

Review

Life Cycle Assessments of Takeaway Food and Beverage Packaging: The Role of Consumer Behavior

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Abstract: Consumer behavior can significantly influence the environmental impact of products. Takeaway food and beverage packaging can be assumed to be an example of this effect, as consumers directly affect its disposal or, in the case of reusable packaging, the reuse rate. While possible environmental impacts of takeaway food and beverage packaging are comprehensively discussed in available Life Cycle Assessment (LCA) studies, consumer behavior is not extensively considered. Thus, a literature review was used to analyze existing LCAs of takeaway food and beverage packaging regarding three aspects: (i) the extent to which consumers are considered in the use phase, (ii) the inclusion of littering, and (iii) the consideration of consumer behavior in the End-of-Life (EoL) phase. The analysis shows that none of the reviewed LCAs includes all reviewed aspects of consumer behavior, and that the depth of implementation varied significantly. We conclude that, currently, the topic is not adequately considered in available LCAs and future studies need to address it more widely. This is especially important for the comparison of single-use and reusable takeaway packaging, as consumer behavior significantly influences the environmental impact of both systems. Finally, we argue why a method that includes littering on takeaway packaging needs to be developed.

Keywords: takeaway food packaging; reusable; single-use; life cycle assessment; use phase; end of life; consumer behavior; littering



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1. Introduction

The worldwide consumption of takeaway food and beverages has increased substantively in recent years due to changing lifestyles [1–3]. A result of these consumption habits is that 500 billion single-use cups are ending up in landfills annually [4]. The COVID-19 pandemic has added to this trend [5,6]. For example, the use of food delivery service increased by 60% in Bangkok during the pandemic [7]. Following this rising consumption, the environmental impacts of the packaging needed for takeaway food and beverages have also increased. With an estimated amount of 8 million tons of plastics littered into the oceans annually and takeaway food packaging as one of the top ten items found at beach cleanups, littering is an example of this environmental impact [8,9].

The potential environmental impacts of different packaging options have been widely studied, with the first LCA studies dating back to 1994 [10]. Therefore, several LCAs for different packaging options for takeaway food and beverages are available (for example [1,11–13]). As part of the “Single-Use Plastic Products Studies”, on behalf of the United Nations Environmental Program (UNEP), the Life Cycle Initiative (LCI) provided an overview of available life cycle assessments of takeaway food and beverage packaging. The goal of the program was to collect information about the (potential) environmental effects of single-use plastic products and their alternatives. Based on this information, recommendations for policymaking were developed. The report on single-use beverage cups and their alternatives was published in 2020 [2]; the report about single-use plastic takeaway food

packaging and its alternatives was published in 2021 [3]. The key findings of the reports are, when used and disposed of properly, alternatives such as reusable containers and compostable bioplastics can have a lower environmental impact than single-use plastic packaging. However, the environmental benefits of these alternatives depend on factors such as the material, usage patterns, and waste management practices. The reports conclude that a combination of measures, such as reducing single-use packaging and cups, improving waste management, and promoting the use of more sustainable alternatives, is needed to minimize the environmental impact of food and beverage packaging.

In addition to the findings regarding environmental impacts of single-use and reusable options, the report also addressed aspects that should be carefully considered when conducting an LCA of takeaway food and beverage packaging. The behavior of consumers is one of these mentioned aspects. As consumer behavior directly affects the environmental impacts of reusable cups [3], it should be carefully assessed. Other research also shows the importance of this consideration. Coelho et al. states in a review of sustainability of reusable packaging that return rates and cleaning are key factors of its environmental impact [14], which are significantly affected by consumer behavior. These findings are in line with other studies on the impact of consumer behavior on results of LCAs [15–17], especially regarding LCAs on food-related topics [18]. Additionally, studies from non-packaging consumables show that a change in the use phase has a high potential for a decrease in the potential environmental impact of a product system [19]. Despite this research, consumer behavior is often not considered in LCAs [20]. Aside from the statement that this topic should be considered carefully, the UNEP studies provide no recommendations on how it should be included in a study. Furthermore, no dedicated analysis on how consumer behavior was included in the reviewed publications is given. Therefore, this paper reviews the inclusion of consumer behavior in available LCAs of takeaway food and beverage packaging and draws recommendations on how this should be included in future LCAs.

Consumer behavior is a key factor in the waste generation and management of food and beverage packaging. There are several factors that can affect consumer behavior and contribute to littering and waste separation practices:

- Regulations and policies: Government policies and regulations can have a significant impact on consumer behavior, for example, recycling behavior [21,22]. A compulsory deposit systems could be an example for that, as for other packaging it leads to an increasing return rate [14,23], which therefore would decrease the amount of littered packaging;
- Culture: Cultural norms and values can also influence consumer behavior and waste management practices [24,25]. For example, in some societies, there is a greater cultural value placed on reducing waste and protecting the environment, which can encourage consumers to adopt more sustainable practices [26];
- Technologies: Technological advances can play a role in encouraging or discouraging littering and waste separation behavior [27,28]. For example, the lack of access to appropriate waste management infrastructure can discourage consumers from properly disposing of waste, leading to littering and other environmental problems [23].

Life cycle assessment, according to ISO 14040/44, is conducted in four steps [29–31]: (1) goal and scope definition, (2) life cycle inventory, (3) life cycle impact assessment, and (4) interpretation. These steps are not necessarily conducted in succession, but iteratively. During the goal and scope step (1), the system boundaries, functional unit, target, etc., of study are defined. Throughout the life cycle inventory (2), all environmental, energy, material and other flows of the analyzed system as well as its system boundaries are collected and related to the functional units. In the life cycle impact assessment (3), the flows from the life cycle inventory are assigned to impact categories and converted into a consistent equivalent unit. In the last step (4), the results are interpreted and analyzed regarding completeness, robustness, and sensitivity.

The remainder of the paper is organized as follows: Section 2 describes the LCA method and potential consumer behaviors that influence the use and disposal of takeaway

food and beverage packaging. It also defines the resulting research questions and the procedure of the literature review. Subsequently, Section 3 presents the results of the reviewed literature as well as the considerations of the use phase in the reviewed LCAs. Section 4 then discusses the results and highlights the limitations of this review. Finally, Section 5 presents the conclusions, and puts forward recommendations regarding the inclusion of consumer behavior in future LCAs of takeaway food and beverage packaging.

2. Materials and Methods

In each step of an LCA, the consideration of user behavior has the potential to improve the overall quality of the study [32]. Hence, we reflect below on different user behaviors that might influence the outcome of LCAs of takeaway food and beverage packaging. This is important for determining which step user behavior needs to be included in a LCA. These reflections are based on available LCAs of takeaway packaging, literature from the social sciences, as well as the development of our own hypotheses.

During the life cycle of takeaway food and beverage packaging, the behavioral routines, habits or practices of consumers can have a significant impact on the environmental impacts of the packaging. These decisions happen during the use phase of the packaging but have an impact on the End-of-Life (EoL) of the packaging. In the case of single-use packaging, the consumer could decide to reuse the packaging. If the packaging is designed to be quite stable and durable, consumers reuse it either for its designed purpose or even for something else, e.g., yoghurt pots for plants [33,34]. In the case of reusable packaging, the number of reuses could vary drastically between different consumers. At the two ends of the spectrum are those consumers who always carry their reusable packaging along and have it available when needed, and those who often forget their reusable packaging at home and need to obtain new ones, respectively [35].

The cleaning of the packaging can also widely vary between different consumers, most of all according to whether a consumer uses a dishwasher for cleaning or washes the packaging by hand. Within each of these two cleaning practices, a wide variety of further options with various potential environmental effects are imaginable. A consumer could, for example, have the latest model of a dishwasher, with the most efficient use of water and energy, or an older model with substantially worse performance. Besides the efficiency of the dishwasher used, the manner of its utilization can have a significant effect on the environmental impact, as the most efficient dishwasher is no more environmentally friendly when used only for one piece of packaging. Likewise, for handwashing, the use of water and soap can vary considerably between different consumers.

With different EoL options that are globally available, consumers also influence which waste stream the packaging will enter. For example, as per intended use a lot of takeaway food and beverage packaging is used outside of the household, wherein dedicated recycling bins for disposal could be unavailable. This could lead to the use of street waste bins, which makes the packaging enter the residual waste stream instead of a recycling waste stream. Furthermore, instead of disposing of the packaging in a waste bin, a consumer could decide to litter the packaging directly onto the environment. This is not unlikely, as analyses of littered waste show a significant share of takeaway food and beverage packaging [36].

2.1. Research Questions

As discussed, the behavior of consumers can have an influence on the potential environmental impact of a product. Therefore, the general research question in this paper is: To what extent is consumer behavior included in available LCAs focusing on takeaway food and beverage packaging? To analyze this overall question in more detail, it was split into the following sub-questions:

- How was the use phase modeled, and was consumer behavior anticipated?
- Was (the possibility of) littering included in the LCAs?
- How was the EoL modeled, and was consumer behavior anticipated?

2.2. Literature Review

This literature review, which was done in January 2023, was conducted in two steps. First, scientific publications on LCAs of takeaway food and beverage packaging were selected for the review. Secondly, the selected publications were analyzed regarding the research questions.

We used Web-of-Science (WoS) for the identification of relevant publications. Based on a preliminary search for LCA studies addressing the topic of takeaway packaging, we created the following search string:

ALL = (("Life cycle assessment*" or "LCA*") and (takeaway* or "single use*" or reusable* or disposable* or to-go*) and (cup* or boxes* or "food container*" or "tableware" or "food service ware" or "drinking cup*" or "food packaging")) AND LANGUAGE@English)

Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years

Subsequently, we double-checked the list of publications with a Google Scholar search. The double-checked results of the search were further analyzed by reading the abstracts of the found publications. Based on the content of the abstracts, all publications which include an LCA of food or beverage packaging for direct consumption were selected. Furthermore, these publications were subsequently checked for references in order to search for relevant important publications that may have been missed out in the search. This was done as forward and backward "snowballing", which mean that all references in the selected publications as well as all later publications which are citing the selected ones (according to Google Scholar) were considered.

As a next step, the resulting publications were compared to the two UNEP meta studies [2,3] to identify additional relevant LCAs studies. Following the selection of the publications, the LCAs were analyzed based on the research questions defined in Section 2.1. Further, a correlation analysis was between the inclusion of consumer behavior and other modeling choices was done with Excel. An overview of the steps of the literature review can be found in Figure 1.

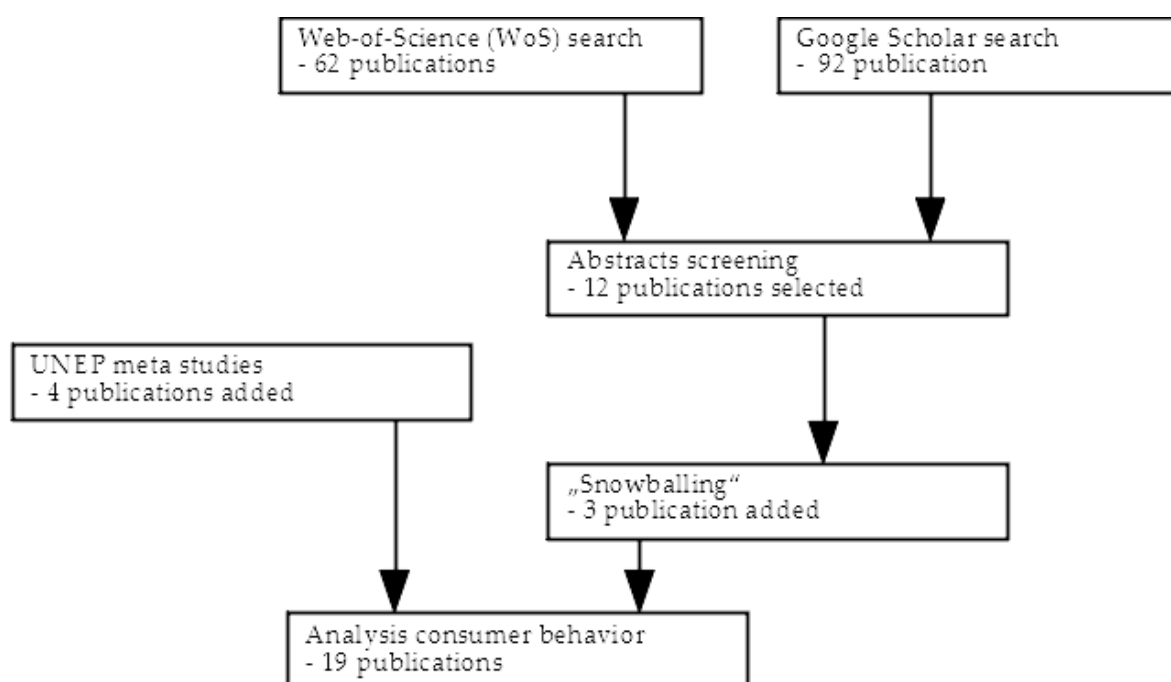


Figure 1. Research framework of the literature review and number of publications added each step of review.

3. Results

In the following, we present the results of our literature review. First, we list the publications and provide a general overview. Afterwards, we address the outcomes of the research questions.

3.1. Literature Review—Overview of Analyzed LCA Studies

The WoS search resulted in 62 publications and the Google Scholar search in 92. A complete list of the found publications is provided in the Supplementary Material. Based on a screening of the abstracts, 13 publications included LCAs of takeaway food and beverage packaging. As one of these publications [37] only covers cradle-to-consumer and did not address the research questions, we excluded it from further analysis. The comparison with the UNEP studies led to the inclusion of an additional 4 LCAs in the review. Therefore, we analyzed a total of 19 LCAs in this paper, which are presented in Tables 1–3.

Table 1. Publications included from the WoS and Google Scholar search considered for the literature review.

Study Number	Title	Reference
1	Environmental Evaluation of Single-Use and Reusable Cups	[11]
2	Environmental impacts of disposable cups with special focus on the effect of material choices and end of life	[38]
3	Life cycle assessment and eco-efficiency analysis of drinking cups used at public events	[39]
4	Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups	[12]
5	Reusable vs. disposable cups revisited: guidance in life cycle comparisons addressing scenario, model, and parameter uncertainties for the US consumer	[40]
6	Facility arrangements and the environmental performance of disposable and reusable cups	[41]
7	Choice of materials for takeaway beverage cups towards a circular economy	[42]
8	How small daily choices play a huge role in climate change: the disposable paper cup environmental bane	[13]
9	Improving the environmental sustainability of reusable food containers in Europe	[43]
10	Environmental impacts of takeaway food containers	[1]
11	Cradle-to-grave life cycle assessment of single-use cups made from PLA, PP, and PET	[44]
12	Assessment of the environmental break-even point for deposit return systems through an LCA analysis of single-use and reusable cups	[45]

As one publication consists of two LCA studies [41], a total of 20 LCAs could be analyzed. As one LCA has already been published in a different publication [12], which is also considered for this review, only the additional LCA of the publication was included. Fourteen of the LCAs analyze both single-use and reusable packaging [1,11,39–42,45–51], while three LCAs solely focus on single-use packaging [12,38,44] and two solely on reusable packaging [43,52]. An overview of the investigated packaging is given in Figure 2.

Table 2. Publications added due to forward and backward check of references.

Study Number	Title	Reference
13	Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison	[46]
14	Sustainability at a Brazilian University: Developing Environmentally Sustainable Practices and a Life Cycle Assessment Case Study	[52]
15	Potential Climate Benefits of Reusable Packaging in Food Delivery Services: A Chinese Case Study	[47]

Table 3. Publications from the UNEP meta-studies considered for the literature review.

Study Number	Title	Reference
16	Reusable Coffee Cups Life Cycle Assessment and Benchmark	[48]
17	A Comparative Life Cycle Assessment (LCA) of 12oz CupClub Cup and Lid	[49]
18	Case Study Ceramic Cup vs. Paper Cup	[50]
19	Taking a Closer Look at Paper Cups for Coffee	[51]

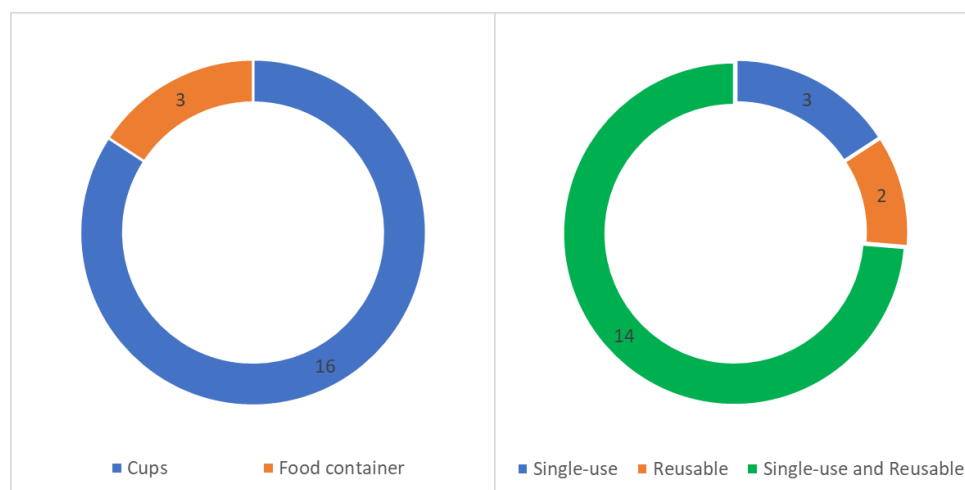


Figure 2. Investigated packaging in analyzed LCAs.

All LCAs were published between 2007 and 2021: five in the years 2010 to 2015 [12,38–41], nine between 2016 and 2020 [1,13,42,43,48–52], and three in 2021 [44,45,47]. The geographical focus of most of the LCAs (14) is either all of Europe or a specific country within Europe [1,11–13,38,39,41,43–46,49–51]. One of the LCAs covers the United States of America [40], one covers the situation in Australia [48], one focuses on China [47], one covers the situation at an university in Brazil [52] and one focuses on Thailand [42].

3.2. Consideration of Consumer Behavior

In the following, we analyze if consumer behavior was mentioned in the publications and if the behavior was considered in the LCAs. First, we analyzed the direct consideration of consumer behavior. This is done by analyzing whether the term “consumer behavior” or related terms are mentioned in the publication, and how the publication directly considered the possible outcomes of consumer behavior. Afterward, we analyzed the inclusion of consumer behavior in the use phase and EoL. An overview of the results of the analysis is given in Table 4. It is important to mention that LCAs can include aspects of consumer behavior even if it is not directly discussed. An example of that would be consideration of the reuse rate without mentioning that it is affected by consumer behavior.

In twelve of the nineteen publications the term “consumer behavior” or related terms such as “consumer choices” are not discussed at all [1,11,12,38,39,42,44,45,47,49–51]. In the five remaining publications, they are mentioned to varying degrees. One publication states that consumer behavior cannot be covered by traditional LCA [40]. Another two note that consumer behavior influences the potential environmental impact of the analysis of coffee cups, but does not include it in the analysis [13,46]. Potting and van der Harst [41] considered the results of a survey for their LCAs: the survey showed that over half of the consumers participating in their analyzed scenario were using reusable cups. One publication mentions the use of reusable cups as an example of a change in consumer behavior [52]. In one publication, consumer behavior is discussed only in the introduction, in relation to different washing behaviors [1]. Only one of the publications mentions consumer behavior as a topic for the sensitivity analysis [48]. This study includes consumer behavior in variation of the lifespan of the cup.

3.2.1. Use Phase

The use phase is considered to various degrees in the analyzed LCAs. Those three LCAs covering only single-use packaging do not include a dedicated use phase [12,38,43]. The possibility of reusing the actual single-use packaging is not discussed in any of these LCAs. Two LCAs which cover reusable packaging mention the reuse of disposable or single-use packaging [1,41], but a further assessment of this behavior is not performed in either of them.

For assessing the use phase of reusable packaging, two main topics can be distinguished: the reuse rate of the packaging and how it is washed. Regarding the reuse rate, we found two approaches. One approach is the use of different scenarios, as performed by three of the studies [11,39,45]. Two of them state this explicitly as sensitivity analysis [11,39]. The other approach is to calculate a break-even point between single-use and reusable packaging. Most of the publications calculated this break-even point only for a climate-related indicator. One publication adds the impact of fossil depletion [42]; one analysis adds six impact categories in addition to climate change [45]; and one publication calculated the break-even point for a total of twelve impact categories [1]. The related topic of the usable lifetime of reusable packaging is only considered partially and always based on assumptions. One publication explains its assumption: “There is no data currently available on how many times the ceramic cups are used in real life, and how long they last in a hygienic and presentable form in cafés or restaurants” [51].

The majority of the analyzed LCAs cover handwashing and dishwashing. Five publications only cover dishwashing and none of them only include handwashing [11,40,47,49,51]. In one publication it is unclear what type of washing is analyzed [52]. The energy, water, and soap required for cleaning were either based on assumptions, one source or multiple sources. In five publications a mix of assumptions and sources were used [42,45–47,50]. For example, the demand for handwashing is based on a study, but for the dishwasher, a specific dishwasher assumption was used [50]. Five LCAs are solely based on assumptions for the energy, water, and soap demand for cleaning the packaging [11,13,39,49,51,52]. These assumptions are not always clearly described as such, so it could also be the case that the sources for these numbers are not mentioned in the publications, but originally, they were

based on some. Three LCAs use the numbers from user (LCA) studies [1,41,43]. Only two LCAs use multiple sources for energy, water, and soap demand for washing as well as the share of hand- and dishwashing [40,48].

3.2.2. Littering

In thirteen of the nineteen publications, the topic of littering is mentioned neither directly nor indirectly [11,38–41,43–47,50–52]. The remaining publications consider the topic to various degrees, from general remarks that littering is a relevant topic up to explanations as to why it is not included. In one publication [51], littering is specified as a problem, but its implications for the conducted LCA are not discussed. Three publications [1,13,42] mention littering as a threat to marine life. The need for further method development, to include littering in the inventory and impact assessment of LCA, is stated in three publications [1,13,48]. In two publications, littering is quoted in the context of a specific material (plastic [48]; expanded polystyrene [1]). Van der Harst et al. [12] excluded the topic on the basis of the scenario under study, as they assume that in this specific case no littering occurs. None of the analyzed LCAs includes littering in the inventory or the impact assessment.

3.2.3. End-of-Life

Almost all LCAs (18) consist of at least two different types of waste disposal. Incineration, which is included 17 times [1,11,12,38–51], and recycling, included 16 times [1,11–13,40–51], are the dominant EoL options in the surveyed LCAs. Landfilling as a waste disposal method is covered in 12 LCAs [1,11,13,38,40,43,44,48–51], with Barros et al. including it as the only waste disposal option [52]. All LCAs which cover a biodegradable packaging material either include composting or digestion (or both) [12,39,42,48,51]. No change in the considered impact assessment method can be observed over the course of multiple years. An overview of the included EoL-Options is given in Figure 3.

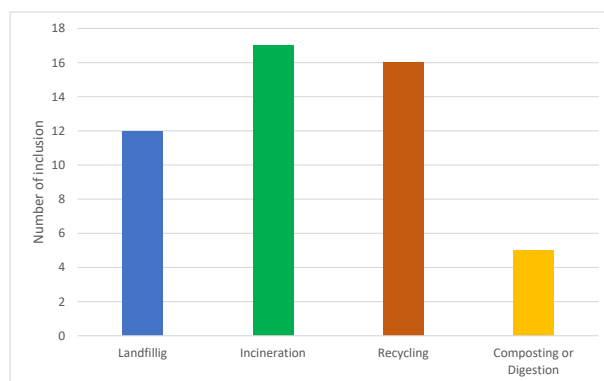


Figure 3. Overview of included EoL-Options in analyzed LCAs.

The EoL is a focus for most of the studies; for example, the study by Häkkinen and Vares analyzes the results of different EoL options in detail [38]. The relevance of EoL is evident, as 12 out of 19 LCAs analyze the impact of different waste disposal routes or distributions as part of their sensitivity analyses [1,12,38–44,46,47,51]. For the initial LCA, either 100% disposal to one EoL option or a specific distribution of different routes was assumed for the takeaway packaging. Neither of these two approaches is predominant. Eight of the LCAs only base the EoL on assumptions [13,38,39,41,42,45,49,52]. Four LCAs use available statistics for the modeling of the EoL, which are either regional [11], national [12] or supranational (European) [48,51]. The remaining seven combine waste statistics with assumptions [1,40,43,44,46,47,50]. Most of the applied waste statistics are on a material level, so for example, the European recycling rate of aluminum or polypropylene is utilized. Only two studies [13,46] use a product-specific number for the modeling of the EoL scenarios. To calculate the results for change in the EoL routes, 12 of the 19 LCAs included either different EoL scenarios or a sensitivity analysis [1,12,13,38,39,41,42,44–47,51].

Table 4. Overview of reviewed LCA studies regrading analyzed aspects.

Study Number and Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	[11]	[38]	[39]	[12]	[40]	[41]	[42]	[13]	[43]	[1]	[44]	[45]	[46]	[52]	[47]	[48]	[49]	[50]	[51]
Investigated Packaging																			
Cups	X	X	X	X	X	X	X	X			X	X	X	X		X	X	X	X
Food container									X	X					X				
Single-use	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X
Reusable	X		X		X	X	X	X	X	X		X	X	X	X	X	X	X	X
Use-Phase																			
Consumer behavior (mentioned)					X	X		X	X				X	X		X			
Break-even reuse rate						X	X	X		X		X				X	X	X	X
Reuse rate scenario or sensitivity analysis	X		X								X								
Handwashing			X			X	X	X	X	X		X	X			X		X	
Dishwashing	X		X		X	X	X	X	X	X		X	X		X	X	X	X	X
Sensitivity analysis washing			X										X				X		
Data source																			
washing																			
Assumptions or unclear	X		X				X	X				X		X			X	X	X
One study						X	X		X	X		X						X	
Multiple source					X								X		X	X			
Littering (mentioned)					X	X		X	X							X			
End-of-Life																			
Landfilling	X	X			X			X	X	X	X		X	X	X	X	X	X	X
Incineration	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
Recycling	X			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Composting			X				X				X	X				X	X		
Data Source EoL																			
Assumptions		X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	
Statistics	X			X	X				X	X	X		X		X	X		X	X
Sensitivity or scenario analysis		X	X	X		X	X	X		X	X	X	X		X				X

3.2.4. Correlation Analysis

Two of the analyzed aspects have a positive correlation with the consideration of consumer behavior, namely the additional consideration of littering and the application of multiple sources for modeling the washing. A negative correlation was found for the number of EoL options included. The same was found for the inclusion of a sensitivity or scenario analysis for the EoL. A significant correlation could only be determined for the consideration of consumer behavior and littering, as the associated p -value was less than 0.05 and even less than 0.01. All other p -values were greater than 0.05; therefore, the correlation can be considered as not significant. An overview of the correlations, t -values and p -values is given in Table 5.

Table 5. Results correlation analysis.

	Multiple Sources for Data Washing	Littering (Mentioned)	EoL Options Included	EoL Sensitivity or Scenario Analysis Included
Consumer Behavior (mentioned)	0.408	0.782	−0.309	−0.321
t -Value	1.845	5.181	−1.338	−1.400
p -Value	0.082	0.000	0.199	0.180

4. Discussion and Limitations

The present review shows that most LCA studies assessing the environmental impacts of takeaway packaging do not often explicitly mention consumer behavior (only 7/19 studies do), which might already indicate that the importance of consumer behavior is undervalued. Nevertheless, consumer behavior is often implicitly considered (e.g., re-use rate by either of two methods in 12 of the studies, and some of the behavior-dependent EoL aspects in all studies), and also proven to often have a decisive role on the outcome. These implicit analyses, however, take into account heterogeneous facets of outcome-relevant consumer behavior. The importance of consumer behavior in the environmental impacts of takeaway packaging thus generally seems to not be sufficiently well understood, and hence also not analyzed. The importance of a detailed analysis of consumer behavior is further stressed by a meta study from Otto et al., which shows that consumer perception of food packaging is often not based on scientific facts [53].

As the use phase influences the results of LCAs of takeaway packaging significantly, especially when comparing single-use and reusable packaging, its detailed inclusion is necessary for reliable results. One of the most crucial parameters for the comparison of single-use and reusable packaging, the reuse rate of the reusable packaging, was mostly resolved with a scenario or break-even calculation. This method yields plausible results and fulfills the requirements of the ISO, but the results are only as good as the assumptions. While assumptions are a necessary tool for any LCA, they should be based on sufficient information [16]. As a first step to include to make assumptions of the use phase of takeaway packaging more robust, we suggest the usage of (online) surveys, questionnaires, interviews and/or diaries. These are instruments proven to generate robust user-related data for LCA studies in related domains such as laundry washing, e-readers smart homes or other food packaging [20,54–56]. Secondly, for the classification of results from break-even calculations, we suggest to provide a context of realistic reuse rates. As mentioned before, methods and instruments of empirical social sciences could be helpful tools to close this existing knowledge gap [51], as none of the reviewed LCAs provides proof that the reuse rate necessary for a lesser environmental impact of the reusable packaging is actually achievable. Finally, the calculations of the break-even points clearly show the necessity of including more than one impact category. The most calculated impact category, “climate

change”, always shows a break-even point in the lower double digits for the reuse rate of reusable packaging. By contrast, the break-even point in other impact categories is significantly higher, and in one case a break-even has never been achieved.

The modeling of the water, soap, and energy demand for reusable packaging has a significant impact on the calculation of the break-even point. Hence, for reliable results, their detailed modeling is required. However, not all reviewed LCAs consider this interdependence, and base the demands only on assumptions without analyzing the sensitivity of the assumption. In contrast to that, Woods and Bakshi [40] use multiple sources to model the washing. Furthermore, they even include a study which uses direct observation of consumer behavior.

In none of the LCAs is the topic of littering included in the inventory and impact assessment. This is in stark contrast to the observations that the topic is highly relevant for takeaway packaging, as stated by some of the publications themselves. A possible explanation for this is that (easily) implementable tools for the inclusion into the inventory, such as the “Plastic Leak Project” [57], have only been available since the 2020s. For other products with high littering potential, such as carrier bags, methods for the quantification of littering were implemented in LCAs [58]. Given its relevance for takeaway packaging as well, the topic of littering should be incorporated in future LCAs, at least as part of the inventory for a quantification of the littering amount.

Different EoL options are addressed in the reviewed LCAs. With material-specific shares of the EoL, some LCAs included a rather detailed modeling of the EoL phase. It could be argued, however, that this material-specific modeling is not sufficient for takeaway packaging. Per its definition, a high share of takeaway packaging is designed to be used on the go and at home. In contrast to the domestic domain, the variability of waste bins is smaller on the street. Hence, it is not always possible for the consumer to bring the packaging into the recycling waste stream. For the model, a product-specific EoL share could be seen as a more viable modeling choice, instead of the material-specific EoL share.

This review regarding the role of consumer behavior in existing LCAs is limited to the information provided by the respective studies. Especially in those studies without peer-review, the quality of this information varies widely. The length of the publications can be taken as approximation for that: they vary between 8 and 158 pages. Moreover, only one peer-reviewed publication provides Supplementary Information. This implies that considerations of consumer behavior might have been missed due to a possibly incomplete picture of a study.

Lastly, the review shows that the environmental impacts of cups or beverage packaging is widely analyzed compared to takeaway packaging for food. This observation is based on the diverging quantity of studies found for both types of packaging (14 to 2).

5. Conclusions

This study reviews the extent to which consumer behavior is incorporated into LCAs of takeaway food and beverage packaging. It was shown that the different aspects of consumer behavior are covered to various degrees, but no LCA covered all aspects in a far-reaching manner. For the assessment of takeaway packaging, three aspects of consumer behavior could be identified as factors with possible high influence. These are relevant both to practitioners for future LCAs of takeaway packaging, but also to researchers to address future research needs: First, an assessment of littering should be carried out. It can be argued that at the time most of the reviewed LCAs were conducted, no methodologies were available to include littering in LCAs, but since the publication of methodologies such as the Plastic Leak Project this no longer remains true. Second, the uncertainty about the real use cycles of reusable takeaway packaging needs to be addressed. With the help of instruments of the social sciences, the basis for such assumptions could be improved. Surveys and journals could for example be used for improved assumptions on the reuse rate of takeaway packaging. Surveys could also be used to test hypotheses such as that single-use packaging is sometimes reused by consumers. Furthermore, with the arrival

of digitally supported pool systems for takeaway packaging, a clearer picture of the reuse rate could be drawn. Third, an investigation of a product-specific waste stream, in contrast to a material-specific one, would be an important aspect to include in further LCAs of takeaway packaging. This is because the takeaway property of the product is likely to induce different waste behavior than other packaging of the same materials. The other aspects of consumer behavior were addressed in an extensive way in some of the analyzed LCAs. For further LCAs for takeaway packaging, it is necessary to combine this accurate analysis of various consumer behaviors to get a complete picture.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su15054315/s1>.

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