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META-STUDY FOR QSRs
TAKE-AWAY SERVICES

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META-STUDY FOR QSRS
TAKE-AWAY SERVICES

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ABBREVIATIONS

EoL	End-of-Life
EPPA	European Paper Packaging Alliance
EPS	Expanded Polystyrene
EU	European Union
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MU	Multiple-Use
PE	Polyethylene
PP	Polypropylene
QSR	Quick service restaurant
RIAM	Rapid Impact Assessment Matrix
SU	Single-Use
UN	United Nations

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1. INTRODUCTION AND SCOPE OF WORK

Ramboll has been appointed by the European Paper Packaging Alliance (hereafter "EPPA" or the Client) as technical consultant for conducting a meta-study assessment in the framework of the LCA study related to single-use (SU) and multiple-use (MU) dishes systems in Quick Service Restaurants (QSRs).

This report is part of a comprehensive study regarding the comparison of environmental performances between single-use and multiple-use systems for servings in QSRs included in the report issued by Ramboll in December 2020 namely *Comparative life cycle assessment (LCA) single-use and multiple-use dishes systems for in-store consumption in Quick Service Restaurants* (Ramboll, 2020) on behalf of EPPA. The study was updated in 2021 due to an extensive GaBi database update (the updated version of the study was not subject to a third-party review). EPPA is an association representing suppliers and manufacturers of renewable and sustainable paper board and paper board packaging for Food and Foodservice Industry. They include, e.g., Seda International Packaging Group, Huhtamaki, AR Packaging, Smith Anderson, CEE Schisler Packaging Solutions, Stora Enso, Metsä Board, Mayr-Melnhof Karton, WestRock, Iggesund/Holmen, Reno De Medici and Paper Machinery Corporation.

The aim of the meta-study is to identify, describe, and assess additional environmental implications of "*take-away services"* of QSRs with regard to single-use and multiple-use food containers, using as a point of reference the existing body of knowledge and the comparative LCA related to in-store consumption of QSRs, conducted in 2020. *Take-away services* include:

- drive-through, where customers reach the restaurant and order food directly from their cars.
- on-the-go, where customers reach the restaurant and take out their food.
- click and collect, similar to the on-the-go option, but booking the food online before reaching the restaurant.
- home delivery, where customers buy food online and it is delivered by means of a courier.

In recent years there has been a surge in evaluating reusable packaging for food and beverage containers about in-store consumption, take-away, and, most recently, home delivery. The corresponding debate has reached authorities, companies and academia equally, often with reaching consensus that reusable products and containers are inherently and intuitively more environmentally sustainable. However, there is evidence that the actual environmental performance between single-use and multiple-use products can be counterintuitive and is, moreover, very dependent on the application context (e.g., in-house consumption in QSRs with specific demands on food and beverage containers, geographical context).

Ramboll performed the following activities:

- Focused literature review on the environmental performance of *take-away services*, market trends, and of similar decision-contexts from which evidence may be transferred to take-away services.
- Identification and description of expected additional effects arising from *take-away services* with regard to both single-use and multiple-use product items.
- Interpretation of literature findings in the context of the existing full comparative LCA study on behalf of EPPA, considering the differences (in terms of systems boundaries) between in-store consumption and *take-away services*.

1.1 Project framework – full LCA study

In 2020, Ramboll has been appointed by the EPPA as technical consultant for conducting a comparative LCA study between a single use dishes system and equivalent multiple-use dishes in Quick Service Restaurants in accordance with ISO standards 14040 and 14044 as a basis for discussion with authority representatives on the current legal developments within the European Union plus the United Kingdom regarding circular economy and waste prevention.

In particular, EPPA wishes to provide policy makers with information to support the application of the 2008 Waste Directive, so that "*when applying the waste hierarchy, Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste."* (Directive 2008/98/EC, article 4§2)

The main goal of the LCA study is to use a systems-based approach to compare the environmental performance of single-use and multiple-use dishes options for in-store consumption in QSR in Europe.

The functional unit was the in-store consumption of foodstuff and beverages with single-use or multiple-use dishes (including cups, lids, plates, containers and cutlery) in an *average* QSR for 365 days in Europe in consideration of established facilities and hygiene standards as well as QSR-specific characteristics (e.g. peak times, throughput of served dishes).

For the comparative assessment, two fundamentally distinct systems are taken into consideration:

- the current system in QSRs based on single-use (disposable) products made of paperboard with a polyethylene (PE) content < 10% w/w (also referred to as single-use product system), accounting for regulatory implications in 2023 (e.g. targets for separate waste collection and end of life (EoL) recycling);
- an expected (hypothetical) future system in the near future based on equivalent multiple-use products (also referred to as multiple-use product system) and respective processes and infrastructure for washing operations (in-store or sub-contracted).

The geographical scope of the baseline comparison is Europe (EU-27 + UK). This geographical boundary is reflected in the assumptions around the systems (e.g. recycling rates) and background datasets (e.g. electricity from grid) as inventory data for the manufacturing stage of certain products will be site-specific or representing average production scenarios (e.g. global, EU).

The comparative LCA study has taken into account the use of **7 different food and beverage containers**:

- A cold cup;
- A hot cup;
- A wrap/clamshell or plate/cover or tray;
- A fry bag/basket/fry carton;
- A salad bowl with lid;
- A cutlery set;
- An ice-cream cup.

Other food containers/packaging (i.e. shovel for coffee, placemat, drinking straw) are not included in the LCA study.

In total, the comparative LCA assessment incorporates the life cycles of:

- **10 different single-use product items** made of paperboard (if coated, PE content is < 10% w/w); and
- **14 different multiple-use product items** (represented in different scenarios and sensitivity analyses) with 2 dishes set options: one set made of polypropylene (PP; one acrylic plastic item), and one set combining PP, ceramic, glass and steel for sensitivity analyses.

2. METHODOLOGICAL APPROACH

2.1 Hotspot definition

For the purpose of the analysis presented in this report, Ramboll considered the definition of hotspot (used in the context of environmental assessment) by the "Life Cycle Initiative", which is hosted by the UN Environment and aims at providing and sharing credible knowledge about Life Cycle Assessment:

> ***"A life cycle stage, process or elementary flow which accounts for a significant proportion of the impact of the functional unit (see UN Framework)"[1].***

2.2 Description of the methodological approach

In absence of a standard procedure for hotspot identification, the methodological approach used by Ramboll is defined based on the suggestion for identifying hotspots reported by UN Environment (2017). It includes the following steps:

- Step 1: Source screening and data gathering.
- Step 2: Hotspot identification.
- Step 3: Interpretation and discussion.

2.2.1 Step 1: Source screening and data gathering

The aim is to identify the existing body of knowledge via desktop-based research. The following activities have been carried out:

1. Definition of the system boundaries analysis.
2. Identification of keywords related to the scope of this assessment.
3. Database and literature screening (via identified key words) on different sources (e.g., scientific peer-reviewed articles, corporate social responsibility reports, EU reports, single-issue studies).

To select relevant sources only, specific quality criteria have been identified. Only sources that meet the selected quality criteria have been used for the hotspot identification.

2.2.2 Step 2: Hotspot identification

Relevant sources have been deeply analyzed to find relevance with respect to the present study. Based on this data gathering, the main hotspots for the system under analysis have been identified. Since the methodological approach is iterative, more hotspots are identified as more sources are screened.

2.2.3 Step 3: Interpretation and discussion

The identified hotspots have been interpreted and discussed with the aim of evaluating (in a qualitative way) environmental implications of *take-away services* of QSRs with regard to single-use and multiple-use food containers.

In particular, the outcomes of the literature review have been interpreted considering the differences between the system boundaries of the in-store consumption and *take-away services*. In addition, QSRs' constrains and intrinsic inherent features are taken into account in the performed assessment with the aim of identifying, describing, and assessing additional

[1] *Source:* https://www.lifecycleinitiative.org/resources/life-cycle-terminology-2/

environmental implications of *take-away services* with regard to single-use and multiple-use food containers.

Results have been presented in a semi-quantitative manner using a simplified approach derived from the Rapid Impact Assessment Matrix (RIAM) method – widely adopted in the framework of Environmental Impact Assessment. In RIAM impact significance is modelled as a multicriteria problem, in which the complex nature of the concept is broken down into smaller, more accessible attributes (criteria) for the decision-makers to work with. Evaluating the significance of impacts this way is a widely used approach in the literature on environmental decision-making, when constructing systematic methods for impact evaluation (Bojórquez-Tapia et al., 1998; Cloquell-Ballester et al., 2007; European Commission, 1999; Thompson, 1990).

Effects of the identified hotspots on relevant Impact Categories are assessed based significance judgements as included in the screened literature sources.

3. LITERATURE REVIEW AND HOTSPOT ANALYSIS

The following sections include the outcomes of the application of the methodological approach (Step 1 and 2) as described in **Section 2**.

3.1 Source screening and data gathering

The first step for the identification of sources to be screened is the definition of the system and to identify its boundaries. For this specific case study, the system is defined as:

> ***consumption of foodstuff and beverages with single-use or multiple-use dishes considering take-away services of an average European QSR***

Since the use of *take-away services* have been growing significantly in recent years, it is important to take into consideration the time reference. This should be as close as possible to the time frame in which this study is carried out[2].

Once the system under analysis is identified, it is possible to proceed with the identification of the sources of information. This identification is carried out using general and specific key words (e.g., take-away, delivery, QSRs, fast food, packaging, single use, disposable, multiple-use, reusable, LCA, hotspot analysis, etc.). The following scientific databases have been scrutinized: Scopus, Elsevier, Springer, Taylor & Francis and google scholar.

Two main kinds of sources can be distinguished:

- scientific sources. They could be considered reliable source of information because they are subjected to third-party review. Due to the recent spread of take-away services (particularly for multiple-use packaging) the scientific literature is still limited.
- commercial publications (e.g., white papers, companies' websites and newspaper articles) have been used to fill the data gaps identified in the screening of scientific sources. Since the aim of this study is to evaluate critical aspects linked to the utilization of single-use and multiple-use dishes for take-away services to find potential hotspots, and although the consideration of commercial publications might be debatable for scientific purposes, they could be used to present a broad overview of the topic by taking into consideration stakeholders' perspectives. The perspective of operators, for example, could help at identifying relevant aspects in the identified supply chain and identifying hotspots that were not mentioned by scientific sources.

Based on this screening, Ramboll has identified 29 different sources of information.

According to the conducted literature review, apparently no studies have used a combined portfolio and systems approach to take into consideration the entire portfolio comprised of single-use and multiple-use items for QSRs (i.e. system approach) and very few are based on primary data. This should be considered since one of the main goals of the comparative LCA study conducted for in-store consumption was to compare for the first time the two systems through a system approach, incorporating representative primary data and information with regards to the functional unit, inventory data as well assumptions around the systems.

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[2] The research was carried out between February and March 2022

3.2 Quality criteria

Different quality criteria have been defined to screen the sources. The following Table 1 presents an overview of the 10 selected criteria and their descriptions.

Table 1. Quality criteria table

Quality criteria	Description of the quality criteria
Peer-review	Peer-reviewed studies.
Features of LCA studies	Peer reviewed LCA studies in compliance with ISO 14040/44, as core of the assignment.
Geographical reference	European studies, as core of the assignment
Time reference	Sources published within last five years, as more relevant for a realistic representation of the current situation.
Core segment: take-away	Take-away supply chain, but due to lack of information, an extension of the topic is required (e.g., catering services or large-scale distribution)
Supply chain (stage)	Sources reporting data about the whole supply chain or stakeholders directly involved in it.
Transport (stage)	Sources/stakeholders reporting data about transport of food and recollection of MU items, or directly involved in it. Due to lack of information, the topic is not limited to transport in take-away services but also to other food transportation systems (e.g., catering services or large-scale distribution)
Cleaning/washing (stage)	Sources/stakeholders reporting data about cleaning/washing of MU items.
Core alternatives	Sources considering the comparison between different items (SU vs MU or different materials).
Environmental hotspots	Sources considering environmental implications of take-away services.

The criteria reported above are based on the sources screened in the previous step. Each criterion helps defining the relevance of the content with respect to the case study. A binary scale (0=no, 1=yes) is used to define fulfillment of each criterion by each source. This approach allows the comparison of different sources and the identification of relevant hotspots in a structured and transparent way. According to the Ramboll adopted methodology a source is considered relevant if it is in line with at least 50% of the defined quality criteria (i.e., when receives a total score of at least 5).

The quality criteria are described in detail in the following sections.

3.2.1 Peer-review

Since the review process confers credibility to a study, identified sources are distinguished between studies subjected to review and non-subjected to review process.

24 of the 29 identified sources have been subjected to the review process.

3.2.2 LCA studies in compliance with ISO 14040/44

LCA studies generally have a holistic and comprehensive point of view on the investigated system, since they take into account different life cycle phases (e.g., production, use phase, end-of-life). Clearly, different assumptions (e.g., functional unit, system boundaries, etc.) lead to different results. Thus, among different possible LCA studies (simplified LCA, LCA in compliance with ISO 14040/14044 standards, peer-reviewed LCA studies), preference is given to peer-reviewed LCA studies in compliance with ISO 14040/44, with assumptions as close as possible to those of the present meta-study. In particular, the following features of LCA studies have been considered: functional unit, system boundaries, cut-off criteria, type of credit allocation, considered impact categories and assessment method, use stage and end-of-life for considered items, data sources (e.g., database, data quality, data gaps). According to the conducted literature review, apparently no studies have used a combined portfolio and systems approach to take into consideration the entire portfolio comprised of single-use and multiple-use items (i.e., system approach) and very few are based on primary data. This should be considered since one of the main goals of the comparative LCA study conducted for in-store consumption was to compare for the first time the two systems through a system approach, incorporating representative primary data and information with regards to the functional unit, inventory data as well assumptions around the systems.

20 analyzed sources are peer reviewed LCA studies in compliance with ISO 14040/44.

3.2.3 Geographical reference

The geographical context is a very important factor that could influence the outcome of a study. This is due to the presence of different supply chain infrastructures, energy mix, specific regulations, or socio-economic conditions in a particular area under investigation, distances between paper producers/converters and location of use. Since this study has the focus at European level, priority is given to studies conducted in the EU.

18 of analyzed sources are related to EU context, and sometimes they have in-depth analysis of specific countries (e.g., Germany, Netherlands, Italy, UK).

3.2.4 Time reference

Regarding the time reference, particular attention is given to the most recent sources. However, as said before, the use of take-away services has been growing significantly in recent years, so it has not been studied deeply and scientific sources are few. Nowadays changes happen quickly and scientific investigation of new phenomena requires time.

25 of analyzed sources have been published in the last five years, which report the most up-to-date data.

It is Ramboll opinion that sources published in last five years depict a realistic representation of the current situation.

3.2.5 Core segment: *take-away services* (Drive-through, on-the-go click and collect, and home delivery)

This criterion considers whether a source has *take-away services* as the main focus.

21 of analyzed sources focus on *take-away services*.

3.2.6 Supply chain (stage)

In order to have a comprehensive overview of the studied system, the completeness of the supply chain is considered as a criterion. In fact, if a study considers only a section of the supply chain it could overlook some significant parameters or report incomplete information.

25 of analyzed sources include an assessment of the entire supply chain of take-away.

3.2.7 Transport (stage)

Even though many sources focus on take-away or on the comparison between SU and MU items, not all of them report data related to transport stage. For this reason, preference is given to sources reporting data about transport of food and recollection of MU items.

23 of analyzed sources include the transport stage (of items) in the assessment.

3.2.8 Cleaning/washing (stage)

As reported above for transport, not all sources investigate the role of cleaning and washing stages. However, this is a fundamental stage for MU items, since it affects the possibility to have an effective reuse (in compliance with applicable hygienic regulations/standards). For this reason, preference is given to sources reporting data about preliminary washing of MU items at home and about their professional washing in store or in specific centralized facilities.

21 of analyzed sources include cleaning/washing stage (of items) in the assessment.

3.2.9 Core alternatives

The criterion regarding core alternatives helps at identifying sources that compare different alternatives (e.g., SU vs MU items or different SU and MU materials) and not only a single specific solution.

18 of the sources compared different solutions while the others focused on a single product.

3.2.10 Environmental hotspots

Finally, the last quality criterion is related to environmental impacts as the main topic addressed in each analyzed source.

28 sources focus the analysis on environmental aspects.

3.3 Relevant sources identified

After the application of the quality criteria, 26 out of 29 sources have been selected, as they met at least 50% of the defined quality criteria. The table reporting the results of the screening based on quality criteria is reported in Appendix 1.

The selected sources are listed below. Those with the highest adherence and representativeness of the abovementioned quality criteria (>90%) are indicated in **bold**.

- **Abejón *et al.*, 2020. When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market**
- Accorsi *et al.*, 2014. Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study
- Albrecht *et al.*, 2013. An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe
- Arunan and Crawford, 2021. Greenhouse gas emissions associated with food packaging for online food delivery services in Australia
- Camps-Posino *et al.*, 2021. Potential climate benefits of reusable packaging in food delivery services. A Chinese case study
- Changwichan and Gheewala, 2020. Choice of materials for takeaway beverage cups towards a circular economy
- Coelho *et al.*, 2020. Sustainability of reusable packaging–Current situation and trends
- **Cottafava *et al.*, 2021. Assessment of the environmental break-even point for deposit return systems through an LCA analysis of single-use and reusable cups.**
- Del Borghi *et al.*, 2021. Sustainable packaging: an evaluation of crates for food through a life cycle approach
- **Fraunhofer Institute for Building Physics IBP, 2018. Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe**
- **Gallego-Schmid, Mendoza and Azapagic, 2019. Environmental impacts of takeaway food containers**
- **Gallego-Schmid, Mendoza and Azapagic, 2018. Improving the environmental sustainability of reusable food containers in Europe**
- **Greenwood *et al.*, 2021. Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream**
- **Kleinhückelkotten, Behrendt and Neitzke, 2021. Review of strategies and measures for takeaway providers towards the establishment of multiple-use products as suitable option.**
- Koskela *et al.*, 2014. Reusable plastic crate or recyclable cardboard box? A comparison of two delivery systems
- Liu *et al.*, 2020. Environmental impacts characterization of packaging waste generated by urban food delivery services. A big-data analysis in Jing-Jin-Ji region (China)
- **Lo-Iacono-ferreira *et al.,* 2021. Carbon Footprint Comparative Analysis of Cardboard and Plastic Containers Used for the International Transport of Spanish Tomatoes**
- **Martin, Bunsen and Ciroth, 2018. Case Study Ceramic cup vs. Paper cup**
- Thorbecke *et al.*, 2019**.** Life Cycle Assessment of Corrugated Containers and Reusable Plastic Containers for Produce Transport and Display
- **Tua *et al.*, 2019. Life cycle assessment of reusable plastic crates (RPCs)**

- **UBA (Umweltbundesamt, Germany), 2019. Untersuchung der ökologischen Bedeutung von Einweggetränkebechern im Außer-Haus-Verzehr und mögliche Maßnahmen zur Verringerung des Verbrauchs**
- UNEP, 2020. Single-use plastic take-away food packaging and its alternatives
- **Verburgt, 2021. Life Cycle Assessment of reusable and single use meal container systems**
- Xie, Xu and Li, 2021. Environmental impact of express food delivery in China: the role of personal consumption choice
- Zhang and Wen, 2022. Mapping the environmental impacts and policy effectiveness of takeaway food industry in China
- **Zhou *et al.*, 2020. Sharing tableware reduces waste generation, emissions and water consumption in China's takeaway packaging waste dilemma**

3.4 Hotspots identification

A critical assessment procedure has been implemented to examine and compare potential sources of impacts, identified in each analyzed source. After identifying those with similar characteristics, they are grouped in the same hotspot definition. The list of identified hotspots is summarized in Table 2.

Table 2. Hotspot table

Number	Hotspot	Description
I	Actual number of uses for MU items	MU items are generally used for a limited number of cycles (lower than nominal/theoretical value)
II	Type of take-back system	Recollection of MU items can be done through different possible schemes
III	Return rate	It reflects the probability that an MU item is returned to QSRs
IV	Distance	*Take-away services* require a number of trips, thus distance that needs to be covered must be taken into account
V	Means of transport	Different means of transport are associated to different levels of emissions but also to different carrying capacities and different distances that can be covered
VI	Type of preliminary washing at home	MU items need to be preliminary cleaned or rinsed at home after usage
VII	Type of professional washing	MU items need a professional washing before reutilization
VIII	Physical limit to number of washings	Several washing cycles imply degradation of material
IX	Additional packaging	*Take-away services* require additional packaging not necessary for in-store consumption

Number	Hotspot	Description
X	Weight optimization	Delivered items should not be too heavy, in order to facilitate their transport
XI	Control and inspection	MU items must be inspected after their return to store before reutilization, since they can be damaged
XII	Application of specific taxes/fees	Fee for use of MU solutions could discourage customers, taxes on SU solutions to discourage use
XIII	Theft	MU items could be easily stolen
XIV	Additional items for QSRs effective functioning	QSRs need many MU items to avoid the possibility of running out of dishes
XV	Improper disposal	Reduction of waste separation at home

Due to the investigated system complexity a partial "overlap" affect some hotspots, meaning that they partially cover different feature of same/similar aspects. However, in order to present the clearest picture possible, and to analyze each hotspot in depth, at this stage they are presented individually.

Identified hotspots can be described as follows:

The **actual number of uses** is very difficult to define because there is no indication of certain data (e.g., statistics), and sources are often covered by non-disclosure agreements or noted as personal communications with a stakeholder. This parameter is influenced by several factors, such as damage to products (breakage rate), efficiency of cleaning, decoloring, theft, return rate, commercial purposes. For instance, Vytal, a company that allows borrowing reusable containers for *take-away services*, claims that its item can be reused up to 200 times[3]; DeliverZero, a platform for ordering meals in reusable containers, claims that its dishes can be used even 1,000 times[4]. One of the most important factors is indeed the source of information and its reliability, whose consideration might drive the findings of a study. In some studies, these sources of information are even not mentioned or cited. Lack of official, consistent, scientifically proven data is clearly an obstacle for reliability of information. To the best of Ramboll's knowledge, no studies have been published so far towards scientific determination of actual number of reuses (in terms of physical properties of materials or customers' behavior). Therefore, no claims based on science have been found in the body of literature regarding the real lifespan of food containers.

Based on the outcomes of the literature review, the actual number of reuses is a key parameter with important environmental consequences, for this reason it is used as a unknow parameter to define for the comparison assessment; several studies identify the break-even point (number of uses according to which SU and MU performances are equivalent) as the key factor of the comparison. Gallego-Schmid, Mendoza and Azapagic (2019) claim that lightweight PP containers shall be used 1-4 times (depending on the analyzed impact categories) and 3-32 times to match the environmental impacts related to single-use aluminum and Expanded Polystyrene (EPS) packaging, respectively. However, when analyzing more robust PP containers ("Tupperware"),

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[3] Source: Vytal | Takeaway food. Without rubbish.
[4] Source: https://instore.deliverzero.com/

the numbers of uses needed grow to 3-39 (vs aluminum) and 16-208 (vs EPS) (Fraunhofer Institute for Building Physics IBP, 2018; IFCO, 2019). Another review of studies concluded that usually 10 to 15 reuses in a multiple-use system are sufficient for a positive carbon footprint compared to the corresponding single-use system (Kleinhückelkotten, Behrendt and Neitzke, 2021). Certainly, by taking into account different boundary conditions and assumptions, different conclusions and findings could be drawn.

The **return rate** is defined as the ratio between returned MU items and those delivered. This parameter is extremely difficult to quantify because there is a lack of certain data (e.g., statistics). However, it can be assumed that this ratio is always lower than 100%, due to impossibility of having a totally efficient system. If this parameter is low, it means that some items do not go back to the reuse cycle (or not immediately). This could lead to a shortage of MU items and thus to an increase in environmental emissions (associated to the additional production). Verburgt, (2021) claims that a return rate of at least 92% could be needed to match single-use's performances in each impact category when comparing three types of reusable meal boxes (from polypropylene, stainless steel and glass) and three types of single-use meal boxes (from polypropylene, aluminum and paper).

The **type of take-back system** can significantly affect the return rate, and the associated environmental impacts of MU core processes (i.e., transports, use and washing). Different take-back systems determine different environmental implications (e.g., related to courier services their means of transport and dishwashing efficiency). Based on information included in the literature (Zhou *et al.*, (2020) two main take-back mechanisms have been identified (as effective solutions):

- a decentralized take-back mechanism where all the reusable items are returned to collection points by consumers. This system determine limited number of trips (especially if the collection points are well distributed, allowing the consumer to make short trips) and associated costs; however the effectiveness is highly influenced by consumer behavior (Pladerer *et al.*, 2008; Beverage industry, 2015; American bakers association, 2020).
- a centralized take-back mechanism whereby all MU items are collected by courier; it would require additional trips (to retrieve the items), with consequent environmental impacts due to the transportation (and additional costs) for the courier service. Since it does not rely on customers' willingness and availability to return the items, the expected return rate is higher.

The **distances** that have to be covered represent a key parameter, since *take-away services* require a number of trips to deliver food but also to recollect MU items, and eventually to transport them to centralized washing facilities (Verburgt, 2021; Xie, Xu and Li, 2021; Coelho *et al.*, 2020). Moreover, the distances are not only associated to emissions, but they also influence the willingness to return MU items. There are no certain data regarding distances for *take-away services*, but some figures can be retrieved from literature or websites: Burger King Germany reports that its restaurant accepts only orders deliverable in maximum 8 minutes[5]: this could mean a maximum distance of a couple kilometers, for instance if delivered with a scooter. A statistic reported by ShopFood[6] indicates that generally restaurants stick to 8 km radius as maximum acceptable distance to deliver food, while Liu, Han and Cohen (2015) established that in five US cities the median distance that a customer needs to cover to reach a QSR is 1 km. Regarding the distances that need to be covered when MU items are washed in an external

[5] Source: https://www.burgerking.de/faq
[6] Source: What's the Average Distance for Food Delivery Services? - Shopfood.com

facility, the amount of information is limited. In the previous LCA study by Ramboll (2020), a distance of 100 km is considered. Cottafava *et al.* (2021) considered a 20 km round trip (10 km from QSR to external washing facility + 10 km back to QSR).

The **means of transport** utilized to cover these distances is another important factor, since different means of transport are related to different levels of emissions (Verburgt, 2021; Camps-Posino *et al.*, 2021; Liu *et al.*, 2020):

- walking to the restaurant to get food or deliver it by bike implies no emissions.
- also using electric bikes or electric scooters imply no direct emissions, but there will be impacts for charging batteries (defined as scope 2 emission according to GHG protocol).
- ICE (Internal Combustion Engine) scooters and cars/vans will have emissions due to fossil fuels consumption. However, using means of transports with higher carrying capacity can allow easier logistic solutions, lowering the number of trips (i.e., a car can carry more items than a bike, thus delivering multiple orders within a single trip).

The **type of preliminary washing at home** can be a significant phase from an environmental point of view. In particular, it can generate significant consumption of water, energy, and detergents (Verburgt , 2021). The absence of preliminary washing process might determine an additional effort during the professional washing process in terms of an increase of rewashing rate (due to encrusted residues of food and drinks).

To overcome this problem, the company Vytal charges the customer an additional cost if the item is not returned within 14 days[7] from the use. To do so, the customer is registered to the service through an app, which charges the cost automatically using the customer's credit card (Rietveld and Hegger, 2015). Due to this mechanism, Vytal claims that 99% of containers are returned withing 14 days. It must be noted that this system is based on a voluntary scheme, i.e., the customer can always choose between SU and MU items.

The **type of professional washing** is then another relevant aspect for the following reasons:

1. It needs to be effective in order to completely remove food and drink residues/encrustations.
2. The energy efficiency of dishwashers can have a significant role in the overall environmental performances of the *take-away services* (Cottafava *et al.*, 2021; Verburgt, 2021).
3. Having a centralized washing facility can allow using more efficient dishwashers and solve the problem of the additional space needed in-store (Ramboll, 2020). On the other hand, it would require additional trips to move the dishes from/to the store (Verburgt, 2021).
4. It is also required a drying step for hygienic purposes (Ramboll, 2020).

The **physical limit to number of washings** relates to the degradation of material due to the effect of chemicals, which can affect the actual number of uses (Accorsi *et al.*, 2014).

The **additional packaging** could have a significant role when comparing *take-away services* with in-store consumption, even though it often has little consideration in current literature. In fact, *take-away services* generally require bags (in plastic or paper) (Zhou *et al.*, 2020), items for insulations (such as cardboard/silicone cup sleeve) and carriers with supplementary materials (glue, aluminum). These additional items can be:

[7] Source: https://www.blauer-engel.de/en/products/vytal-mehrwegsystem-mit-schalen-menueschalen-und-bechern

1. Voluminous, reducing the number of orders that can be delivered at the same time (Verburgt, 2021).
2. Heavy, especially for MU items, as they could be more structured due the higher weight of the plastic items. This could have an influence on emissions associated to the transportation (Cottafava *et al.*, 2021).

The **weight optimization** is then a natural consequence of the previous discussed hotspot, which can help in improving environmental performances of *take-away services* (Koskela *et al.*, 2014; Thorbecke *et al.*, 2019)

The **control and inspection** in-store of returned MU items is then a fundamental step. It is generally performed by employees and is necessary since MU items could have been damaged during transportation and use phases, and so they would not be suitable for further reutilization (Fraunhofer Institute for Building Physics IBP, 2018).

The **application of specific taxes/fees** could prevent misusing by the customer and help having higher return rates. Fee deposit system has indeed a considerable effect on a MU system and its return rate, as pointed out by a study on MU system for *take-away services* (UBA, 2019). This has been adopted by companies like Vytal[8], and through pilot projects by McDonald's[9], Starbucks[10], Burger King and Tim Hortons[11]. On the other hand, the same fee system might discourage customers from using MU items: in fact, all these systems are based on a voluntary scheme, i.e., the customer can always choose between SU and MU items. Moreover, if policy makers will introduce taxes on the utilization of SU items, this could lead QSRs to adopt the utilization of MU items.

The **theft** of MU items implies that a MU system should have higher number of items than expected. Consequently, this would imply higher environmental impacts. This hotspot is difficult to estimate, and is often omitted in other studies (Fraunhofer Institute for Building Physics IBP, 2018; Abejón *et al.*, 2020).. However, it could be expected that this number would be higher for MU items delivered at home (compared to in-store consumption). This is again based on behavioral aspects, but could be limited by registering customer's data, as in the system provided by the company Vytal[12].

Additional items for QSRs effective functioning are required, since QSRs could face the possibility of running out of dishes, and this could require additional space in store.

The **improper disposal** is related to end of life (EoL) of SU and MU items when delivered. In fact, there might be reduction of waste separation at home, with environmental consequences, as it could lower the amount of waste sent to recycling in favor of other options (incineration or disposal in landfill).

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[8] Source: Vytal | Takeaway food. Without rubbish.
[9] Source: https://www.circularonline.co.uk/news/mcdonalds-pilots-world-first-cup-take-back-scheme-in-northampton/
[10] Source: https://www.geekwire.com/2021/starbucks-trying-reusable-cups-cut-waste-teaming-seattle-recycling-startup/
[11] Source: https://www.packworld.com/issues/sustainability/article/21207262/loop-expands-into-qsr-with-burger-king-and-tim-hortons
[12] Source: Vytal | Takeaway food. Without rubbish.

4. INTERPRETATION AND DISCUSSION

4.1 Comparison of *take-away services* vs in-store consumption

The following sections include the description of the system boundaries of two different systems:

- in-store consumption for QSRs (as investigated in the framework of the conducted LCA (Ramboll, 2020)).
- *take-away services* for QSRs using also MU items (as expected to be).

The main scope is to identify the main differences of the two systems, and use them as driver elements for the identification, description, and preliminary evaluation of environmental implications of *take-away services* compared with in-store consumption system.

4.1.1 System boundaries of in-store consumption

The main goal of the performed LCA study is to use a systems-based approach to compare the environmental performance of single-use and multiple-use dishes options for in-store consumption in QSR in Europe.

The functional unit was the **in-store consumption of foodstuff and beverages with single-use or multiple-use dishes (including cups, lids, plates, containers and cutlery) in an *average* QSR for 365 days in Europe in consideration of established facilities and hygiene standards as well as QSR-specific characteristics (e.g., peak times, throughput of served dishes)**.

For the comparative assessment, two different systems have been investigated:

- the current system in QSRs based on SU items (disposable) made of paperboard with a polyethylene (PE) content < 10% w/w (also referred to as single-use product system), accounting for regulatory implications in 2023 (e.g., targets for separate waste collection and end of life (EoL) recycling).
- an expected (hypothetical) future system based on equivalent MU products (also referred to as MU product system) and respective processes for washing operations (in-store or sub-contracted).

The upstream, core, and downstream processes of in-store consumption included in the *Comparative life cycle assessment (LCA) single-use and multiple-use dishes systems for in-store consumption in Quick Service Restaurants* issued by Ramboll on behalf of EPPA (Ramboll, 2020) is represented in **Figure 1**.

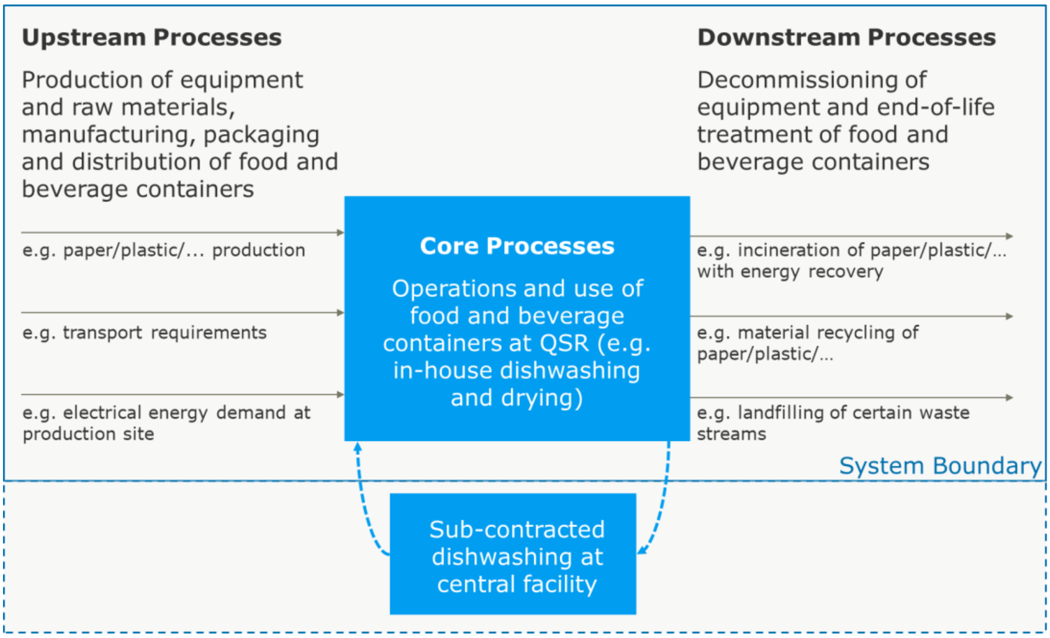

Figure 1: Schematic system boundary and differentiation between upstream, core, and downstream processes of in-store consumption from the perspective of a QSR (Source: own depiction)

The list of main processes involved in the packaging value chain for in-store consumption is reported in Table 3.

Table 3 Processes involved in the packaging value chain for in-store consumption

Type of processes	List of processes for SU items	List of processes for MU items
Upstream	Materials production, transport, energy requirement at production site	
Core	Use in store	Use in store, dishwashing (in-house or at central facility), drying
Downstream	Incineration with energy recovery, recycling, landfilling	

4.1.2 System boundaries of *take-away services*

Since *take-away services* using reusable items is an emerging market and only a limited number of pilot projects is currently in place, the related system boundaries have been identified using as reference publicly available documentation so far (including newspapers articles). Indeed, these boundaries and identified process might be affected by different levels of uncertainties and may be subject to future modification.

For the comparative assessment, two different systems have been taken into consideration:

- the current *take-away services* from QSRs, based on single-use (disposable) products made of paperboard with a polyethylene (PE) content < 10% w/w (also referred to as single-use product system).

- The possible *take-away services* based on equivalent plastic multiple-use products and respective processes and operations (transport from/to QSRs, inspection, washing (at home and in-store).

The upstream, core, and downstream processes of *take-away services* are represented in **Figure 2**.

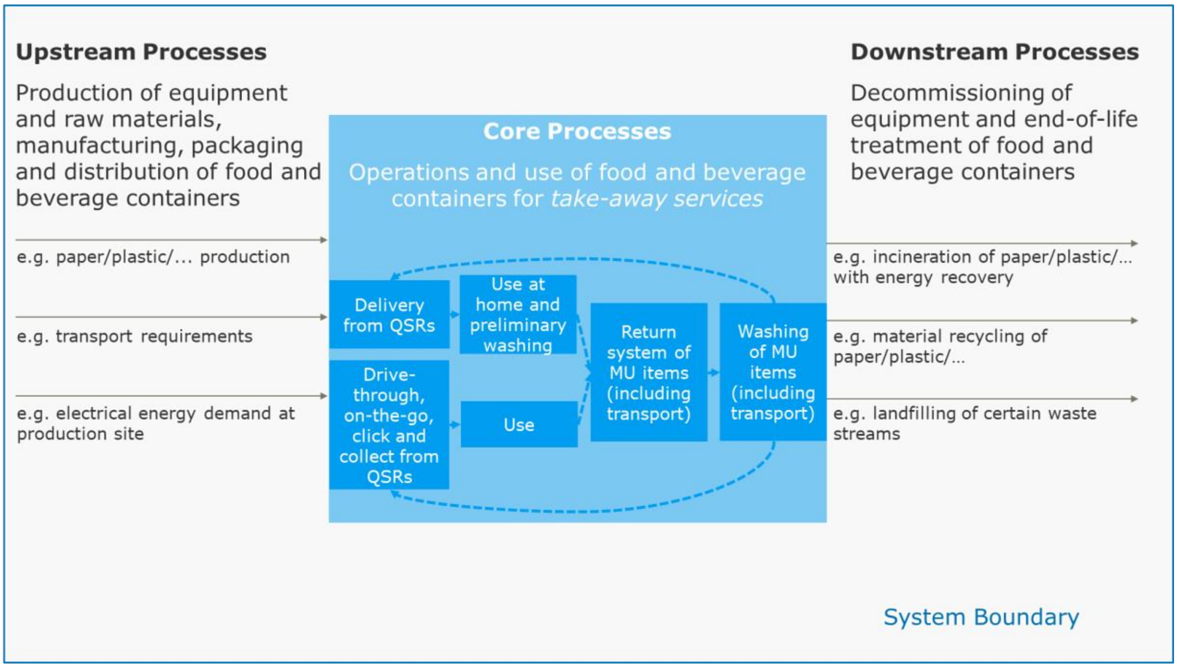

Figure 2 Schematic system boundary and differentiation between upstream, core, and downstream processes of *take-away services* from the perspective of a QSR (Source: own depiction)

Based on information provided by EPPA members - whose market share cover more than 65% of QSRs in Europe -, and on the outcome of a literature screening review, the expected (hypothetical) future system for *take-away services* will use plastic products (for MU system) as confirmed also by the analysis of commercial publications related to QSRs and other types of restaurants[13,14,15,16]. No literature data regarding *take-away services* using glass/ceramic items in the specific case of QSRs have been identified.

The list of main processes involved in the packaging value chain for *take-away services* is reported in Table 4.

Table 4 Processes involved in the packaging value chain for *take-away services.*

Type of processes	List of processes for SU items	List of processes for MU items
Upstream	Materials production, transport, energy requirement at production site	

[13] Source: Vytal | Takeaway food. Without rubbish.
[14] Source: https://www.circularonline.co.uk/news/mcdonalds-pilots-world-first-cup-take-back-scheme-in-northampton/
[15] Source: https://www.geekwire.com/2021/starbucks-trying-reusable-cups-cut-waste-teaming-seattle-recycling-startup/
[16] Source: https://www.packworld.com/issues/sustainability/article/21207262/loop-expands-into-qsr-with-burger-king-and-tim-hortons

Type of processes	List of processes for SU items	List of processes for MU items
Core	Transport (drive-through, on-the-go, click and collect, and home delivery), use	Transport (drive-through, on-the-go, click and collect, and home delivery), use, preliminary washing, transport back to store, dishwashing (in-house or at central facility), drying
Downstream	Incineration with energy recovery, recycling, landfilling, but with possible increase in improper disposal	

4.1.3 Identified differences

From the conducted literature screening, it can be stated that the upstream and downstream processes are the same for in-store consumption and *take-away services* (Table 5). However, the following differences can be identified:

1. Items (both SU and MU) for *take-away services* might need additional items for insulation, such as cardboard/silicone cup sleeve, together with additional secondary packaging, such as bags, carriers and boxes.
2. *Take-away services* need additional transport routes, such as from QSRs to home (and back, in the case of MU items). Moreover, MU packaging could need further additional transport routes from QSRs to subcontracted dishwashing facilities (in case the washing is not provided in store), and back to QSRs.
3. *Take-away services* of MU items requires preliminary washing at home.
4. *Take-away services* might entail reduction of waste separation at home (thus improper disposal).
5. In *take-away services*, the return rate of MU packaging could be low (in any case, <100%), due to different factors (behavioral aspects, willingness, long distances).
6. In *take-away services*, MU packaging could be affected by additional brakeage rate, due to additional handling/transport steps.

Table 5 Processes involved in the packaging value chain for in-store consumption and *take-away services*

	In-store consumption		*Take-away services*	
Type of processes	**List of processes SU**	**List of processes MU**	**List of processes SU**	**List of processes MU**
Upstream	Materials production, transport, energy requirement at production site			
Core	Use in store	Use in store, dishwashing (in-house or at central facility), drying	Transport (drive-through, on-the-go, click and collect, and home delivery), use	Transport (drive-through, on-the-go, click and collect, and home delivery), use, preliminary washing, transport back to store, dishwashing (in-house or at central facility), drying

	In-store consumption		*Take-away services*	
Type of processes	List of processes SU	List of processes MU	List of processes SU	List of processes MU
Downstream	Incineration with energy recovery, recycling		Incineration with energy recovery, recycling, landfilling, but with possible increase in improper disposal	

4.2 Semi-quantitative assessment

Taking into account the differences between the system boundaries of the in-store consumption and *take-away services* for SU e MU, a semi-quantitative impact assessment is performed, with the aim of identifying, describing, and assessing additional environmental implications of take-away services with regard to single-use and multiple-use food containers using as points of refence the LCA impact categories of the ReCiPe methodology, in order to keep symmetry with the previous LCA study provided by Ramboll on behalf of EPPA, where ReCiPe was the selected methodology (Ramboll, 2020)

Since each source utilizes a specific LCIA methodology, the impacts reported by each source have been "translated" in the corresponding ReCiPE impact category (e.g., if a source utilized the Impact 2002+ methodology, reporting impacts in the category "carcinogens", these are reported in the corresponding ReCiPe "human toxicity: cancer"). Moreover, some categories have been grouped together: "eutrophication, terrestrial", "eutrophication, freshwater", "eutrophication, marine" are all grouped under the "eutrophication" category. Same for "acidification" category.

Results are presented in a semi-quantitative manner using the Rapid Impact Assessment Matrix (RIAM) method – adopted in the framework of Environmental Impact Assessment - applied to each identified hotspot, to provide an accurate and independent score for each impact category.

4.2.1 Selection and grouping of most frequent hotspots

The first step was selecting the hotspots, by identifying those most frequently cited and analyzed in the sources of reference. A hotspot is selected when it is mentioned at least one third of the times of the most frequent hotspot. The results of this screening show that the most frequent hotspot is the actual number of uses, cited by 16 sources. Thus, hotspots cited at least by 5 sources are selected. The selected hotspots are schematized in **Table 6**.

Table 6. Selection of most cited hotspots according to literature review.

Hotspots	Number of citations
Actual number of uses for MU items	16
Type of take-back system	7
Return rate	7
Distance	15
Means of transport	8
Type of preliminary washing at home	6
Additional packaging	5

Hotspots	Number of citations
Weight optimization	5

A table with a further detailing of hotspots selection is presented in Appendix 2.

The hotspots that cover different feature of same/similar aspects, have been grouped together, as reported in **Table 7.**

Table 7 Grouping of selected hotspots for the modelling of RIAM.

Hotspots	Grouped hotspot
Actual number of uses for MU items	**Group 1: Reutilization rate**
Type of take-back system	
Return rate	
Distance	**Group 2: Transport**
Means of transport	
Type of preliminary washing at home	**Group 3: Additional washing***
Additional packaging	**Group 4: Weight**
Weight optimization	

Note that very few identified sources of information include a comparative evaluation between centralized washing facilities and washing in QSRs for take-away system. In order to carry out the RIAM, it is necessary to focus on sources reporting quantitative assessments of the identified hotspots in different impact categories. For this reason, sources reporting only qualitative information are excluded.

Moreover, since the semi-quantitative impact assessment shall take into account the environmental implications related to shifting from in-store consumption to take-away services, only sources focused on this latter aspect are considered.

4.2.2 Semi-quantitative assessment results

A score is assigned to each hotspot in each impact category, considering the following approach:

- Score=0: if the hotspot has not been investigated/cited or if it has been considered not relevant by the author in the specific impact category.
- Score=1: if the hotspot has been considered relevant by the author (i.e., it determines impacts) in the specific impact category.
- Score=2: if the hotspot has been considered very relevant by the author in the specific impact category.

A matrix correlating the sources and the impact categories has been prepared for each group of hotspots. The four tables are reported in Appendix 3, together with the cumulative scores.

In order to depict a global evaluation, scores of each impact category are summed up, giving a result for each group of hotspots.

Overall results are reported in **Table 8,** which provides a score to significance judgements included in the screened literature sources in terms of effects of the identified hotspots on relevant Impact Categories.

Table 8 Results of semi-quantitative assessment for the selected hotspots in different impact categories. Columns are ranked from highest to lowest cumulated score.

	Climate Change	Fossil depletion	Photochemical oxidant formation	Ozone depletion	Ecotoxicity	Acidification	Eutrophication	Human toxicity: non-cancer	Fine particulate matter formation	Human toxicity: cancer	Metal depletion	Water use	Land use	Ionizing radiation	SUM
Group 1: Reutilization rate	19	12	8	7	4	7	7	3	5	2	4	2	2	1	**83**
Group 2: Transport	10	6	5	6	6	5	5	4,5	1	3,5	2	2	3	3	**62**
Group 3: Additional washing	9	4	6	4	4	4	4	2	2	2	0	2	0	0	**43**
Group 4: Weight	6	0	2	0	2	0	0	2	2	2	0	0	0	0	**16**
SUM	**44**	**22**	**21**	**17**	**16**	**16**	**16**	**11,5**	**10**	**9,5**	**6**	**6**	**5**	**4**	

NOTE:
A value of zero means that the hotspot has not been investigated/cited or has been considered not relevant in the specific impact category.

4.2.2.1 Results interpretation

Results summarized in **Table 8** shows that Climate Change is by far the most potentially affected impact category by the adoption of take-away services, being its overall score more than twice of that of the following impact categories (Fossil depletion and Photochemical oxidant formation). Other categories that can have a relevant role are Ozone Depletion, Ecotoxicity, Acidification, Eutrophication, Human toxicity (cancer and non-cancer) and Fine particulate matter formation. The two most important hotspots groups contributing to these impacts are "reutilization rate" and "additional washing", with another potentially relevant role covered by "transport". Apparently, less relevant is the hotspot group "weight".

According to methodology used water consumption does not result as one of the main affected impact categories, because in the existing body of literature it has been analyzed only by few sources. Ramboll LCA study for in-store consumption shows that the comparison between the SU and the MU systems is dependent on underlying assumptions. However, there is a tendency that on average the SU system shows very significant environmental benefits in terms of freshwater consumption. Moderate environmental benefits for the MU system are solely identified in hypothetical situations where the effects of post-consumer paper recycling are less prevalent (i.e. 0% post-consumer recycling and/or different EoL allocation assumption) and optimized or external washing is fully adopted. For the take-away services system, a take-back system according to which all MU items are sent to centralized washing facilities (with high level of efficiency) could determine a significant reduction of overall impacts (if compared to take-back mechanism whereby all MU items are washed in QSRs).

Hotspots groups 1 (Reutilization rate) and 2 (Additional washing) refer only to MU systems, since the SU system by definition does not entail any reutilization, nor additional washing at home. Instead, **hotspots groups 3 (Transport) and 4 (Weight)** affect both SU and MU *take-away* systems, but to different degrees:

1. SU items need to be transported only to customers' homes, while MU items need to be transported back to store (and sometimes to/back from an external washing facility).
2. The weight of items and the additional packaging needed for their transportation might be more relevant for MU items than SU items, being the first heavier.

Hotspots group 1 (Reutilization rate): Ramboll (2020) included in the assessment an average reuse PP rate of 100 reuses. Reuse rates also includes potential replacement reasons such as damages, stains, theft or loss. The latter reasons are considered to be relatively important in QSRs as higher volumes of product items are involved than in regular restaurants. In addition, a varied demand for multiple-use items (30% higher; 30% lower) has been considered. Overall comparison between the two systems was not significantly affected by a varied demand for multiple-use items. It is expected that – using the same items - the shifting from in-store consumption to *take-away services* will determine a reduction of the reuse rate. Below the main findings of performed literature review are summarized.

Cottafava *et al.*, 2021 compared different types of SU and MU cups. Results highlight that some reusable plastic cups can reach a break-even point, i.e., the minimum number of uses necessary for a reusable cup to be preferable than a single-use cup, for Climate Change and Fossil depletion categories for a number of reuses <150 with respect to all analyzed single-use cups. Moreover, it must be noted that these results are reached when assuming specific assumptions, e.g., for washing or EoL: by varying these conditions, tens, hundreds or even thousands of reuses are required to reach the break-even point for all analyzed impact categories.

Overall, the impacts analyzed by the authors could have a relevant role mainly in the categories of: Climate Change, Acidification, Eutrophication, Ozone Depletion, Photochemical oxidant formation and Fossil depletion.

Gallego-Schmid, Mendoza and Azapagic, 2019 compared the life cycle impacts of three types of single-use takeaway containers (aluminum, polypropylene and extruded polystyrene) and one type of reusable containers (polypropylene). Their findings suggest that a key factor relies in the EoL of single-use containers: if they were recycled in accordance with the European Union 2025 policy on waste packaging, most of their impacts would be reduced by around 20%. Implementing the European Union 2025 policy on recycling of waste packaging would reduce all the impacts by 2%-60%, including a 33% reduction in Climate Change. This could lead to a saving of 61,700 t CO2 eq./yr, equivalent to the emissions of 55,000 light-duty vehicles. One of the impact categories mostly affected in this study is that of Metal depletion, followed by all the others.

In a previous study by the same authors (Gallego-Schmid, Mendoza and Azapagic, 2018), two reusable food containers (plastic and glass) were evaluated in a life cycle perspective in the European context. The results suggest that, for example, the Climate Change of using both types of food containers in the EU amounts to 653 kt CO2 eq./year, equivalent to the annual greenhouse gas emissions of Bermuda. In this regard, the production of container materials plays an important role, particularly for Fossil depletion, Climate Change, and Photochemical oxidant formation, contributing by more than 15% of total life cycle. This highlights that a high number of reuses is a key factor in order to avoid high production of these containers. However, this can vary depending on the materials the items are made of: glass food savers should have up to 3.5 times greater lifespan to match the environmental footprint of plastic containers.

The findings in terms of impact categories affected are similar to those of the study by the same authors reported above, with a relevant role of Climate Change and Ozone depletion.

Greenwood et al. (2021) performed a life cycle assessment comparing the environmental impacts of single-use, refillable, and returnable containers for a takeaway meal. The break-even point analysis showed that a variable number of uses (from five to dozens, depending on the specific items considered), are necessary to reach the break-even points, underlying again the reutilization rate as fundamental for environmental performances of *take-away services* with MU items. The most relevant impact categories in this analysis are those of Climate Change, Ecotoxicity and Human toxicity: non-cancer.

Martin et al. (2018) applied LCA to compare the environmental impacts of a traditional reusable ceramic mug with and without lid with those of a paper cup. They found out that the ceramic mug without lid could be the best option assuming that the mug will be used at least 140 times. Thus, reutilization rate always seems to have a key role for the environmental performance of MU system.

Impacts associated to disposable lids have been raising concern (UBA, 2019). This is, in general, typical issue of *take-away service*, as in-house system does not in general require lid to protect the product. To overcome this issue for *take-away services*, companies has adopted eco-labels (e.g., Blauer Engel in Germany) claiming to implement deposit-refund system for reusable lids made of one single material (100% polypropylene) for the *take-away services* (e.g., FairCup GmbH[17]). However, Blauer Engel eco-label highlights that "cups must be durable and have a

[17] Source: https://fair-cup.de/blog/produkte-mehrwegbecher/

service life of at least 500 wash cycles" [18]. The question arises as how the latter can be verified, and whether this value might be considered realistic[19].

Verburgt (2021) conducted research using the LCA method to determine the environmental impacts of reusable and single-use meal container systems with different configurations. More specifically, the research analyzed the product systems of three commonly used types of reusable meal boxes (from polypropylene, stainless steel and glass) and three commonly used types of single-use meal boxes (from polypropylene, aluminum and paper). The author suggested that:

1. establishing reusable meal container systems with a high return rate is of utmost importance.
2. The potential options for recollecting the containers and how the return rates of these types of systems can be optimized must be further analyzed prior these systems can be really implemented.

Based on the results of the study, the most relevant impact categories are Acidification, Climate Change, Eutrophication, Ozone depletion, Photochemical oxidant formation and Fossil depletion.

Zhou *et al.* (2020) presented the life-cycle environmental emissions and water consumption for different food home packaging options. Results show that, for MU items, the production phase generates the largest environmental emissions, followed by transportation (including take-back logistics) and the washing phase. The decentralized collection scenario (i.e., when MU items are recollected by a courier at customers' homes) has larger SO_2, NO_x and COD emissions than centralized take-back (i.e., when customers bring MU items back to a centralized collection point) owing to the extra impacts of take-back logistics. Regarding these conclusions it should be noted that Ramboll LCA study (2020) - using a system approach - has highlighted that for in-store consumption the main contributor to the impacts of the multiple-use system is the use phase, i.e., the washing of items. This conclusion is expected to be confirmed also for the *take-away services* with different magnitude that should be assessed by a full LCA study.

A study conducted for the German Ministry of Environment (UBA, 2019) highlighted a beneficial effect on the impact category Climate change for MU systems only from a reutilization rate higher than 50 cycles of all individual cups placed on the market. As the number of reuses is a critical parameter for *take-away services* due to lower return rate[20] than in-house consumption, this could be considered an important difference between the two systems. Moreover, when the MU system made of polypropylene is equipped with a disposable lid (not necessary for in-house systems), no environmental beneficial effects on a SU system could be achieved in almost any impact category in the *take-away services*.

Hotspots groups 2 (Additional washing): Cottafava *et al.*, 2021 stated that onsite handwashing is the worst solution while onsite dishwashing is an intermediate solution. For instance, in terms of Climate Change, they are comparable with offsite washing with a distance of 350km and 50km, respectively.

Gallego-Schmid, Mendoza and Azapagic (2018) claimed that the use stage is the main contributor to the impacts (>40%) for both types of food saver, mainly due to dishwashing or

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[18] Blauer Engel eco-label, Source: https://www.blauer-engel.de/en/productworld/reusable-systems-to-go-for-food-and-beverages?mfilter%5B0%5D%5Btype%5D=producttypes&mfilter%5B0%5D%5Bvalue%5D=779&url=https%3A%2F%2Fwww.blauer-engel.de%2Fen%2Fproductworld%2Freusable-systems-to-go-for-food-and-beverages

[19] Doubts have been raised on firms' claims. See, e.g., comments on (UBA, 2019) about a firm (www.freiburgcup.com) claiming 400 usage cycles. The study highlighted that cup, and especially the imprint, could become unsightly after a significantly lower number of rinsing cycles than the claimed ones.

[20] Example of lower return rate for cups: https://www.zeit.de/wissen/umwelt/2017-08/kaffeebecher-pfand-nachhaltigkeit-umweltschutz/seite-2?utm_referrer=https%3A%2F%2Fwww.google.com%2F

handwashing. Thus, as conclusion, the authors suggested that consumers can help to reduce the impacts of food savers by using efficient dishwashers or following recommendations for improved handwashing, and, in addition, consumers should aim to prolong the lifetime of food containers.

Greenwood et al. (2021) suggested that, when analyzing the type of washing performed by consumers, handwashing is likely to increase green-house gas emissions and water consumption relative to using a dishwasher.

Martin et al. (2018) found out that, when taking into account handwashing as customers' washing method, the ceramic mug with lid never reaches a break-even point, highlighting that additional washing have a key role for the environmental performance of MU system. The study indicates that the washing stage can have a relevant role in all analyzed impact categories.

Verburgt (2021) suggested that customers' cleaning method can be fundamental for the environmental performances of *take-away services* with MU items. This phase is as important as the method for recollecting the containers, and they are both even more important than the professional cleaning stage. In fact, the author stated that when customers apply a cleaning method with high associated environmental impacts the environmental performances of the system are heavily affected.

Zhou *et al.* (2020) suggested that additional washing could lead to much better environmental performances when dishwashing is applied instead of handwashing.

In the study performed by UBA (2019) it is suggested that type of electricity could influences the results. This is indeed relevant when MU systems are cleaned in dishwashers operating with certified green electricity, whose use could reduce the environmental impacts with an average reutilization rate of 10 (UBA, 2019). This procedure could be considered identical either at in-house or take-home system. Although pre-washing is not suggested by companies[21] to avoid double washing[22], it is expected in *take-away services* to avoid bad smells[23]. In the case of pre-washing performed via domestic dishwasher, this aspect might be a relevant parameter influencing environmental impacts[24].

Hotspots groups 3 (Transport): Cottafava *et al.*, 2021 stated that reusable cups midpoint impact categories are strongly affected by the distance during the use phase. They quantified a limit in terms of maximum distance allowed during the use phase in order to achieve an environmental break-even point after an infinite number of reuses. With respect to PP single-use cup, the environmental break-even point is never achieved for Acidification, Eutrophication, and Water Use, while for PET, PLA, and cardboard single-use cup the environmental break-even point is attained for all midpoint impact categories. Excluding also Photochemical oxidant formation impact category with respect to PP single-use cups, in all the other cases a break-even point is always achieved for a transport distance during the use phase lower than 100km.

Verburgt (2021) considered different transportation mode (electric bike, scooter or van) and difference distances, indicating that, when the containers are retrieved with fossil fuel-based vehicles over long distances, the environmental performances of the system are heavily affected.

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[21] Source: https://esseninmehrweg.de/wp-content/uploads/2020/07/20200723_F04_Factsheet_Nutzung_Mehrweg_Poolsystem.pdf

[22] Source: (UBA, 2019, page 95) [translated from German]: "It must also be taken into account that in some cases the cup is rinsed twice, when consumers wash the cup at home and it is then rinsed again at the return point"

[23] Source: https://ixtenso.de/store-design/hygiene-bei-der-leergutruecknahme.html

[24] Pre-washing is assumed, for example, by a recent study (Verburgt, 2021). The authors assumed this possibility, "It is therefore possible that the customer will thoroughly clean the meal container already after use anyway, even though this is not necessary, because they will also be professionally cleaned. It was expected that customers that will do this will either wash them by hand or wash them by using a dishwasher." If dishwasher is assumed, its energy demand is indeed related to the energy grid mix.

Zhou *et al.* (2020) considered transportation by means of electric bicycles, showing that, with respect to total emissions calculated, transport for take-back system contributes 4% of CO_2 emissions, less than 16% of air pollutant emissions (SO_2, $PM_{2.5}$ and dioxin) and water consumption, and 21% of COD emissions, but contributes the largest NOx emissions (75%).

Hotspots groups 4 (Weight): Cottafava *et al.*, 2021 stated that the weight of the cups can have an influence on environmental performances of the system, e.g., the high weight of glass reusable cups negatively affects the transport phase.

A recent study commissioned by UNEP (UNEP, 2020) evaluated single-use plastic take-away food packaging and its alternatives. The study, which summarizes results of many LCAs, reported that weight, among other aspects, is hotspot for the Climate Change indicator (e.g., reusable PP has lower emissions than reusable glass).

Also other studies, such as those provided by Arunan and Crawford (2021) and Liu *et al.*, (2020) agree that weight of items associated with *take-away services* can have an impact in the Climate Change category.

Based on the results of the previous Ramboll study (2020), the **environmental hotspots predominantly occur in different life cycle phases in the two systems**: for the single-use system, major impacts are generated during the upstream production of the items whereas the main contributor to the impacts of the multiple-use system is the use phase, i.e. the washing of items. The main outcomes of the study are:

- for the baseline scenario: the washing phase of MU items is the main contributor for several impact categories (e.g.: climate change, fine particulate matter, fossil depletion, freshwater consumption, freshwater eutrophication, ionizing radiation, stratospheric ozone depletion, terrestrial acidification);
- for the sensitivity analyses: the main differences with the baseline are related to different washing options.

It is a Ramboll opinion that the type of take back system might play an important role for the environmental aspects of MU system. Since take-back system in which all MU items are sent to centralized washing facilities (with high level of efficiency) determine a significant reduction of overall impacts (if compared to take-back mechanism whereby all MU items are washed in QSRs) (Ramboll, 2020; Cottafava *et al.*, 2021; Verburgt, 2021). This is explained by the fact that conveyer-type dishwashing (those utilized in centralized facilities) are more efficient than door/hood-type dishwashing (utilized in QSRs) (Ramboll, 2020; Verburgt, 2021). Certainly, professional washing in centralized facilities requires additional transportation, additional sets of MU items and a more complex logistic management. However, research by Cottafava *et al.* (2021) indicated that, with distances up to 50 km, this option was still environmentally preferred over the other washing options.

5. CONCLUSIONS

On behalf of European Paper Packaging Alliance, Ramboll has conducted the present meta-study with the aim of identifying, describing, and assessing additional environmental implications of *take-away services* (e.g., drive-through, on-the-go, click and collect, and home delivery services) of QSRs with regard to single-use and multiple-use food containers, using as a point of reference the existing body of knowledge - relating to QSRs in-store consumption - of the recently comparative LCA conducted by Ramboll on behalf of EPPA.

For the purpose of the analysis the definition of hotspot (used in the context of environmental assessment) by the "Life Cycle Initiative" has been used:

"A life cycle stage, process or elementary flow which accounts for a significant proportion of the impact of the functional unit (see UN Framework)"[25]. The following activities have been performed:

- Focused literature review on environmental performance of *take-away services*, market trends, and similar decision-contexts from which evidence may be transferred to *take-away services*.
- Identification and description of expected additional effects arising from *take-away services* with regard to both single-use and multiple-use product items.
- Interpretation of literature findings in the context of the existing full comparative LCA study on behalf of EPPA, considering the differences (in terms of systems boundaries) between in-store consumption and *take-away services*.

The system under analysis has been defined as:

> ***consumption of foodstuff and beverages with single-use or multiple-use dishes considering take-away services of an average European QSR***

Based on this, several keywords have been utilized to carry out desktop-based research, with the aim of identifying the existing body of knowledge: **29 literature sources have been identified** and have been subsequently refined by defining different quality criteria, selecting only the sources that have met at least 50% of defined quality criteria, resulting in **26 relevant sources**.

Based on these relevant sources, the following hotspots have been identified: Actual number of uses for MU items; Type of take-back system; Return rate; Distance; Means of transport; Type of preliminary washing at home; Type of professional washing; Physical limit to number of washings; Additional packaging; Weight optimization; Control and inspection; Application of specific taxes/fees; Theft; Additional items for QSRs effective functioning; Improper disposal.

The identified hotspots have been interpreted and discussed with the aim of evaluating (in a qualitative way) environmental implications of take-away services of QSRs with regard to single-use and multiple-use food containers.

In particular, the outcomes of the literature review have been interpreted considering the differences between the system boundaries of the in-store consumption and *take-away services*, with **the aim of identifying, describing, and assessing additional environmental implications of take-away services with regard to single-use and multiple-use food containers.**

[25] *Source:* https://www.lifecycleinitiative.org/resources/life-cycle-terminology-2/

Results have been presented in a semi-quantitative manner using the Rapid Impact Assessment Matrix (RIAM) method – widely adopted in the framework of Environmental Impact Assessment -, to provide an accurate and independent score for each impact category.

Based on the results of the hotspot analysis, the following claims can be established:

1. Reutilization rate (hotspots group 1) and washing (hotspots group 3) affect only the MU system.
2. Transport (hotspots group 2) and weight (hotspots group 4) affect both SU and MU systems, but to different extents, as they are more burdensome on the MU system for the reasons extensively discussed in the previous paragraphs.

Table 9 summarizes what are the impact categories mostly affected when shifting from in-store consumption to *take-away services*, comparing the results for SU and MU systems. The table provides a qualitative indication of the effects of *take-away services* life cycle stages and processes in terms of trend, i.e. increase or reduction of impacts. These conclusions are based on literature review (**Annex 3**) and knowledge developed based on the full LCA study conducted for in-store consumption (Ramboll, 2020). However, the mentioned additional/typical life cycle stages of *take-away services*, may generate significant impacts also in other impact categories. A quantitative assessment by means of a Life Cycle Assessment study is recommended in this perspective.

Table 9 Impact categories mostly affected when shifting from in-store consumption to *take-away services* for SU and MU systems

Impact categories	SU system Life cycle stage / process and effects	MU system Life cycle stage / process and effects
Climate Change	Additional packaging (+) Transport to home (+)	Additional packaging (+) Transport to home (+) Transport back to QSRs and to dishwashing centralized facility (+) Possible decrease in the number of reuses (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-) Possible increase in improper disposal (+)
Photochemical oxidant formation	Additional packaging (+) Transport to home (+)	Additional packaging (+) Transport to home (+) Transport back to QSRs and to dishwashing centralized facility (+) Preliminary washing at home (+) Possible decrease in the number of reuses (+)
Fine particulate matter formation	Additional packaging (+) Transport to home (+) Possible increase in improper disposal (+)	Additional packaging (+) Transport to home (+) Transport back to QSRs and to dishwashing centralized facility (+) Possible decrease in the number of reuses (+) More efficient dishwashing in case of centralized facility (-)
Water use	Additional packaging (+) Possible increase in improper disposal (+)	Additional packaging (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-)
Eutrophication	Additional packaging (+) Possible increase in improper disposal (+)	Additional packaging (+) Possible decrease in the number of reuses (+)
Ionizing radiation	Additional packaging (+) Possible increase in improper disposal (+)	Additional packaging (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-)
Resource use, minerals and metals	Additional packaging (+)	Additional packaging (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-) Possible decrease in the number of reuses (+)

Impact categories	SU system Life cycle stage / process and effects	MU system Life cycle stage / process and effects
Resource use, fossils	Additional packaging (+) Transport to home (+) Possible increase in improper disposal (+)	Additional packaging (+) Transport to home (+) Transport back to QSRs and to dishwashing centralized facility (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-) Possible decrease in the number of reuses (+)
Ecotoxicity	-	Preliminary washing at home (+)
Ozone depletion	Additional packaging (+)	Additional packaging (+) Preliminary washing at home (+) More efficient dishwashing in case of centralized facility (-) Possible decrease in the number of reuses (+)
(+) increase; (-) reduction		

For SU systems, the additional impacts obtained when shifting from in-store consumption to *take-away services* relate to the additional packaging, the transport to home and the possible increase in improper disposal. In particular, the main impact categories potentially affected by the shifting are those of Climate Change, Photochemical oxidant formation, Fine particulate matter formation, Water use, Eutrophication, Ionizing radiation, Resource use, minerals and metals, Resource use, fossils and Ozone depletion. More specifically:

- **Additional packaging** generates impacts almost in all reported categories due to the production phase of bags and other secondary packaging (Liu *et al.*, 2020; Zhou *et al.*, 2020; Arunan and Crawford, 2021).
- **Transport to home** generates impacts mainly in the Climate Change, Photochemical oxidant formation, Fine particulate matter formation and Resource use, fossils categories due to the direct emissions of the utilized means of transport (Cottafava *et al.*, 2021; Verburgt, 2021).
- **Possible increase in improper disposal** generates impacts mainly in the Fine particulate matter formation, Water use, Eutrophication, Ionizing radiation and Resource use, fossils categories due to the higher utilization of incineration instead of recycling (Ramboll, 2020).

For MU systems, the additional impacts obtained when shifting from in-store consumption to *take-away services* relate to additional packaging, transport to home, preliminary washing at home, transport back to QSRs, possible decrease in the number of reuses and possible increase in improper disposal. In particular, the main impact categories potentially affected by the shifting are those of Climate Change, Photochemical oxidant formation, Ozone depletion, Ecotoxicity and Fossil depletion. More specifically:

- **Additional packaging** is <u>at least</u> the same for SU.
- **Transport to home** is <u>at least</u> the same for SU.
- **Preliminary washing at home** generates impacts mainly in the Climate Change, Photochemical oxidant formation, Water use, Ionizing radiation, Resource use, minerals and metals, Resource use, fossils, Ecotoxicity and Ozone depletion categories due to consumptions of electric energy (or natural gas), water and detergents (Gallego-Schmid, Mendoza and Azapagic, 2018; Martin, Bunsen and Ciroth, 2018; Ramboll, 2020; Greenwood *et al.*, 2021; Verburgt, 2021). On the other hand, **more efficient dishwashing in case of centralized facility** may determine a reduction of overall impacts for MU systems (if compared to take-back mechanism whereby all MU items are washed in QSRs) mainly in the Climate Change, Water use, Ionizing radiation, Resource use, minerals and metals, Resource use, fossils and Ozone depletion categories due to the reduced consumptions of electric energy (or natural gas), water and detergents (Gallego-Schmid, Mendoza and Azapagic, 2018; Martin, Bunsen and Ciroth, 2018; Ramboll, 2020; Greenwood *et al.*, 2021; Verburgt, 2021)
- **Transport back to QSRs**: as for the transport to home. This means that overall impacts related to transport are at least twice than those of SU systems.
- **Possible decrease in the number of reuses** generates impacts mainly in the Climate Change, Photochemical oxidant formation, Fine particulate matter formation, Eutrophication, Resource use, minerals and metals, Resource use, fossils and Ozone depletion categories due to necessity to increase the production of MU items (Martin, Bunsen and Ciroth, 2018; Ramboll, 2020; Greenwood *et al.*, 2021; Verburgt, 2021)

- **Possible increase in improper disposal** generates impacts mainly in the Climate Change category due to the higher utilization of incineration instead of recycling (Ramboll, 2020).

Water use can have a significant contribution to overall impacts of use stage of MU items, with different possible environmental performances associated to different adopted washing methods for *take-away services.*

Based on this comparison, it can be concluded that, when shifting from in-store consumption to *take-away services*, both SU and MU systems can suffer from additional environmental impacts in several categories, but to different extent, meaning that additional impacts for SU systems are limited to few aspects, while MU systems are affected not only by the same impacts as for SU systems but also by another series of impacts related to phases that are exclusive of the MU system, i.e.: preliminary washing at home, transport back to QSRs, possible decrease in the number of reuses.

However, a take-back system in which all MU items are sent to centralized washing facilities (with high level of efficiency) could determine a significant reduction of overall impacts (if compared to take-back mechanism whereby all MU items are washed in QSRs).

On this basis, it can be concluded that a shifting from in-store consumption to *take-away services* would be more burdensome for MU system than SU system. This conclusion could be further confirmed with a quantitative assessment by means of a Life Cycle Assessment study.

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APPENDIX 1
SCREENING BASED ON QUALITY CRITERIA TABLE

Author	Peer Review	LCA/ISO compliance	Geographical Context (Europe)	Time reference (<5 years ago)	Take-away services	Whole supply chain	Transport stage	Cleaning/washing stage	Comparison between different items or materials	Environmental hotspots	Number of quality criteria met	Does the source meet at least 50% of quality criteria?
(Abejón *et al.*, 2020)	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	9	**Yes**
(Accorsi *et al.*, 2014)	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	8	**Yes**
(Albrecht *et al.*, 2013)	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8	**Yes**
(Arunan and Crawford, 2021)	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	7	**Yes**
(Camps-Posino *et al.*, 2021)	✓	✓	✗	✓	✓	✓	✓	✓	✗	✓	8	**Yes**
(Changwichan and Gheewala, 2020)	✓	✓	✗	✓	✓	✓	✗	✓	✓	✓	8	**Yes**
(Coelho *et al.*, 2020)	✓	✗	✗	✓	✓	✓	✗	✗	✗	✓	5	**Yes**
(Cottafava *et al.*, 2021)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	**Yes**

Author	Peer Review	LCA/ISO compliance	Geographical Context (Europe)	Time reference (<5 years ago)	Take-away services	Whole supply chain	Transport stage	Cleaning/washing stage	Comparison between different items or materials	Environmental hotspots	Number of quality criteria met	Does the source meet at least 50% of quality criteria?
(Del Borghi *et al.*, 2021)	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8	**Yes**
(Fraunhofer Institute for Building Physics IBP, 2018)	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	9	**Yes**
(Gallego-Schmid, Mendoza and Azapagic, 2019)	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	9	**Yes**
(Gallego-Schmid, Mendoza and Azapagic, 2018)	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	9	**Yes**
(Greenwood *et al.*, 2021)	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	9	**Yes**
(Kleinhückelkotten, Behrendt and Neitzke, 2021)	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	9	**Yes**
(Koskela *et al.*, 2014)	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	7	**Yes**
(Li, Mirosa and Bremer, 2020)	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	4	**No**

Author	Peer Review	LCA/ISO compliance	Geographical Context (Europe)	Time reference (<5 years ago)	Take-away services	Whole supply chain	Transport stage	Cleaning/washing stage	Comparison between different items or materials	Environmental hotspots	Number of quality criteria met	Does the source meet at least 50% of quality criteria?
(Liu *et al.*, 2020)	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	7	**Yes**
(Lo-Iacono-ferreira *et al.*, 2021)	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	9	**Yes**
(Martin, Bunsen and Ciroth, 2018)	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	9	**Yes**
(Molina-Besch, Wikström and Williams, 2019)	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	4	**No**
(Thorbecke *et al.*, 2019)	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	8	**Yes**
(Tua *et al.*, 2019)	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	9	**Yes**
(UBA, 2019)	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	9	**Yes**
(UNEP, 2020)	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	8	**Yes**

Author	Peer Review	LCA/ISO compliance	Geographical Context (Europe)	Time reference (<5 years ago)	Take-away services	Whole supply chain	Transport stage	Cleaning/washing stage	Comparison between different items or materials	Environmental hotspots	Number of quality criteria met	Does the source meet at least 50% of quality criteria?
(Verburgt, 2021)	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	9	**Yes**
(Vytal, 2022)	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	3	**No**
(Xie, Xu and Li, 2021)	✓	✗	✗	✓	✓	✗	✓	✗	✗	✓	5	**Yes**
(Zhang and Wen, 2022)	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	7	**Yes**
(Zhou *et al.*, 2020)	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	9	**Yes**

APPENDIX 2
HOTSPOTS SELECTION TABLE

Author	**Actual number of uses for MU items**	**Type of take-back system**	**Return rate**	**Distance**	**Means of transport**	**Type of preliminary washing at home**	**Type of professional washing**	**Physical limit to number of washings**	**Additional packaging**	**Weight optimization**	**Control and inspection**	**Application of specific taxes/fees**	**Theft**	**Additional items for continuous availability**	**Higher cost of MU items**	**Improper disposal**
(Abejón *et al.*, 2020)	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Accorsi *et al.*, 2014)	✓	✗	✗	✓	✓	✗	✓	✓	✗	✗	✓	✓	✓	✗	✓	✗
(Albrecht *et al.*, 2013)	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Arunan and Crawford, 2021)	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗
(Camps-Posino *et al.*, 2021)	✓	✗	✗	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
(Changwichan and Gheewala, 2020)	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Coelho *et al.*, 2020)	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✓	✓	✗	✗	✗	✗
(Cottafava *et al.*, 2021)	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗

Author	Actual number of uses for MU items	Type of take-back system	Return rate	Distance	Means of transport	Type of preliminary washing at home	Type of professional washing	Physical limit to number of washings	Additional packaging	Weight optimization	Control and inspection	Application of specific taxes/fees	Theft	Additional items for continuous availability	Higher cost of MU items	Improper disposal
(Del Borghi *et al.*, 2021)	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Fraunhofer Institute for Building Physics IBP, 2018)	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗
(Gallego-Schmid, Mendoza and Azapagic, 2019)	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
(Gallego-Schmid, Mendoza and Azapagic, 2018)	✓	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Greenwood *et al.*, 2021)	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Kleinhückelkotten, Behrendt and Neitzke, 2021)	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	✗
(Koskela *et al.*, 2014)	✓	✗	✗	✓	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗
(Li, Mirosa and Bremer, 2020)	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Author	Actual number of uses for MU items	Type of take-back system	Return rate	Distance	Means of transport	Type of preliminary washing at home	Type of professional washing	Physical limit to number of washings	Additional packaging	Weight optimization	Control and inspection	Application of specific taxes/fees	Theft	Additional items for continuous availability	Higher cost of MU items	Improper disposal
(Liu *et al.*, 2020a)	✓	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Lo-Iacono-ferreira *et al.*, 2021)	✓	✗	✓	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
(Martin, Bunsen and Ciroth, 2018)	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Molina-Besch, Wikström and Williams, 2019)	✓	✓	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗
(Thorbecke *et al.*, 2019)	✓	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
(Tua *et al.*, 2019)	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(UBA, 2019)	✗	✓	✗	✓	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗
(UNEP, 2020)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Author	Actual number of uses for MU items	Type of take-back system	Return rate	Distance	Means of transport	Type of preliminary washing at home	Type of professional washing	Physical limit to number of washings	Additional packaging	Weight optimization	Control and inspection	Application of specific taxes/fees	Theft	Additional items for continuous availability	Higher cost of MU items	Improper disposal
(Verburgt, 2021)	✗	✓	✗	✓	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗
(Vytal, 2022)	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Xie, Xu and Li, 2021)	✓	✗	✗	✓	✓	✗	✓	✓	✗	✗	✓	✓	✓	✗	✓	✗
(Zhang and Wen, 2022)	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
(Zhou *et al.*, 2020)	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗

APPENDIX 3
MATRICES CORRELATING THE SOURCES AND THE IMPACT CATEGORIES

Table 10 Matrix correlating sources and impact categories for the hotspots group REUTILIZATION RATE

<table>
<tr><th>Impact categories</th><th>(Accorsi et al., 2014)</th><th>(Camps-Posino et al., 2021)</th><th>(Changwichan and Gheewala, 2020)</th><th>(Cottafava et al., 2021)</th><th>(Gallego-Schmid, Mendoza and Azapagic, 2019)</th><th>(Gallego-Schmid, Mendoza and Azapagic, 2018)</th><th>(Greenwood et al., 2021)</th><th>(Martin, Bunsen and Ciroth, 2018)</th><th>(UBA, 2019)</th><th>(Verburgt, 2021)</th><th>(Zhou et al., 2020)</th><th>SUM</th></tr>
<tr><td>Acidification</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>2</td><td>0</td><td>7</td></tr>
<tr><td>Climate Change</td><td>2</td><td>2</td><td>2</td><td>2</td><td>1</td><td>2</td><td>2</td><td>0</td><td>2</td><td>2</td><td>2</td><td>19</td></tr>
<tr><td>Ecotoxicity</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>2</td><td>0</td><td>0</td><td>0</td><td>0</td><td>4</td></tr>
<tr><td>Eutrophication</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>2</td><td>0</td><td>7</td></tr>
<tr><td>Human toxicity, cancer</td><td>0</td><td>0</td><td>0</td><td>0</td><td rowspan="2">1</td><td rowspan="2">1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td></tr>
<tr><td>Human toxicity, non-cancer</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>0</td><td>0</td><td>0</td><td>0</td><td>3</td></tr>
<tr><td>Ionising radiation, human health</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>Ozone Depletion</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>2</td><td>0</td><td>0</td><td>0</td><td>2</td><td>0</td><td>7</td></tr>
<tr><td>Particulate matter</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>0</td><td>2</td><td>5</td></tr>
<tr><td>Photochemical ozone formation, human health</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>2</td><td>2</td><td>8</td></tr>
<tr><td>Resource use, fossils</td><td>0</td><td>0</td><td>2</td><td>2</td><td>1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>2</td><td>0</td><td>12</td></tr>
<tr><td>Resource use, minerals and metals</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>4</td></tr>
<tr><td>Land use</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>2</td></tr>
<tr><td>Water use</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>0</td><td>2</td></tr>
</table>

Table 11 Matrix correlating sources and impact categories for the hotspots group TRANSPORT

Impact categories	(Accorsi et al., 2014)	(Camps-Posino et al., 2021)	(Cottafava et al., 2021)	(Liu et al., 2020)	(Verburgt, 2021)	(Zhou et al., 2020)	SUM
Acidification	0	0	2	0	2	0	**4**
Climate Change	2	2	2	0	2	1	**9**
Ecotoxicity	0	0	0	2	0	2	**4**
Eutrophication	0	0	2	0	2	0	**4**
Human toxicity, cancer	0	0	0	2	0	0	**2**
Human toxicity, non-cancer	0	0	0	2	0	0	**2**
Ionising radiation, human health	0	0	0	0	0	0	**0**
Ozone Depletion	0	0	2	0	2	0	**4**
Particulate matter	0	0	0	0	0	2	**2**
Photochemical ozone formation, human health	0	0	2	0	2	2	**6**
Resource use, fossils	0	0	2	0	2	0	**4**
Resource use, minerals and metals	0	0	0	0	0	0	**0**
Land use	0	0	0	0	0	0	**0**
Water use	0	0	0	0	2	0	**2**

Table 12 Matrix correlating sources and impact categories for the hotspots group ADDITIONAL WASHING

Impact categories	(Gallego-Schmid, Mendoza and Azapagic, 2018)	(Greenwood et al., 2021)	(Martin, Bunsen and Ciroth, 2018)	(UBA, 2019)	(Verburgt, 2021)	SUM
Acidification	1	0	2	0	2	**5**
Climate Change	2	2	2	2	2	**10**
Ecotoxicity	2	2	2	0	0	**6**
Eutrophication	1	0	2	0	2	**5**
Human toxicity, cancer	1	1	2	0	0	**3.5**
Human toxicity, non-cancer		2	2	0	0	**4.5**
Ionising radiation, human health	0	1	2	0	0	**3**
Ozone Depletion	2	0	2	0	2	**6**
Particulate matter	0	0	1	0	0	**1**
Photochemical ozone formation, human health	1	0	2	0	2	**5**
Resource use, fossils	2	1	1	0	2	**6**
Resource use, minerals and metals	1	0	1	0	0	**2**
Land use	0	1	2	0	0	**3**
Water use	0	0	0	0	2	**2**

Table 13 Matrix correlating sources and impact categories for the hotspots group WEIGHT

Impact categories	(Arunan and Crawford, 2021)	(Cottafava et al., 2021)	(Liu et al., 2020)	(Zhou et al., 2020)	SUM
Acidification	0	0	0	0	**0**
Climate Change	2	2	2	0	**6**
Ecotoxicity	0	0	0	2	**2**
Eutrophication	0	0	0	0	**0**
Human toxicity, cancer	0	0	0	2	**2**
Human toxicity, non-cancer	0	0	0	2	**2**
Ionising radiation, human health	0	0	0	0	**0**
Ozone Depletion	0	0	0	0	**0**
Particulate matter	0	0	0	2	**2**
Photochemical ozone formation, human health	0	0	0	2	**2**
Resource use, fossils	0	0	0	0	**0**
Resource use, minerals and metals	0	0	0	0	**0**
Land use	0	0	0	0	**0**
Water use	0	0	0	0	**0**