complemented by field visits at two reconditioning plants. The study results showed that reuse of bottles is the environmentally preferable solution compared to single-use glass bottles. However, this result was stated to be dependent on the transportation distance between the bottling and the distributor of the reusable glass bottles. At distances of 200 km and 400 km, two and four number of uses was required, respectively, for the reusable glass bottle to achieve a better environmental performance than its single-use alternative. While at distances >800 km, the single-use bottles were concluded by Tua et al. (2020) to be the best solution as 30 number of uses would not be enough to make the reusable bottles preferable to single-use bottles from an environmental perspective.

3.2.2 Reusable glass and PET bottles

Simon et al., 2016

Simon, Amor, and Földényi (2016) examined the impact of different bottle types and collection strategies by comparing reusable glass and PET with single-use glass, PET and aluminium beverage packaging. The focus in their study was to compare various bottle collection systems, but an attempt was also made to assess reusable bottles. The data applied in the study were mainly obtained from LCA databases. The return distance was set to 250 km while no sensitivity analysis was conducted for this parameter in their study. The break-even points for refillable glass and PET bottles compared to all the single-use alternatives assessed, were two and three trips, respectively. The authors stated that the number of reuses as well as transport distances are critical parameters when assessing reuse systems. Furthermore, Simon et al. (2016) highlighted the influence that consumer behaviour have on these systems in terms of collection rates.

Nessi et al., 2012

In the study by Nessi, Rigamonti, and Grosso (2012), the energetic and environmental performance of two waste prevention activities related to the distribution of drinking water in Italy were assessed. Public network water facilities, i.e., tap water and public fountains, and reusable glass and PET bottles were compared to single-use PET and polylactic acid (PLA) bottles. The reuse system was modelled based on the distribution systems of major Italian producers of bottled water were bottles become transported by lorries over 300 km from the producers to the local distributor. The return trip was also accounted for. The bottles then become transported in crates over 20 km by the local distributor to the customers houses who also collects the empty bottles on the way back. Three parameters, also tested in the sensitivity analysis, were highlighted in the study due to the expected high influence of these parameters on the study results: the allocation factor of burden connected to customers purchasing trip, the distance from bottling plant to retailers/local distributors and the number of uses for refillable bottles. Nessi et al. (2012) concluded that the environmental performance of refillable glass bottles compared to its single-use alternatives was mainly dependent on the distance between retailers/local distributor from bottling plants rather than the trip rate. The refillable PET bottle outperformed its alternatives for all impact categories assessed except for eutrophication. The use of refillable glass was in general slightly worse than single-use PET bottles in most cases. If the refillable PET bottle had to be transported for a longer distance than the one-way bottled water, its advantages disappeared. The authors concluded that reusable PET bottles are preferable to reusable glass bottles and, for equal or shorter distances, also preferable to single-use bottles. If implementing a reuse system, it was concluded that the distribution distance should be short (no more than 150 km), and PET bottles should be reused at least 15 times and glass bottles at least 20-25 times to able to compete with the single-use alternatives.

3.3 Modelling of reuse, trip rates and stockpiles

This section addresses the questions (4) What approaches exist in LCA literature to model reuse? and (5) How is the number of rotations for bottles, i.e., the number of times that the bottle is used during its lifetime, modelled in these LCA studies? (Section 2.1). First, the results from the reviewed LCA studies are presented (Section 3.3.1). Then, suggestions for modelling trip rates as described by the Product Environmental Footprint (PEF) guidelines (Section 3.3.2) and empirically determined trip rates from a German study (Section 3.3.3) are presented.

3.3.1 Approach to model reuse, trip rates and stockpiles in the reviewed LCA studies

The approach to modelling reuse in the reviewed LCA studies is in general to conduct a break-even analysis to identify the number of cycles needed for the reusable bottle to become environmentally preferable compared to its single-use alternatives, see e.g. Amienyo et al. (2013), Simon et al. (2016) and Tua et al. (2020). In this way, the trip rate is used to calculate the environmental impact of the reusable bottle, typically by dividing the impact of production by the number of uses (trip rate) and then adding the impacts associated with transporting the bottle back to the manufacturer, washing and returning it to the store for each cycle.

The value applied for the trip rate clearly affect the LCA results for the reusable bottle in the reviewed studies. However, the baseline value applied for the trip rate, or the range of values applied in a sensitivity analysis, are seldom explained in a transparent manner but rather assumed or hypothesized without clear motivations, see further Table 2. A limited number of studies provide some motivation or explanation for their selected trip rates. Ferrara and De Feo (2020) stated that their selected trip rate was based on data from an Italian mineral water company on the annual loss of bottles, which do not pass the control phase. It was, however, not clear whether this figure incorporated both internal losses, e.g. bottles sorted out at the filling station, and external losses, e.g. at customers. Tua et al. (2020) stated that their upper end value for the trip rate at 30 was assumed based on collected primary data and further represents the average reuse rate of glass bottles as recommended by Zampori and Pant (2019). A few studies apply only one single value for the trip rate without conducting any further uncertainty analysis for this parameter, see e.g. Ponstein et al. (2019) and Ferrara and De Feo (2020). A trip rate at five was assumed for wine bottles in the study by Ponstein et al. (2019) and it was stated that the optical requirements are higher for wine glass bottles compared to glass bottles used for other beverages. In general, trip rates for wine glass bottles are lower compared to glass bottles for other beverages in the reviewed studies. Stockpiles were not considered in any of the reviewed studies, except being mentioned in the study by Simon et al. (2016) who stated that the exclusion of stock pools was a limitation of their study.

Table 2. Summary of trip rates applied in the reviewed life cycle assessments of reuse systems listed per reusable bottle type in the order of increasing recycled content. PET=polyethylene terephthalate

Recycled content	Trip rates: Baseline value (range)	Reuse system actors involved in the study	Comment	Reference
Reusable glass bottles				
Not specified	10 (0-50)	Italian bottling company	Hypothesised based on data from some Italian bottling companies	Nessi et al. (2012)
Not specified	(1-20)	-	No motivation provided	Simon et al. (2016)
35%	1 (1-25)	-	Break-even analysis and sensitivity analysis was conducted for the trip rate. The specific range applied was not clearly motivated	Amienyo et al. (2013)
55-75%	15 (10-20)	-	No motivation provided	Cleary (2013)
62.5%	8 (30)	Italian water packaging company, Lauretana and Italian company producing bottle washing and filling machines, R. Bardi	The trip rate at 8 was based on data from an Italian company, Lauretana, packaging water in returnable and non-returnable glass bottles who stated that a glass bottle can be used 8 times before it becomes damaged due to scuffing. The higher value at 30 were provided from an Italian company specialized in the production of industrial bottle washing and filling machines and stated to be based on data from some European countries	Stefanini et al. (2021)
70%	7	Italian mineral water company	The average number of uses of the glass bottle was provided by the Italian bottling company and stated to be based on the annual number of bottles that do not pass the control phase but become replaced by new bottles which was about 14%	Ferrara et al. (2021)
80%	(1-30)	Italian bottling companies	Sensitivity analysis, the higher value at 30 was assumed based on collected primary data and further stated to represent the average reuse rate of glass bottles as recommended by PEF guidelines, see Zampori and Pant (2019)	Tua et al. (2020)
80%	15	-	No motivation provided, except that a reference was given to Cleary (2013)	Ferrara and De Feo (2020)
87%	5	-	While glass bottles for water and beer were stated to be able to be reused up to 50 times based on a report by the German Environmental Agency (in German) from 2002, a lower value was assumed due to lack of data for wine bottles and due to higher optical requirements for such bottles	Ponstein et al. (2019)
Reusable PET bottles				
Not specified	(1-21)	-	No motivation provided	Simon et al. (2016)
0%	15 (0-25)	Italian bottling company	Hypothesised based on two LCA studies in German	Nessi et al. (2012)

3.3.2 Suggestions for trip rates in the Product Environmental Footprint methodology

The Product Environmental Footprint (PEF) methodology is a LCA-based method that put certain requirements on the modelling procedure to enable studies that are more reproducible, comparable and verifiable (Zampori & Pant, 2019). To reach a high level of comparability, there exist product environmental footprint category rules (PEFCRs), which have been developed for specific product categories, that should be followed. For example, there exist PEFCRs for beer, packed water and wine (European Commission, 2021). The PEF methodology is still under development and several suggestions for further updates of the methodology have been provided (Zampori & Pant, 2019). When it comes to the treatment of extended product lifetimes, e.g. when a product is reused a certain number of times before it becomes discarded, Zampori and Pant (2019) provide several suggestions for company-owned pools and third party operated pools, respectively. An important parameter in this context is the reuse rate. Zampori and Pant (2019) describes the reuse rate as the number of times that a material is used at the factory, often also called trip rates, reuse time or number of rotations. Furthermore, they state that the reuse rate may be expressed as the absolute number of reuses, i.e., the total number of uses during the life of the material, or as % reuse rate.

Company-owned pools

Company-owned pools imply that the packaging return system is organized by the company owning the packaging material. According to Zampori and Pant (2019), in first hand, supply-chain specific data should be applied for calculating trip rates of these pools. When the previous and the current bottle pools are comparable, the supply-chain specific data applied for the current pool should be based on accumulated experience of previous bottle pools. The reuse rate, in terms of number of reuses, of the bottle pool should in this case be calculated by dividing the number of bottles filled during the lifetime of the bottle pool (*#F_i*) by the number of bottles at initial stock plus purchased over the lifetime of the bottle pool (*#B*) according to:

$$\text{reuse rate, in terms of number of reuses} = \frac{\#F_i}{\#B} \qquad [1]$$

The number of uses, can also be calculated as a function of the % reuse rate, as described in Zampori and Pant (2019) according to:

$$\text{Number of reuse} = \frac{1}{100\% - \%\text{ reuse rate}} \qquad [2]$$

Hence, based on Equation 2, the % reuse rate can be calculated according to:

$$\%\text{ reuse rate} = 1 - \frac{1}{\text{Number of reuse}} \qquad [3]$$

In second hand, if no supply-chain specific data are available, conservative estimates partly based on assumptions could be made. In this case, the reuse rate should be calculated as a function of (i) the estimated lifetime of the bottle pool in years, (ii) the average number of rotations, including filling, delivery, use and back to brewer for washing, of a single bottle during one calendar year if not broken and (iii) the average percentage of loss per rotation, including both loss at consumers and bottles scrapped at filling sites.

Third-party operated pools

Third party operated pools imply that the packaging return system is organized by a third party, such as a government or pooler. For these pools, the PEF guidelines suggests trip rates in turn assumed based on the monopoly system in Finland (Zampori & Pant, 2019), see Table 3. Note that for bottles, data are provided for glass only.

Table 3. Average number of cycles suggested for third-party operated pools (Zampori & Pant, 2019)

Type of packaging	Number of cycles
Glass bottles (water or beer)	30
Glass bottles (wine)	5

3.3.3 Empirical data for trip rates by Deloitte (2013)

The study by Deloitte (2013) (written in German) provided circulation figures of refillable bottles recorded at a total of 1 072 companies in the German beverage industry between March 2012 and July 2013. The study was commissioned by the Federation of German food and drink industries and the German trade organisation. Trip rates were empirically determined according to the production method, a method which calculates number of reuse (trip rate) by determining the number of bottles in circulation for a certain period and divide this by either the number of lost or purchased bottles over the same period. In the study by Deloitte (2013), the trip rates were calculated based on the total loss of bottles, including both internal and external losses. The average resulting trip rates for different bottle types are presented in Table 4. Utilizing Equation 3 in Section 3.3.2, these average trip rates can be re-calculated into % reuse rates that ranges between 92.8% to 97.7% for the corresponding systems.

One important reason for calculating trip rates based on losses was stated to be the availability of such data from the companies assessed. Furthermore, the chosen procedure for calculation of trip rates based on the production method using empirically determined data for internal and external losses was presented and discussed with numerous organizations, interest groups and companies. The focus of the discussions was the methodological foundation, the practical feasibility of the measurements, the limitations of an empirical determination and related uncertainties. For further details on the results of these discussions and limitations of the applied method to calculate trip rates, please refer to e.g. Table 4 in the report by Deloitte (2013).

Table 4. Average trip rates for various reusable glass and polyethylene terephthalate (PET) bottles based on Deloitte (2013)

Bottle specification	Average trip rate
Refillable glass bottles	
NRW beer pool bottle, 0.5 L	42
Longneck pool bottle, 0.5 L	33
Beer pool bottle	36
Individualized refillable beer bottle (only used by one brand or producer), 0.5 L	25
Pool bottles for mineral water and soft drinks, 0.7 L	38
Pool bottles for mineral water and soft drinks, 0.75 L	44
Refillable PET bottles	
Mineral water bottle, 1 L	20
Soft drink bottle, 1 L	14

4 Review of reuse system actors

In total, four European reuse system actors located in Germany, Denmark, Estonia, and Finland were included in the review (Table 5). Short descriptions of the identified European reuse system actors are provided in this section. Note that some of the company websites were not available in English, which complicated the data collection somewhat.

Table 5. Summary of the identified reuse system actors. Trip rates indicate the number of rotations for reuse bottles over their lifetime. "-" indicates that no such information was readily available from the references. PET = polyethylene terephthalate

Company	Country	Type of reuse packaging	Trip rate(s)	Stockpile size(s)	Deposit	References
Dansk Retursystem	Denmark	Glass and plastic bottles	-	-	0.13-0.4 €	Dansk Retursystem (2021a), Dansk Retursystem (2021b) *References in Danish*
EESTI PANDIPAKEND (EPP)	Estonia	Glass bottles	-	-	0.1 €	EPP (2021a), EPP (2021b), EPP (2021c)
Genossenshaft Deutscher Brunnen eG (GDB)	Germany	Glass and plastic (PET) bottles	Glass: up to 50 PET: up to 25	-	Typically 0.15 €	GDB (2021a), GDB (2021b),GDB (2021c) *References in German*
Palpa	Finland	Glass bottles	33 (on average)	-	0.1 €	Palpa (2021a), Palpa (2021b), Palpa (2021c), Palpa (2021d)

Dansk Retursystem

Dansk Retursystem has been responsible for the Danish deposit system since 2002. Reusable bottles, e.g., typically green glass bottles for beer, are collected in a deposit system, washed and refilled by the producer. It is the producer, or importer, that is responsible for establishing the reuse system and not Dansk Retursystem. A minimum return rate at 75% should be ensured to be reached by the producer of refillable bottles and the amounts of bottles sold, and the amounts of collected bottles should be reported to Dansk Retursystem by the producer/importer.

EESTI PANDIPAKEND (EPP)

A producer responsibility organisation acting under accreditation by the Estonian Ministry of the Environment. Reuse systems exist for glass beverage packaging of various volumes. The packaging is collected by the retail seller, e.g., by reverse vending machines, and then become sent to the beverage maker for washing, refilling, and reselling.

Genossenshaft Deutscher Brunnen eG (GDB)

The Association of German Mineral Water Wells manages the largest pool system in Europe. Various companies are connected to the pool system that currently involves nine different types of bottles. GDB offers their customers machines and systems needed for beverage production, filling and transport. At the bottling company, the bottles become cleaned and quality controlled. The bottles provided by GDB are used by many companies and the collected bottles do not necessarily become returned to the same bottling company after use. Hence, the bottles can be transported in ways that minimize transport distances.

Palpa

The Palpa reuse system was created in the 1950s and is owned by Franchising groups and companies in the beverage industry. The refillable bottles are mostly of the traditional brown beer bottle type. Collected bottles become transported from the return point, where reverse vending machines or containers are applied, to the beverage manufacturer where they become washed, rinsed, refilled, and relabelled. A return rate at approximately 97% is reported refillable glass bottles. Furthermore, the return rate is stated to have varied between 88-87% between 2018-2020.

5 Concluding discussion

Several aspects have been highlighted as important in the reviewed LCA studies of reuse systems and these should be taken into consideration in future LCAs of such systems:

Packaging size and material composition: Packaging with a higher volumetric content has lower impacts compared to packaging with a lower volumetric content. This is due to a reduction in the amount of packaging materials needed per volume of packaged beverage, see e.g. Stefanini et al. (2021), Amienyo et al. (2013) as well as UNEP (2020). The recycled content of the packaging also has clear effects on the environmental impacts, both for reusable and single-use packaging.

Trip rate and collection rate: The trip rate largely influences LCA results for the reuse system, but the assessed trip rates are, in general, not well motivated nor explained in the reviewed studies. Information about the data applied to calculate trip rates, such as collection rates, in turn dependent on internal and external losses and on sizes of stocks of bottles, are limited. Detailed discussions on various collection systems, such as deposit systems versus voluntary collection systems, in turn associated with different collection rates are rarely provided in the reviewed studies. Nor do the reviewed studies discuss potentials for the improvement of, or the introduction of other, collection systems for single-use and/or reuse systems in any detail. It is important that these aspects are considered and discussed and then in line with the study goal, which could be to e.g. assess the current situation in a region/country or to compare potential future single-use and reuse systems.

The collection rate of the packaging in the systems assessed is an important and sensitive parameter both for single-use and reusable beverage packaging, as it strongly affects the share of used bottles that become recycled and reused in the respective single-use and reuse systems, see e.g. Ferrara and De Feo (2020). On the other hand, the collection rate is strongly influenced by the type of collection system in place, most importantly whether a deposit system is applied or not. When different collection systems are applied for the compared reuse and single-use bottle systems (e.g. a deposit for reusable bottles and a voluntary system for single-use bottles), different collection rates will typically occur (Albrecht, Brodersen, Horst, & Scherf, 2011). A direct comparison of the environmental impact for such systems might therefore be misleading depending on the study goal. If the goal of a study is to compare potential future bottle systems, the collection systems applied should be carefully selected to ensure a comparison focusing on differences between the bottle systems, rather than on differences reflecting the underlying collection systems. This is especially important when there are no clear arguments for why the selected collection systems should be different for the bottle systems assessed. However, if the goal is to compare the impact of existing bottle systems, the collection systems in place for the respective bottle systems should be considered. The collection systems applied for the compared reuse and single-use bottle systems should always be selected in line with the study goal; and the collection rates applied and their influence on the results should be acknowledged.

The approach to modelling reuse in comparisons with single-use systems is in general to conduct break-even and sensitivity analysis for the trip rate, in turn dependent on the collection rate, to assess its influence on the study results. This approach, where break-even and sensitivity analysis are applied for the assessments, seems appropriate given the potential limited availability of empirical data on trip rates in the specific studies reviewed. For future LCAs of reuse systems, it would be interesting to make use of existing empirical data when available and relevant and/or to gather empirical data. Assessments of whether it would be realistic to achieve a trip rate in line with the break-even point identified for reusable packaging or not would also be relevant. Furthermore, the effect of number of reuses on the decrease in environmental impacts of reusable bottles is largest for the first number of uses while significance of larger trip rates gradually levels off. For higher trip rates, the impact of the washing and distribution phase become important (Amienyo et al., 2013; Stefanini et al., 2021). Thus, to reduce the impacts of the reusable bottle it should not only be prioritized to have a high trip rate but also to minimize the environmental impacts associated with its reuse cycle, i.e., washing and distribution.

Transport distance: The transport distance between retailers and washing/bottling is important for reuse systems. Typically, shorter transport distances are required for reusable bottles to become environmentally preferable to single-use bottles. The efficiency of transportation, including for example the palletizing efficiency, have also been highlighted, see e.g. Ferrara and De Feo (2020).

End-of-life modelling: The end of life for packaging materials are typically modelled by giving credits for avoided burdens from recycling of these materials. The quality of the recycled material, affecting the amount of primary material production that can be avoided, is sometimes considered by the application of so-called substitution factors, see e.g. Nessi et al. (2012) and Ferrara and De Feo (2020). Furthermore, the modelling of the waste management phase, where various shares of packaging material become recycled, incinerated or landfilled, also have a large influence on the results.

Other aspects: In addition, there are several other aspects that are important related to reuse systems. Some aspects have been highlighted in the reviewed LCA literature, for example, the economics of reuse systems (Amienyo et al., 2013), technical limitations to bottle weight reductions and the requirement of an infrastructure with washing facilities located not too far from retailers (Ponstein et al., 2019). In relation to this, Amienyo et al. (2013) also highlight similar considerations for single-use systems, such as technical barriers for a very high recycled content in single-use PET bottles. Furthermore, reduced littering and waste generation have also been highlighted as important aspects to consider (Briedis et al., 2019). In general, there are many aspects, including environmental, economic and social aspects, that need to be considered in assessments of these systems (Albrecht et al., 2011). It should be acknowledged that all these aspects are perhaps not always that well captured in LCAs, why such studies need to be complemented by additional analysis, such as qualitative discussions on these aspects.

Thus, in summary, the results from LCAs of reuse systems are to a large extent influenced by several aspects and many aspects are in general addressed in the reviewed LCA studies. An aspect that has been highlighted as specifically important in this context is littering. It is commonly highlighted as an issue related to single-use plastic products, including plastic bottles, and is one of the reasons of increased interests in the identification of alternatives to such products (Section 1). However, only one LCA study assessed such impacts, see Stefanini et al. (2021), with the conclusion that the reusable glass bottle turned out as preferable in comparison to single-use glass and PET bottles. This was furthermore stated to be due to the low number of glass bottles needed, the higher weight of glass bottles making them less prone to become dragged into the sea by winds or waves if dispersed, and higher return incentives for glass bottles in their study. Detailed discussions on littering as a consequence of the type of collection system, in turn affecting the collection rates or return incentives, were not provided in that study but consumer behaviour was raised as important in influencing environmental dispersion of bottles.

When it comes to reuse system actors, data on stockpile sizes, trip rates and the technology applied (strengths/weaknesses) were limited and typically not readily available on the company websites for the four reuse actors addressed in this review. Note that the review of current practice in European reuse systems is not exhaustive but should rather be seen as an initial review of readily available information of some reuse actors via company websites providing a starting point for a more in-depth review of such actors.

Despite the non-exhaustive nature of this review, it provides an overview of recently published LCAs of reuse systems for bottles and the results can be applied to identify important aspects to consider in future LCAs of such systems.

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Appendix 1

Table A1. List of European reuse system actors provided by Infinitum

Company	Country	Contact information/website
Dansk Retursystem	Denmark	https://danskretursystem.dk
EESTI PANDIPAKEND (EPP)	Estonia	https://eestipandipakend.ee/en/how-does-the-deposit-system-work/
GDB	Germany	https://www.gdb.de/
Palpa	Finland	https://www.palpa.fi/svenska/

NORSUS
Norwegian Institute for Sustainability Research

The vision of NORSUS Norwegian Institute for Sustainability Research (formerly Ostfold Research) is to provide knowledge for sustainable societal development. We apply and develop knowledge and methods to understand and implement sustainable solutions in society. Together with a wide range of public and private clients, we undertake projects locally, nationally and internationally to enhance environmental performance, often also generating economic benefits.

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