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COMPARATIVE LIFE CYCLE ASSESSMENT (LCA)

SINGLE-USE AND MULTIPLE-USE TABLEWARE SYSTEMS FOR TAKE-AWAY SERVICES IN QUICK SERVICE RESTAURANTS

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SUMMARY

APPENDIXES

Abbreviations

Acd	Acidification
ADP	Abiotic resource depletion
AE	Accumulated Exceedance
B2B	Business-to-Business
CB	Corrugated box
CC	Climate Change
CTUe	Comparative Toxic Unit for ecosystems
CTUh	Comparative Toxic Unit for human
DI	disease incidence
EoL	End-of-Life
EF	Environmental Footprint
EcoF	Ecotoxicity Freshwater
EPD	Environmental Product Declaration
EPPA	European Paper Packaging Alliance
FE	Freshwater Eutrophication
GHG	Greenhouse Gas
GWP	Global Warming Potential
HORECA	Hotellerie, Restaurant, Café
HT-C	Human toxicity, cancer
HT-NC	Human toxicity, non cancer
IR	Ionizing Radiation
kBq U235 eq.	kilobecquerels of Uranium-235 equivalents
kg CFC-11 eq.	kilograms of trichlorofluoromethane equivalents
kg CO2 eq.	kilograms of carbon dioxide equivalents
kg N eq.	kilograms of nitrogen equivalents
kg NMVOC eq.	kilograms of non-methane volatile organic compounds equivalents
kg P eq.	kilograms of phosphorus equivalents
kg Sb eq.	kilograms of antimony equivalents
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LU	Land Use
m^3 world eq.	cubic meters world equivalents
ME	Marine Eutrophication
MJ	megajoule

mol H+ eq.	moles of charge equivalent
mol N eq.	moles of nitrogen equivalent
MU	Multiple Use
OD	Ozone Depletion
ODP	Ozone Depletion Potential
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PM	Particulate Matter
POF	Photochemical Ozone Formation
QSR	Quick Service Restaurant
(R)PC	(Reusable) plastic crate/container
RU-F	Resource Use (fossil)
RU-M	Resource Use (mineral and metals)
SU	Single use
TE	Terrestrial Eutrophication
WU	Water Use

EXECUTIVE SUMMARY

Ramboll has been appointed by the European Paper Packaging Alliance (hereafter "EPPA" or the Client) as technical consultant for conducting a comparative Life Cycle Assessment (LCA) study related to single-use (SU) and multiple-use (MU) tableware systems for take-away services in Quick Service Restaurants (QSRs), in accordance with ISO standards 14040 and 14044, subjected to internal review conducted by two senior LCA experts of the international Ramboll Decarbonisation (GHG/LCA) Steering Committee and to external third-party review by a panel composed by three independent reviewers.

EPPA is an association representing suppliers and manufacturers of 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.

This comparative LCA study is focused on QSRs *Take-away services* that include:

- **drive-through**: customers reach the restaurant and order food directly from their cars;
- **on-the-go**: 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:** customers buy food online and it is delivered by means of a courier.

It is understood that this assessment is embedded in an ongoing debate around the environmental performance of single-use and multiple-use products. Consequently, there is already a quite mature body of knowledge concerning several products and applications from either category. However, previous studies adopt a rather product-focused approach in comparative assertions (i.e., comparing single-use cups with multiple-use cups). In these assessments less attention is given to the underlying systems and obtained functions from respective products. **Next to taking into account previous findings this study seeks to adopt a holistic perspective on the comparison of single-use (SU) and multiple-use (MU) products in QSRs**.

The functional unit is:

Take-away services (drive through, on-the-go, click and collect, home delivery) of foodstuff and beverages with single-use or multiple-use tableware (including cups, lids, containers, cutlery, carriers and bags) in an average QSR for 365 days in Europe in consideration of established facilities and hygiene standards and take-away services specific characteristics (e.g., selling channels, distances, means of transport).

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

- current system for take-away services from QSRs based on single-use (disposable) products made of paperboard with a PE content < 10% w/w (also referred to as single-use product system) and related transport from/to QSRs;
- expected (hypothetical) system for take-away services from QSRs based on equivalent multiple-use products (also referred to as multiple-use product system) and respective

processes and operations (transport from/to QSRs, inspection, washing at home and/or in-store, take-back system).

It should be noted as of now that considerations regarding take-back system of MU items are affected by the unpredictability of customers' behaviour, which is in contrast with the science-driven nature of LCA, thus implying the need to make specific assumptions for the correct functioning of the system. These assumptions are clearly reported in this study to guarantee transparency of the assessment.

The distinctive features of this study compared to other assessments within this field of research are the following:

- **Approach**: the main goal of the LCA study is to compare through a system approach the environmental performance of single-use and multiple-use tableware options for take-away consumption in QSR in Europe and not focused on the environmental performance of a single product;
- **Robustness and reliability of the investigated system**: the incorporation of representative data and information with regards to the functional unit, inventory data as well as assumptions around the systems.

  In order to have robust and reliable sources of data related to the potentially relevant parameters, Ramboll performed a specific data gathering (via datasheets, questionnaire) to QSRs operators related to the use stage in take-away systems, such as distribution channels repartition, type of washing and type of dishwashers, number of reuses of a product, return rates, means of transport and distances covered. Moreover, primary data and information (reflected in the functional unit) for single-use system are obtained from EPPA members' which market shares cover more than 65% of QSRs in Europe. Also, data from scientific papers in Q1 journal with high level of consistency have been incorporated for both SU and MU systems.
- **Extensive sensitivity analysis:** to test decisive assumptions in the systems, several sensitivity scenarios were analysed. The suggested sensitivity scenarios are based on both the contribution analysis of the baseline comparison and the identified variability regarding critical parameters. 9 scenarios have been analyzed (5 for MU system; 4 for both systems), including: different number of reuses, different return rate, different assumptions related to take-back system, different washing scenarios, different EoL shares, different EoL allocation approaches.

The geographical scope of the baseline comparison is Europe (EU-27 + UK). This geographical boundary was 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 was site-specific or representing average production scenarios (e.g., global, EU).

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

- A cold drink cup;
- A clip-on lid for the drink cup;
- A cup holder;
- A wrap/clamshell for burgers;

- A fry bag/basket/fry carton;
- A small bag for fries' transport;
- An ice-cream cup.
- A spoon (cutlery item) for the ice cream cup;
- Bag for delivery.

Other food containers/packaging (i.e., hot drink cups, salad bowls) are not included in the LCA study: items corresponding to less than 1% of total items used for take-away services (based on confidential QSRs data) are excluded.

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

- **8** different products for the single-use system, made of paperboard (if coated, PE content is < 10 % w/w);
- **6** different products for the multiple-use system, made of PP; and
- **3** products (cup holder, bags for transport of fries and delivery bag) considered for both single-use and multiple-use systems: even though these products are intended for single-use, it is understood from information gathered from relevant stakeholders that these items would not be replaced by equivalent function multiple-use items.

For the **baseline scenarios** the following key assumptions have been made:

<u>Single-use system</u>:

- Paper manufacturing refers to the respective geographical context of the paper mill or manufacturer from which primary data is used and is considered representative for EU-average supply chain.
- Products are made solely from virgin paper (with the exception of cup holder, bags for transport of fries and delivery bags considered for both single-use and multiple-use systems).
- Intermediate transport from paper producers to converters is modelled according to primary data provided by converters.
- Paper converting stage is modelled based on primary data obtained from converters located in representative European countries.
- Production paper wastes during converting (i.e., post-industrial wastes) are materially recycled as indicated in primary information obtained from converters.
- Types and amounts of packaging materials (cardboard and PE foils) for all single-use product items (except for wooden cutlery) are based on primary data from converters.
- Four different take-away selling channels are considered:
    - Drive through, by means of EURO4[1] cars;
    - Delivery, on-the-go, and click and collect, all three by means of an equal share of EURO4 cars, scooters, bikes, public transport and by walking.

[1] Due to lack of data related to the potential fleet of vehicles involved in the system, a conservative assumption is made by considering only EURO4 cars.

- Transport from QSR to point of consumptions is symmetrical for SU and MU systems. It is then excluded from the analysis.
- End-of-life (paper products):
  - 30% paper recycling, 60% incineration with energy recovery and 10% landfilling, based on an extensive analysis of literature data and taking into account regulatory aspects provided for EU legislation (see full report for details).
  - Transport of waste from QSR to incineration facility is assumed to be 100 km.
  - The baseline allocation approach is the system expansion methodology (i.e., the avoided burdens method).

Multiple-use system:

- PP manufacturing in Europe.
- Four different take-away selling channels are considered:
  - Drive through, by means of EURO4 cars[2];
  - Delivery, on-the-go, and click and collect, all three by means of an equal share of EURO4 cars, scooters, bikes, public transport and by walking.
- Transport from QSR to point of consumptions is symmetrical for SU and MU systems. It is then excluded from the analysis.
- An average scenario for preliminary washing is used to reflect different possible processes. It considers an equal share of handwashing, dishwashing, cold rinsing and dry wiping, and is applied to half of total items (50%) taken back to QSRs (with the exception of those bought by means of drive through, which are assumed to be returned directly after consuming food and beverages as conservative assumption).
- The phase of transport back to QSR is considered, being this exclusive of the MU system.
- For returning MU items to QSRs, a decentralized take-back mechanism is considered, where MU items are returned to collection points by consumers.
- For on-the-go, click and collect and delivery, it is assumed an average distance between QSR and point of consumption of 3 km (as reported by QSRs in specific data gathering questionnaires prepared by Ramboll). For drive through, as conservative assumption, it is assumed that food and beverages are consumed near the QSR and MU items are returned directly after consumption of food and beverages, covering a distance of 1 km.
- It is then assumed that trips for returning MU items to QSRs can provide a multifunctionality (i.e., a trip not only intended to return MU items, but also intended for other reasons external to the system boundaries), however multifunctionality may be highly affected by consumers' activities, decisions, and behaviour. There are limited studies that provide analytics on behaviour toward take-back program. In this study the impacts associated with these trips are only partially allocated to the system, assuming - in the baseline - that only 50% of consumers make the average distances described above specifically for returning the MU items. According to this scenario, 1/2 of trips for take-back are neglected (e.g., 1 out of 2 people return MU items in case of buying of

[2] Due to lack of data related to the potential fleet of vehicles involved in the system, a conservative assumption is made by considering only EURO4 cars.

another menu). Given the unpredictability of customers' behaviour more conservative scenarios have been also tested with sensitivity analysis.

- Average reuse rate of 50 reuses and average return rate of 50%[3] are considered as reported by confidential QSRs data (gathered by means of specific questionnaires prepared by Ramboll to assure reliability of potentially key figures). Reuse rate and return rate also include potential replacement reasons such as damages, stains, theft or loss.
- Washing, rinsing and drying processes are performed in-house (in QSRs) by means of hood-types dishwashers (as reported by confidential QSRs data); inputs to these processes are based on literature values for water, energy, detergent and rinse agent demand (per item basis). An average scenario for dishwashers is used to reflect different grades of devices' efficiencies;
- State-of-the-art detergent, rinse agent and softener compositions are assumed;
- Average rewashing rate for all items of 10% is considered: this assumption is to consider the presence of persistent residues that might remain after washing (Antony and Gensch, 2017). The presence of persistent residues is a peculiarity of take-away systems, since items could be returned in a long time frame (e.g., weeks) after food consumption, which leads to food/beverages encrustations. For this reason, the rewashing rate value has been increased to 10% (the original publication reports a 5% rewashing rate referring to items that are washed immediately after their use) to consider this further constraint of the system. However, the exact rate will depend on organisational structures in a QSR (e.g., time between serving of tableware and washing; pre-rinsing of tableware by hand, time frame before returning MU items).
- End-of-life (PP products):
  - 30% recycling, 60% incineration with energy recovery and 10% landfilling based on an extensive analysis of literature data and taking into account regulatory aspects provided for EU legislation (see full report for details).
  - Transport of waste from QSR to waste treatment facility is assumed to be 100 km.
  - The baseline allocation approach is the system expansion methodology (i.e., the avoided burdens method).
  - In addition, for MU system there is also a residual share of items disposed of within QSRs, which is represented by those items that are returned to QSRs but are no longer usable. For these items higher recycling rates are assumed considering that take-back systems are normally organized on purpose to guarantee collection and recycling of items. Those MU items that are returned to QSRs are therefore assumed to be 70% recycled and 30% incinerated.

By using the baseline model, impact results are provided, and main contributors to the results are presented for each impact category, allowing for a comparison between the two systems. Moreover, a contribution analysis is facilitated by showing contributions for each life cycle stage within the respective systems; for each impact category, the most important emissions are

[3] These assumptions are based on primary data gathered from QSRs operators.

reported, as well as the most relevant sources of impacts on LCI level (see the full report for more details).

Analysis of relevant findings for the comparative assertion follows a consistent terminology[4] as presented in **Table 1.**

Table 1: Terminology for results interpretation

Relative difference in %	Terminologies in comparative assertion and interpretation of results
<5%	**marginal** *difference (i.e., uncertainty threshold)*
5-10%	**minor** *difference*
10-20%	**noticeable** *difference*
20-30%	**moderate** *difference*
30-50%	**significant** *difference*
>50%	**very significant** *difference*

By using classification on terminology of **Table 1**, overall results are given in **Table 2**. In the following comparative analysis of the environmental emissions Climate Change is considered as a single impact category. Therefore, the comparative analysis is presented by highlighting differences of SU and MU only for Climate Change total, by excluding a comparison of its three constituents. Yet, in the contribution analysis, investigation on shares of impacts is extended further to the three constituents of Climate Change, total (*Climate change, biogenic; Climate change, fossil; Climate change, land use and land use change*).

The baseline comparison of SU and MU shows that the SU system has lower impacts in all impact categories.

Table 2: Summary of aggregated total impacts of the baseline scenario and discussion of the insights through the sensitivity analyses.

Impact category	SU system - Baseline Scenario	MU system - Baseline Scenario	Comments
EF-Acidification [mol H+ equivalents]	77.5	167.6	The **single-use system** shows **very significant** benefits (MU is + 54%)
EF-Climate change, total [kg CO2-Equivalents]	20,811	39,788	The **single-use system** shows **significant** benefits (MU is + 48%)
EF-Eutrophication, freshwater [kg N equivalents]	5.48	9.28	The **single-use system** shows **significant** benefits (MU is + 41%)
EF-Eutrophication, marine [kg P equivalents]	37.8	49.6	The **single-use system** shows **moderate** benefits (MU is + 24%)
EF-Eutrophication, terrestrial [mol N equivalents]	254.5	449.3	The **single-use system** shows **significant** benefits (MU is + 43%)

[4] The terminology used for interpretation is based on relative difference in %, where the system with associated highest impact for each category is set to 100% and the other system is normalized to this value.

Impact category	SU system - Baseline Scenario	MU system - Baseline Scenario	Comments
EF-Ionising radiation, human health [kBq U235 equivalents]	3,976	4,318	The **single-use system** shows **minor** benefits (MU is + 8%)
EF-Ozone depletion [kg CFC11 equivalents]	0.00276	0.00561	The **single-use system** shows **very significant** benefits (MU is + 51%)
EF-Particulate matter [disease incidence]	0.00083	0.00188	The **single-use system** shows **very significant** benefits (MU is + 56%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	69.8	213.5	The **single-use system** shows **very significant** benefits (MU is + 67%)
EF-Resource use, fossils [MJ]	314,931	581,979	The **single-use system** shows **significant** benefits (MU is + 46%)
EF-Resource use, minerals and metals [kg Sb equivalents]	0.06	0.32	The **single-use system** shows **very significant** benefits (MU is + 82%)
ReCiPe 2016 Midpoint (H)-Water consumption	136.8	224.5	The **single-use system** shows **significant** benefits (MU is + 39%)

Figure 1 shows the relative impacts of both system per impact category – the system with associated highest impact for each category is set to 100%, and the other system is normalized to this value, to facilitate the visualization and the difference between the results.

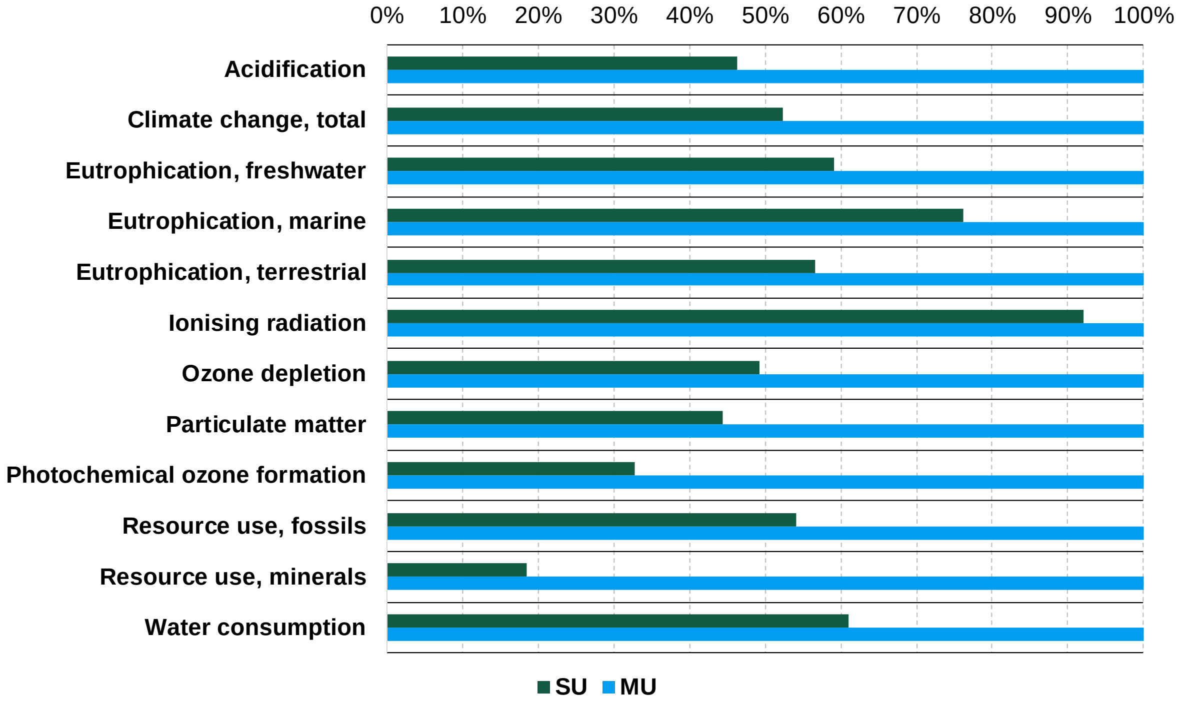

Figure 1 Results of both SU and MU systems, normalized to the highest impacts per impact category

The contribution analysis shows that the **environmental hotspots of the two systems (SU and MU) predominantly occur in different life cycle phases in the two systems (see the full report for more details)**:

- environmental impacts in the SU system are predominantly driven by the **Raw material extraction** and **Converting** life cycle stages,
- environmental impacts in the MU system are predominantly driven by **Use phase transport** and **Washing** life cycle stages.

To test decisive assumptions in the systems, several sensitivity scenarios were analysed.

In order to present the contribution to the total impacts, the Product Environmental Footprint Category Rules Guidance (version 6.3) reports a methodology for "Impact categories cumulatively contributing at least 80% of the total environmental impact (excluding toxicity related impact categories)". Note that also Water consumption impact category is excluded, since it has been calculated with a different LCIA methodology (ReCiPe 2016 Midpoint (H)). Following this procedure, the results show:

- **SU system**: Based on the normalized and weighted results, and excluding the toxicity related impacts, the most relevant impact categories are *Acidification, Climate Change, total, Particulate matter, Photochemical ozone formation, human health* and *Resource use, fossils* for a cumulative contribution of 81.5% of the total impact (**Table 3**).
- **MU system**: Based on the normalized and weighted results, and excluding the toxicity related impacts, the most relevant impact categories are *Climate Change, total, Particulate matter, Photochemical ozone formation, human health, Resource use, fossils*

and *Resource use, minerals and metals* for a cumulative contribution of 84.6% of the total impact (**Table 4**).

Most relevant categories common to both systems are indicated in the **brown cells**, while most relevant categories for only one system are indicated in **orange cells**.

Table 3 Impact categories cumulatively contributing at least 80% of the total environmental impact for SU system

Single-use system - Impact category	Contribution to the total impact (%), excluding toxicity impact categories
EF 2.0 Acidification [Mole of H+ eq.]	5.7%
EF 2.0 Climate Change - total [kg CO2 eq.]	36.4%
EF 2.0 Eutrophication, freshwater [kg P eq.]	3.9%
EF 2.0 Eutrophication, marine [kg N eq.]	2.6%
EF 2.0 Eutrophication, terrestrial [Mole of N eq.]	3.4%
EF 2.0 Ionising radiation, human health [kBq U235 eq.]	3.1%
EF 2.0 Ozone depletion [kg CFC-11 eq.]	0.5%
EF 2.0 Particulate matter [Disease incidences]	7.6%
EF 2.0 Photochemical ozone formation, human health [kg NMVOC eq.]	5.4%
EF 2.0 Resource use, fossils [MJ]	26.3%
EF 2.0 Resource use, mineral and metals [kg Sb eq.]	5.1%

Table 4 Impact categories cumulatively contributing at least 80% of the total environmental impact for MU system

Multiple-use system - Impact category	Contribution to the total impact (%), excluding toxicity impact categories
EF 2.0 Acidification [Mole of H+ eq.]	5.8%
EF 2.0 Climate Change - total [kg CO2 eq.]	32.8%
EF 2.0 Eutrophication, freshwater [kg P eq.]	3.1%
EF 2.0 Eutrophication, marine [kg N eq.]	1.6%
EF 2.0 Eutrophication, terrestrial [Mole of N eq.]	2.9%
EF 2.0 Ionising radiation, human health [kBq U235 eq.]	1.6%
EF 2.0 Ozone depletion [kg CFC-11 eq.]	0.5%
EF 2.0 Particulate matter [Disease incidences]	8.1%
EF 2.0 Photochemical ozone formation, human health [kg NMVOC eq.]	7.7%
EF 2.0 Resource use, fossils [MJ]	22.9%
EF 2.0 Resource use, mineral and metals [kg Sb eq.]	13.09%

For the **sensitivity analysis** and respective scenarios only one parameter or assumption has been changed per system to maintain transparency and ensure traceability of results. The following sensitivity analyses have been performed:

1. Parameters related to take-back system of MU items:
    a. S01: Increase in number of reuses (100 reuses).

   b. S02: Increase of return rate (70%).

   c. S03: Reduction of trips for take-back: 4 out of 5 people return MU items in case of buying of another menu.

   Customers' behaviour might represent a decisive factor when considering overall environmental performance of MU system. It is therefore worth considering a scenario where only 20% of consumers cover the full average distance to return MU items (i.e., 4/5 of trips for take-back are neglected) which appear a rather conservative assumption.

2. Parameters related to washing of MU items:
   a. S04: No preliminary washing at home.
   b. S05: Type of professional washing: External washing with band transport dishwasher.
3. Parameters and allocation methodology related to End-of-Life for SU and MU systems:
   a. S06: 30% recycling and 70% incineration.
   b. S07: 60% recycling, 30% incineration and 10% landfilling.
   c. S08: Eurostat data:
      i. SU: 82.9% recycling, 7.8% incineration and 9.3% landfilling
      ii. MU: 41.8% recycling, 33.5% incineration and 24.7% landfilling.
   d. S09: Cut-off 50:50 allocation approach.

Here below, a detailed discussion is given by presenting a focus on the three groups of scenarios (described above) in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems. The complete sensitivity analysis for all impact categories is reported in **section 5.3** of the full report

The following charts report the results of the sensitivity analysis for each impact category, showing them in terms of percentage difference between SU and MU systems. The charts have two parts:

- if SU system is less impacting than MU system in a selected impact category, the bars are shown in the upper part of the chart.
- if MU system is less impacting than SU system in a selected impact category, the bars are shown in the lower part of the chart.

This means that the 0% line represent the "starting point", and any variation from that line represent the environmental performance in terms of percentage difference between SU and MU systems when varying a specific parameter (for reference, the baseline scenario is included in the chart).

If the bars are not visible, it means that both systems show a comparable performance when varying that specific parameter (i.e., the bars rely on the 0% line).

With this type of visualization, robustness can be visualized as follows:

- When a parameter is not crucial and does not change the results of the analysis, the bar of the correspondent product is visualized in the same side of the chart (either upper or lower part). This means that, to some extent and depending on the percentage variation of the results, the results due to the variation of the selected parameter could be considered robust

- When a parameter is crucial and changes the results of the analysis, for instance, the bar of the correspondent product is visualized in the opposite side of the chart (either upper or lower part).

Take-back system parameters in MU system (S01, S02, S03)

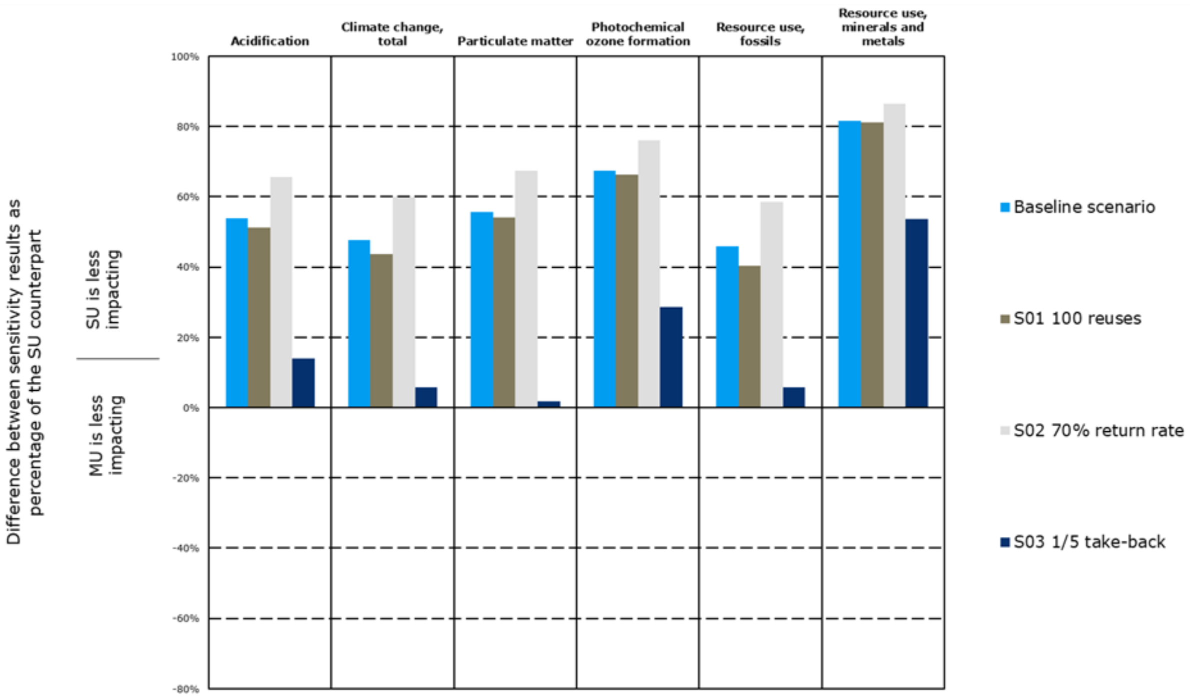

Figure 2 Sensitivity analysis for take-back system parameters in MU system in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems.

The chart of **Figure 2** reports results for the variation of the logistic parameters for MU system, showing that such variation does not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. Going into detail:

1. The variation of number of reuses to 100 is able to provide a little variation for the analysed impact categories (with the exception of *Resource use, minerals and metals*). However, this variation is very limited and does not change the overall results.
2. The variation of return rate to 70% even provides a widening of the delta between the two systems (i.e., a higher return rate implies higher impacts for the MU system). For the MU system, a higher return rate means:
    a. lower impacts for the production and end-of-life phase.
    b. higher impacts for the use phase transport.

    Since use phase transport is the main hotspot of MU system, increasing the return rate implies more direct and indirect environmental impacts than avoided ones.

3. The reduction of total trips for take-back, considering that 4/5 of total trips to return MU items are neglected (i.e., 4 out of 5 people returning MU items in case of buying another menu), provides the largest improvement for MU system with some results almost comparable to those of SU system, but still not changing the results (i.e., SU system is still less impacting).

   However, results of this scenario reflect a very conservative approach, according to which 4/5 of trips for take-back are neglected (i.e., return of MU items occurs in case of buying of another menu).

Washing phase in MU system (S04, S05)

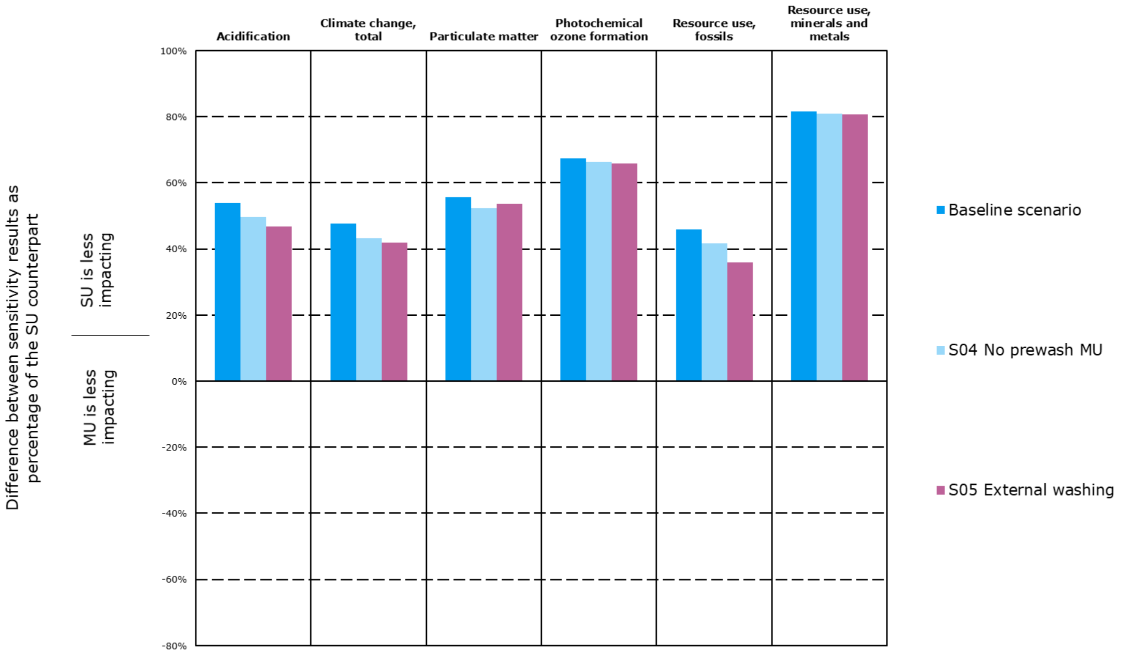

Figure 3 Sensitivity analysis for washing phase in MU system in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems.

The chart of **Figure 3** reports results for the variation of the washing phase for MU system, showing that such variation does not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. Overall, the variation provided by both scenarios in the analysed impact category is very limited.

Different End-of-life shares and allocation approach for SU and MU systems (S06, S07, S08, S09)

In the previous in-store LCA study (Ramboll, 2020), a symmetrical approach for paper and PP was assumed: this means that hypothetical recycling and incineration share (of 30% and 70%, respectively) were assigned to the treatment of both SU and MU items. When shifting to the present take-away LCA study, a further element should be considered, which is the share of separation at home. To the best of Ramboll knowledge, there are no sources reporting figures related to share of separation at home. However, it is generally recognised that B2B systems have better waste management, including separation compared to B2C systems. Considering these uncertainties, it is confirmed that:

- keeping a symmetric approach for both systems is confirmed to be most appropriate for a fair comparison;
- it is worth keeping a conservative approach adopting lower recycling rate in the baseline (i.e., 30% for both systems,) even if this choice might be more penalizing for paper.

Beside this, a set of sensitivity analyses specifically focused on EoL shares was performed, in order to test the effects of the variation of End-of-Life shares on overall results.

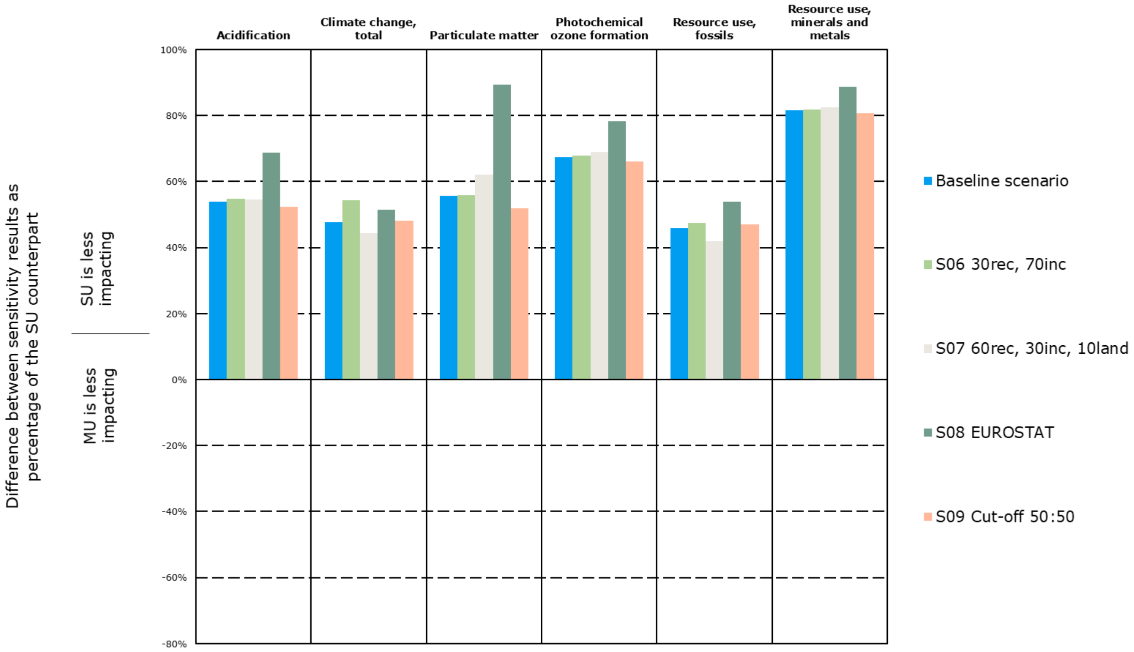

Figure 4 Sensitivity analysis for different End-of-life shares for both SU and MU systems in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems.

When analysing the results of different end-of-life shares and allocation approach (**Figure 4**), again it is shown that such variations do not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. The Eurostat shares gives a larger delta between the two systems (i.e., by utilising data provided by Eurostat, SU is less impacting than the baseline), even though figures by Eurostat cannot be assumed as fully representative of the analysed system, as explained in **section 4.3**.

<u>Main conclusions</u>

Results of this study are partly in contrast to other LCA studies that are mainly product-focused and often reveal clearer environmental advantages for multiple-use items compared to their single-use equivalents as long as a certain minimum number of reuses is considered (see **full report** for the literature screening). This difference can be largely explained by the fact that previous studies are mainly relying on secondary data (in particular concerning the paper upstream value chain) whereas the study at hand implemented primary data to a large extent, in particular for the environmental hotspots of paper production and conversion in the single-use system. However, for the multiple-use system, data is based on literature information and assumptions combined with inputs from QSRs operators where possible. This is due to the fact that the return scheme of multiple-use system presents a hypothetical future scenario for which no consolidated primary data exists. With regard to specific functioning of QSRs, it is mainly based on data provided by QSRs operators retrieved from in-store consumption (multiple-use items, dishwashing process, selling channels) where multiple-use scheme is already in place.

In this sense, it must be noted that considerations regarding take-back system of MU items and features of related trips (distance, multifunctionality (i.e., the fact that a trip is made specifically to return MU items or not), allocation of burdens) strongly depends on customers' behaviour and might represent a decisive factor when considering overall environmental performance of MU system. With reference to these aspects, the study tried to implement assumptions as much conservative as possible. However, the complexity around these assumptions arises from:

- the hypothetical nature of MU system for QSRs, since it is not yet fully established at industrial scale, implying a partial lack of data availability. Although based on data provided by QSRs operators MU plastic alternative might be predominant in future considering specific nature of QSR industry (i.e., high volumes, need of hygiene and food safety at the highest level).
- The unpredictability of customers' behaviour, which is in contrast with the science-driven nature of LCA, thus implying the need to make specific assumptions for the correct functioning of the system. These assumptions are clearly reported in this study to guarantee transparency of the assessment.

This study is not intended to present or interpret environmental impacts on a product level. Modelling choices, data quality and assumptions are to be seen in the light of the overarching goal and systems perspective.

The study shows that there are different potentially crucial assumptions and parameters that can have a key role in the functioning of analysed systems and associated environmental impacts. This is particularly evident with reference to the hot-spots of the system, which are:

- **Raw material extraction** and **Converting** life cycle stages for SU system: due to the geographical scope of the study (i.e., Europe), European averages are used for important (background) processes such as the electricity mix and pulp production for EoL allocation (i.e., avoided impacts associated with assumed substitution of average pulp products from virgin sources). Thus, the selection of another geographical scope can influence the results and comparative assertion.
- **Use phase transport** and **Washing** life cycle stages for MU system: these are again influenced by the electricity mix (and then the geographical scope), as well as selling channels, specific means of transport, and customers' behaviour regarding several aspects (preliminary washing at home, separate collection of waste, choices regarding the take-back system).

The results of the study also point to further need for research and investigation of relevant parameters, with particular emphasis to take-back system of MU items and features of related trips: distance, multifunctionality (i.e., the fact that a trip is made specifically to return MU items or not), allocation of burdens.

Internal and External review

This executive summary is based on an ISO-compliant full LCA report that was subjected to:

1. Internal QA/QC conducted by two senior LCA experts of the international Ramboll *Decarbonisation (GHG/LCA) Steering Committee.*
2. External third-party review by a panel composed by the following reviewers:
    - Michael Sturges (lead panelist) - RISE Research Institutes of Sweden / RISE Innventia AB, Sweden – a life cycle assessment practitioner with specific experience of environmental studies relating to the packaging and food service sectors.
    - Prof. Umberto Arena – University of Campania "Luigi Vanvitelli", Italy - a chemical engineer with experience of packaging systems, including LCA studies on valorisation of paper and plastic waste streams.
    - Frank Wellenreuther, ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH, Germany – a life cycle assessment practitioner with specific experience of environmental studies relating to packaging systems.

EXECUTIVE ANNEX

Processes of the life cycle are divided in three life cycle stages: upstream, core, and downstream (see **Figure 5**).

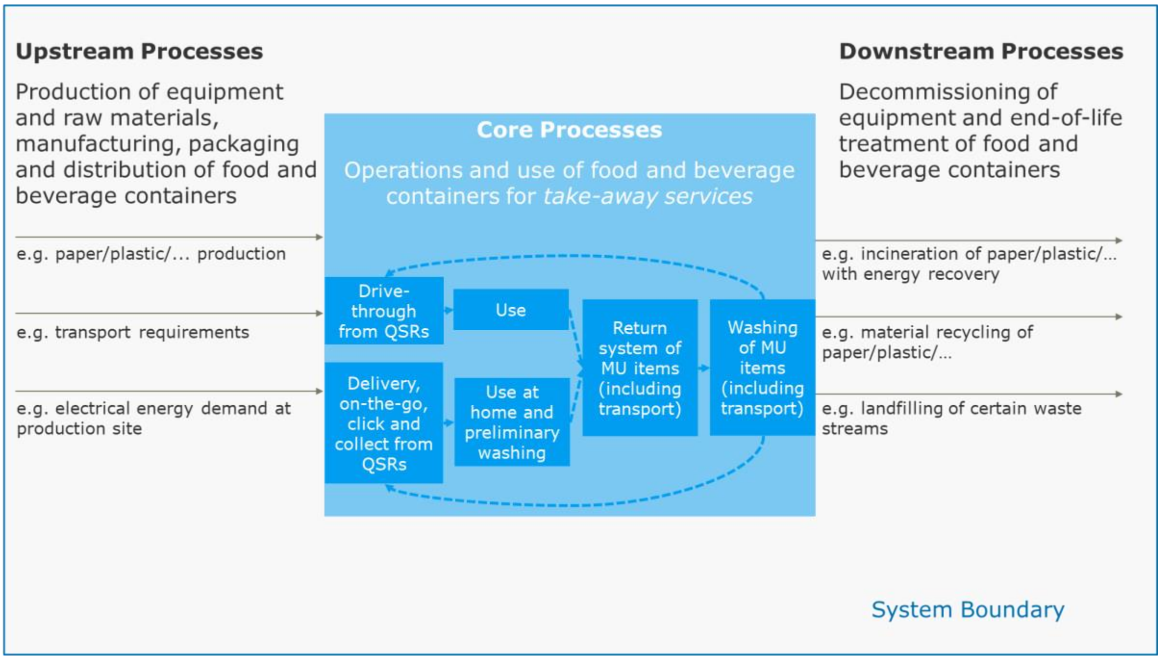

Figure 5: Schematic system boundary and differentiation between upstream, core, and downstream processes of take-away services from the perspective of a QSR (Source: own depiction)

As outlined above, the comparison of the single-use and multiple-use systems shows that the environmental hotspots predominantly occur in different life cycle phases in the two systems: for the single-use system, major impacts and credits are generated during the upstream production and converting of the items whereas the main contributor to the impacts of the multiple-use system is the use phase, i.e., the take-back system to QSRs (transport) and washing of items. Hence, further details on the respective important life-cycle stages are provided here.

Further details on the production and EoL treatment phases of the single-use system

Primary LCI data for pulp and paper products are obtained from several producers located in countries representative for the pulp and paper market situation in Europe. Hence, the entire raw material production and processing phase for paper products is represented by using primary data (only exceptions are background processes such as chemicals, auxiliary materials, electricity, thermal energy). To this end, the primary information indicated in **Table 5** is implemented in the assessment.

Table 5: Primary data for paper making implemented in the assessment

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Chemical pulp (softwood, bleached)	Primary data	Confidential	Finland	1 t pulp	2021

PE-coated paperboard (different variants and specifications)	Primary data	Confidential	Finland	1 t board	2021
Thin greaseproof paper with soy-based coating	Primary data	Confidential	Austria	1 t paper	0% recycled content
High-brightness paperboard	Primary data	Confidential	Austria	1 t paperboard	80% recycled content

Some paperboard products listed in Table 5 have recycled content. Therefore, recycled pulp obtained from wastepaper treatment is assumed as used as input of the paperboard manufacturing. The input recycled pulp is modelled following the approach of the PEFCR for recycled input material, which includes collection of wastepaper for recycling, transport to a sorting facility, sorting into paper grades, transport to a recycling facility, wastepaper recycling into recycled fibres.

The production stage of single-use product items is modelled based on primary data obtained from converters based in Germany, Finland, and France. Wooden cutlery marks the only exemption, for which only secondary data is implemented. To this end, the primary information indicated in **Table 6** is implemented in the assessment.

Table 6: Primary data for paper converting implemented in the assessment

Provider process name	Classification	Source	Geographical coverage	Reference year
Cold drink cup	Primary data	Seda	Germany	2020
Clip on Lid	Primary data	Seda	Germany	2020
Cup holder	Primary data	Hutamaki	Finland	2022
Clamshell	Primary data	Seda	Germany	2020
Paper wrap	Primary data	CEE Schisler	France	2019
Fry bag	Primary data	Seda	Germany	2020
Paper fry bag	Primary data	CEE Schisler	France	2019
Ice Cream Cup	Primary data	Seda	Germany	2020
Wooden cutlery	Secondary data	Paspaldzhiev *et al.* (2018)	Europe	2017
Paper bags	Primary data	CEE Schisler	France	2022

In this study, wastepaper recycling depends on the type of wastepaper treated. Two types of materials are considered: non-coated paperboard (including corrugated grades of shipment boxes), coated paperboards used in SU products (including pre-consumer trimmings for their manufacturing).

For non-coated paperboard and corrugated grades, the approach for modelling wastepaper recycling is given in detail in **APPENDIX 2. Life Cycle Inventory - Wastepaper recycling**. The resultant LCI describes the recycling of wastepaper from placing the recovered wastepaper into the pulper to recovered pulp, and it refers to 1 ton of recovered pulp.

For coated paperboard, a specific LCI for wastepaper recycling (confidential data) was described in the In-store EPPA report. This is primary gate-to-gate inventory data of a dedicated recycling process for plastic (PE)-coated paperboard products.

Table 7: Sources of primary data for coated/uncoated paper recycling implemented by means of inventory data and own modelling

Provider process name	Classification	Source	Geographical coverage	Reference year
Wastepaper recycling, corrugated grades	Hybrid data (primary and secondary)	Calculations and expert judgment	Europe	2021
Recycling of sorted paperboard from post-consumer waste PE-coated paper	Primary data	Confidential	Europe	2019

Further details on the use phase (take-back transport and washing) of the multiple-use system

Table 8 reports the shares of means of transport for returning MU items to QSRs, considering different selling channels. The exact shares of total sales in each single channel are not disclosed due to confidentiality of the primary data provided by QSRs operators.

For on-the-go and click and collect, no information is available related to the specific means of transport utilised. For this reason, as conservative assumption, an equal share of cars, scooters, bike, public transport and trips by walking are considered. The same assumption is assumed for the take-back of MU items bought by means of delivery.

Table 8: Shares of means of transport for returning MU items to QSRs, considering different selling channels

Selling channel	Share of total sells	Means of transport	Share of total means of transport in the specific selling channel
Drive through	Confidential	Car	100%
On-the-go, click and collect	Confidential	Car	One fifth
		Scooter	One fifth
		Bike	One fifth
		Public transport	One fifth
		Walking	One fifth
Delivery*	Confidential	Car	One fifth
		Scooter	One fifth

Selling channel	Share of total sells	Means of transport	Share of total means of transport in the specific selling channel
		Bike	One fifth
		Public transport	One fifth
		Walking	One fifth
* for the delivery selling channel, items are mostly delivered by means of scooters and bikes (as reported by primary data from QSRs and from literature data), but since the take-back system is performed by customers, the same means of transport assumed for on-the-go and click and collect are assumed for this phase.			

For the preliminary cleaning/washing stage of MU items, different methods were identified. Different companies working with reusable meal containers encourage the customers to either not clean them or only clean them shortly by rinsing with cold water (Verburgt, 2021). However, this also depends on customers behaviour. It is therefore possible that the customer will thoroughly clean the meal containers already after use anyway, even though they will also be professionally cleaned. However, in order to reflect different possibilities, the following assumptions are taken into account:

- Preliminary washing is not considered for MU items not returning to QSR (i.e., those for which the return rate does not apply).
- Among the items returning to QSR (i.e., those for which the return rate does apply), preliminary washing is considered just for 50% of items. This is a conservative assumption considered to reflect the possibility that a share of items is returned without a preliminary washing.
- For drive through selling channel, it is assumed that preliminary washing is not performed, since MU items are assumed to be used nearby the QSR and directly took-back.

For the modelling of this stage, four different system configurations were taken into account:

1. Handwashing
2. Dishwashing
3. Dry wiping (with paper towels)
4. Cold water rinsing

For handwashing, the data were obtained from research by Verburgt (2021) and Potting and van der Harst (2015) and complemented with data from Joseph *et al.* (2015) and data from Martin, Bunsen and Ciroth (2018). It is expected that hot water and detergent are required for handwashing an item, and that paper towels are used for drying it. Data reported in these studies have been recalculated with reference to the average volume of items considered in this study. Thus, 1.5 L of water, 0.09 kWh for heating the water (based on an 85% efficiency natural gas boiler), 1.5 g of detergents and 5.8 g of paper towels are required. The treatment of wastewater required as a result of washing the container was added, assuming that the amount needs to be the same as the water input according to Martin, Bunsen and Ciroth (2018).

For dishwashing, data were obtained from research by Verburgt, (2021) and Potting and van der Harst (2015). It is expected that a dishwasher uses 0.27 L of water, 0.03 kWh of electricity, 0.28 g of detergent and 0.03 g of rinse agent per item (with reference to the average volume of items in this study). The treatment of wastewater required as a result of washing the items was also added (Martin, Bunsen and Ciroth, 2018). Data for this process are different from those reported in the following for professional washing, since it is expected a sensible difference between dishwashers for domestic use and those for professional use.

For dry wiping, it is expected that the same amount of paper towels is required as included in the handwashing option.

Data for cold water rinsing were based on research by Binstock, Gandhi and Steva, (2013). **Table 9** provides an overview of the collected inventory data for the four options. The final reference process is the average of the four considered options.

Table 9: Technical specifications of preliminary washing methods (LCI data).

	Handwashing (including rinsing)	Dishwashing	Dry wiping	Cold rinsing	Average preliminary washing process
Energy demand [kWh/item]	0.09	0.03	0*	0*	0.03
Water demand [l/item]	1.5	0.27	0*	1.5	0.81
Detergent [g/item]	1.5	0.28	0*	0*	0.43
Rinse agent [g/item]	-	0.03	0*	0*	0.01
Paper towels [g/item]	5.8	0*	5.8	0*	2.9
Wastewater treatment [l/item]	1.5	0.27	0*	1.5	0.81
Source	Based on (Joseph *et al.*, 2015; Potting and van der Harst, 2015; Martin, Bunsen and Ciroth, 2018; Verburgt, 2021)	Based on (Potting and van der Harst, 2015; Bosch, 2020; Verburgt, 2021)	Based on (Joseph *et al.*, 2015; Potting and van der Harst, 2015; Verburgt, 2021)	Based on (Binstock, Gandhi and Steva, 2013; Martin, Bunsen and Ciroth, 2018; Verburgt, 2021)	

NOTE: data have been calculated with reference to the average volume of items considered in this study.
*the considered value is zero since the parameter is not applicable for the specific washing method.

Professional washing and drying

In commercial dishwashers, washing is performed with standard temperature (generally higher than 65°C), followed by a rinsing process performed at temperatures higher than 85°C for hygiene reasons (Ferco, 2009). Washing can be performed with different dishwasher types, ranging from undercounter devices to hoods or conveyor-based dishwashers. Generally, two types of commercial dishwashers are considered suitable to be used (and installed) in QSRs in an in-house washing scenario: undercounter and hood-type dishwashers. In general, undercounter dishwashers are smaller, cheaper, with longer cycle time and higher energy and water demand than hood-type machines (Rüdenauer et al., 2011).

Based on data provided by QSRs operators, the type of dishwashers to be installed and used for washing MU items is hood-type. To reflect the different options of hood-type dishwashers in QSRs and the different levels of efficiencies, an average washing scenario is assumed for the baseline comparison. This average washing scenario consists of three options of hood-type dishwashers based on the fabrication year (2011, 2017, 2021), resulting in different demands for electricity, water and chemicals.

Due to limited existing experience with washing processes of multiple-use items in QSRs and limited data availability for washing demands on a per item-basis, each option is weighted equally to define an overall average washing scenario for the in-house washing process.

With respect to drying of tableware after dishwashing, it is often performed using residual heat from rinsing. For plastic items however, drying with residual heat only is not sufficient, but a dedicated drying phase for plastic products is required to ensure completely dried items after washing (e.g., through a combination of drying and ventilation). This is essential for hygiene reasons as omitting the drying phase may lead to cross-contamination or bacterial development in moist environments. Literature information identified for the hood-type dishwashers focuses on ceramic products only. Thus, it must be assumed that plastic item washing and drying in QSRs requires additional energy for a dedicated drying process. According to literature data, drying accounts for approximately 30% of the overall energy demand for washing and drying[5]. Therefore, energy demands reported in literature for the hood-type devices are assumed to reflect 70% and are increased by 30% to model in-house dishwashing of plastic-based multiple-use items, with the exception of Winterhalter dishwashers, which possess dedicated plastic washing and drying programmes that ensure plastic items are completely dry. The reported energy demands are therefore considered sufficient for drying PP products in a QSR context.

Data for modelling detergent, rinse agent and softener demands are retrieved from literature as far as available on a per item basis. Chemical composition is based on (Rüdenauer *et al.*, 2011) and was combined with expert judgement to reflect regulatory and efficiency developments since 2011[6].

The different washing options, along with their LCI data and the resulting overall average used for the baseline comparison, are summarised in **Table 10**. Inputs for the washing and drying processes are energy demand (kWh/item), water demand (litres/item), detergent, rinse agent and softener demand (g/item).

[5] 30% is an approximation based on: 26% reported by EC, JRC (2007), Best Environmental Practice in the tourism sector; 33% reported for Meiko Flight Conveyor Dishwasher by Slater (2017), Energy Efficient Flight Conveyor Dishwashers; 32% reported for Hobart Flight Conveyor Dishwasher by Slater (2017), Energy Efficient Flight Conveyor Dishwashers.

[6] Expert judgement was done by in-house chemists with experience in the sector. Reported compositions for 2011 were deemed outdated due to regulatory restrictions of potassium use.

Table 10: Technical specifications of dishwashers for the inhouse washing and drying scenario (LCI data).

	Hood-type dishwasher			Average washing process
Reference year	2011	2017	2021	
Energy demand* [kWh/item]	0.024	0.014	0.014	0.017
Water demand [l/item]	0.16	0.08	0.23	0.16
Combined detergent, rinse agent and softener demand [g/item]**	0.50	0.17	0.44	0.37
Source	Based on (Rüdenauer *et al.*, 2011)	Based on (Antony and Gensch, 2017)	Based on Winterhalter (2021)	

* including assumption for energy demand for drying, see details below

** 90% of the total is detergent and softener demand, 10% rinse agent demand

1. INTRODUCTION

Ramboll has been appointed by the European Paper Packaging Alliance (hereafter "EPPA" or the Client) as technical consultant for conducting a comparative Life Cycle Assessment (LCA) study related to single-use (SU) and multiple-use (MU) tableware systems for take-away services in Quick Service Restaurants (QSRs), in accordance with ISO standards 14040 and 14044, subjected to internal review conducted by two senior LCA experts of the international Ramboll Decarbonisation (GHG/LCA) Steering Committee and to external third-party review by a panel composed by three independent reviewers.

EPPA is an association representing suppliers and manufacturers of 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.

As anticipated, this comparative LCA study is focused on QSRs *Take-away services* that include:

- drive-through: customers reach the restaurant and order food directly from their cars.
- on-the-go: 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: customers buy food online and it is delivered by means of a courier.

It is understood that this assessment is embedded in an ongoing debate around the environmental performance of single-use and multiple-use products. Consequently, there is already a quite mature body of knowledge concerning several products and applications from either category. However, previous studies adopt a rather product-focused approach in comparative assertions (i.e., comparing single-use cups with multiple-use cups). In these assessments less attention is given to the underlying systems and obtained functions from respective products. **Next to taking into account previous findings this study seeks to adopt a holistic perspective on the comparison of single-use (SU) and multiple-use (MU) products in QSRs**.

1.1 Project framework

1.1.1 In-store LCA study

In 2020, Ramboll has been appointed by EPPA as technical consultant for conducting a comparative LCA study between a single use tableware system and equivalent multiple-use tableware system in Quick Service Restaurants in accordance with ISO standards 14040 and 14044. The main goal of the LCA study was to use a systems-based approach to compare the environmental performance of single-use and multiple-use tableware 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 tableware (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 tableware).*

For the comparative assessment, two fundamentally distinct systems were 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[7] (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 reusable packaging system is an emerging market and only a limited number of pilot projects is currently in place. It is currently being deployed in different countries (e.g., France, Germany) by QSR operators for in-store consumption and it can be assumed that the same reusable tableware system will be used for takeaway

The geographical scope of the baseline comparison was Europe (EU-27 + UK). This geographical boundary was 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 was site-specific or representing average production scenarios (e.g., global, EU).

The study was subjected to a third-party review process conducted by TUV Nord (report n. 35280651 issued on December 16th, 2020).

1.1.1.1 Differentiation with respect to the robustness and reliability of existing studies

- The study adopted a system approach, focused on functions obtained from respective products and their combination through a holistic understanding of the specific context;
- Representative data and assumptions were utilised: functional unit and assumptions were based on industry (EPPA Members) and primary data from representative QSRs operators;
- State-of-the-art data for paper manufacturing processes obtained from EPPA members' (covered market share of QSRs in Europe >65%); Washing process was deeply investigated obtaining data from producers/operators, reflecting QSR specifics;
- An extensive sensitivity analysis was performed: 12 scenarios analysed (9 for MU system; 3 for SU system), including: different recycling rates, different washing scenarios, different EoL allocation approaches.

1.1.2 Meta study for take away services

In 2022, Ramboll performed on behalf of EPPA a meta-study (Ramboll, 2022) 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.

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

[7] the reusable packaging system is being deployed in France by QSR operators for in-store consumption and it can be assumed that the same reusable tableware system will be used for takeaway

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 food home delivery services of QSRs with regard to single-use and multiple-use food containers.

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). This conclusion needs to be tested and confirmed with a specific quantitative assessment by means of a Life Cycle Assessment study. Conclusions of the meta-study conducted by Ramboll on behalf of EPPA (Ramboll, 2022) are reported in **APPENDIX 7. Conclusions of the meta-study conducted by Ramboll on behalf of EPPA (Ramboll, 2022).**

The collected sources of information are used as reference for the development of this LCA study.

2. METHODOLOGICAL APPROACH

The methodological approach comprises a literature screening and a full comparative LCA.

2.1.1 Literature screening

Several sources have been taken into account for this study, including those collected for the meta-study conducted in 2022 by Ramboll on behalf of EPPA (Ramboll, 2022). A non-exhaustive list of sources is reported here:

- 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.
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2.1.2 Life cycle assessment and modelling

Currently, Life Cycle Assessment (LCA) provides the most mature framework for assessing the potential environmental impacts of products and services according to the European Commission (European Commission, 2019). One of the most frequent applications of LCA studies is the comparison of specific goods or services (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

The methodology of LCA applied in accordance with relevant ISO standards 14040 and 14044 is widely recognized as a reliable tool for quantitative assessments from an environmental point of view. The general methodology for LCA aims to assess identified and generated Life Cycle Inventories (LCIs), consisting of quantified elementary flows referring to the functional unit, in relation to their potential impact on the natural environment, human health, and issues related to natural resource use (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

LCA is a four-step methodology. These steps are iterative and involve the following tasks (Guinée *et al.*, 2001):

Goal and scope definition is the first phase of an LCA. The Goal definition must specify:

- The intended application and the type of analysis to be developed.
- The reasons that lead to develop the study
- The type of audience to which it is intended.

The Scope definition must specify:

- The system (or systems) under analysis.

- The function and boundaries of the system under analysis.
- The functional unit, which is the quantification of the function of the system, to be used as a reference for the input and output elements.
- The quality of the data, as well as the assumptions and limitations of the study.
- The allocation procedures.
- The selected methodology for Life Cycle Impact Assessment (LCIA) and the type of impacts.

The second phase of any standardised LCA is the Life Cycle Inventory (LCI). In this phase, all the environmental burdens connected to a good or a service are identified and quantified, preparing an inventory related to the entire life cycle. A discrete number of process units are identified within the system, and inputs and outputs are quantified for each of them (including transport).

The identified environmental burdens are distinguished in:

- Generated burdens:
    - Direct, which come from the activities under analysis.
    - Indirect, which come from the production, transport and auxiliary processes needed to carry out the activities under analysis.
- Avoided burdens (credits), obtained through “savings” (avoided production) of materials and energy related to the activities under analysis.

The environmental burdens quantified in the LCI are then "translated" into environmental impacts in the Life Cycle Impact Assessment (LCIA) phase. The purpose of this third phase is to identify and quantify the environmental impacts caused by the system under analysis, highlighting the extent of the changes that are generated as a result of the consumption of materials and energy, as well as emissions into the environment.

The impact assessment consists of five elements, the first three of which are mandatory according to the ISO 14040 standard. The mandatory steps are:

1. Selection of impact categories representative of the assessment parameters that were chosen as part of the scope definition.
2. Classification of elementary flows from the inventory by assigning them to impact categories according to their ability to contribute by impacting the chosen indicator.
3. Characterisation using environmental models for the impact category to quantify the ability of each of the assigned elementary flows to impact the indicator of the category (Hauschild, 2017). The obtained characterised indicator scores are expressed in a common metric for the impact category. This allows aggregation of all contributions into one score, representing the total impact that the system has for that category. The collection of aggregated indicator scores for the different impact categories (each expressed in its own metric) constitutes the characterised impact profile of the system.

Optional steps in LCIA:

1. Normalisation is used to provide a normalised impact profile of the product system in which all category indicator scores are expressed in the same metric.

2. Grouping or weighting supports comparison across the impact categories by grouping and possibly ranking them according to their perceived severity, or by weighting them using weighting factors that for each impact category gives a quantitative expression of how severe it is relative to the other impact categories.

Fourth and last phase of an LCA is the Interpretation, which consists in the development of critical analysis of the results to draw conclusions for the improvement of the environmental performance of the analysed system. Main objectives of this phase are:

- The assessment of significant aspects (such as, main environmental results and critical methodological choices).
- The assessment of the reliability of the results (e.g., through sensitivity analyses).
- Provide possible recommendations to improve environmental performances/mitigate environmental impacts.

An attributional Life Cycle Assessment (LCA) study according to the ISO 14040/44 standards is carried out. The attributional approach allows accounting for impacts directly related to the system of interest and attributing them to the activities within the system in a current perspective. Key parameters and environmentally important life-cycle stages of the systems are identified and analysed. Further, the influence of certain key variables for the results is evaluated.

The LCA model for this study is developed with open LCA software[8], using background data from Ecoinvent[9] (version 3.8) and scientific literature, primary data from EPPA and QSRs operators, and available public or commercial extension databases. Details are given in the following sections.

2.1.2.1 Background of the selected methodological approach

According to the revised recommendation adopted in December 2021 by EU Commission[10], Environmental Footprint (EF) is the suggested method to measure and communicate the life cycle environmental performance of products (PEF, Product Environmental Footprint) and organizations (OEF, Organization Environmental Footprint).

However, PEF method is not fully applicable to the systems to be investigated due to different reasons. As a matter of example, the following limitation have been highlighted:

- PEF studies are mainly intended for a product level approach, while this study is focused on a system approach;
- PEF Guide is not intended to directly support comparisons or comparative assertions (i.e., claims of overall superiority or equivalence of the environmental performance of one product compared to another (based on ISO 14040);
- PEF category rules (PEFCRs), which allow methodological harmonisation and reproducibility for a given product-type, are currently available only for intermediate paper products, while this study considers SU paper-based items; Moreover, PEFCRs for plastic products are not currently available;

However, this study is carried out considering some relevant PEF study features:

[8] openLCA.org
[9] ecoinvent v3.8 – ecoinvent
[10] Recommendation on the use of Environmental Footprint methods (europa.eu)

- The Life Cycle Impact Assessment of this study will refer to EF impact categories;
- The contribution to the total impacts is further carried out by presenting "Impact categories cumulatively contributing at least 80% of the total environmental impact (excluding toxicity related impact categories)" as reported in the Product Environmental Footprint Category Rules Guidance (version 6.3)[11].

[11] PEFCR_guidance_v6.3.pdf (europa.eu)

3. GOAL AND SCOPE OF THE STUDY

3.1 Goal of the study

The following sections highlight the general goal of the study. To this aim, reasons for carrying out the study are presented, as well as intended audience and application.

3.1.1 Intended application

The intended application of this study is the comparative evaluation of the environmental performances of two systems (one based on single-use items, and one based on multiple-use items) for take-away services in Quick Service Restaurant.

3.1.2 Reasons for carrying out the study

In recent years there has been a surge in evaluating reusable packaging for food and beverage containers for in-store consumption and take-away services. However, this is often done by applying a product-vs-product perspective rather than a system approach.

The aim of the study is to perform a comparative Life Cycle Assessment between the utilization of single-use and multiple-use tableware for take-away services in QSRs, for the following reasons:

- QSR restaurants operate under a standardized system that is long- established, quantifiable in robust data, and geographically sensitiveness. It also provides a referential for best-in-class dishwashers in the HORECA (*hotellerie-restaurant-café*) sector
- Take-away services cover more than half of the total sales from QSRs (as reported by the main QSRs operators). This figure may also have increased further recently, due to the pandemic and the spread of delivery services;
- It might be general opinion that reusable products and containers are inherently and intuitively more environmentally sustainable. However, there might be evidence that the actual environmental performance between single-use and multiple-use products could be counterintuitive and could be, moreover, very dependent on the application context (e.g., in-house consumption in QSRs or take-away services with specific demands on food and beverage containers, geographical context, etc.).

3.1.3 The intended audience

The intended audience is mainly that of QSR operators, companies active in the production of SU and MU items for QSRs, consumers and policy makers.

3.1.4 Potential utilisation of results in comparative assertions

When using this LCA for external communication purposes it is crucial to acknowledge and highlight that this is a tailor-made and case-specific ISO-compliant comparative assertion (e.g., several specific modelling choices are applied - which are transparently documented and explained). As a consequence, results from this study are not directly comparable with other sources and results.

3.2 **Scope of the study**

The following sections highlight the general scope to achieve the goal presented in the previous section. Therefore, general function of QSRs, specific functioning of QSRs in the context of LCA system boundaries and functional unit are described, as well as geographical scope, cut-off criteria, LCIA methodology, data quality requirements, End-Of-Life allocation approach, assumptions and limitations on a system level, normalization and weighting, and critical review process.

3.2.1 General functioning of Quick Service Restaurants

QSRs are a specific classification of restaurants and entail certain high-volume food and beverage operations. The following inherent features are deemed relevant when discussing and assessing in-store or take-away consumption of foodstuff and beverages and the hypothetical shift from single-use food and beverage containers to multiple-use equivalents:

- A high number of menus, drinks and food items served per day;
- Demand for food and beverages occurs at two daily key peak times representing around 80% of all the orders;
- Menus are easily and quickly prepared;
- Hygiene and food safety are to be at the highest level;
- Tableware should be recyclable, easy to transport and security providing: multi-use plastic would therefore be the base-case material responding to all imperative;
- Menus may be changed frequently (e.g. dedicated offering for breakfast);
- Specific products require individual labelling (diet beverages, meat-free, etc.);
- The entire offering is available and equally processed for either immediate in-store consumption or take-away
- Take away services (drive through, on-the-go, click and collect, home delivery) has fast grown (double digit) over the last few years representing up to 50% of the total sales;
- The restaurants are open 365 days per year and opening hours can be up to 24/7;
- Food preparation and service are labour intensive in which both skilled and unskilled staff are needed;
- City restaurants are typically small, with limited seating and without the necessary separate rooms or areas to deal with used tableware or to accommodate dishwashers, dryers or extra storage space;
- Larger out-of-city restaurants have optimised kitchen and serving spaces;
- Food affordability is expected and critical for a large part of restaurant’s users;

While some of above aspects can be implemented into the framework of LCA (e.g., in terms functional unit and assumptions), others may not be reflected in the quantitative assessment due to methodological constraints (e.g., space requirements).

3.2.2 Specific functioning of Quick Service Restaurants in the context of LCA

LCA is by definition the environmental assessment of the fulfilment of needs focusing on functions first and then on the products and processes needed to provide these functions (Hauschild, 2017). Consequently, the functions are to be described from the perspective of a QSR. The definition of an appropriate function is particularly delicate in comparative assessments because a comparison is only fair and meaningful if the compared systems provide (roughly) the same function(s) to QSRs. To facilitate a fair and relevant quantitative assessment of alternative ways of providing a function, specific knowledge of the functions provided by the alternative product systems (single- and multiple-use) must be used to define a functional unit. It is understood that supply chains, facilities and infrastructures, restaurant capacities, work routines and operating cycles, product labelling, and traditionally high hygiene standards have been shaped by the use of single-use food and beverage containers.

In order to provide a holistic perspective and to not systematically delimit the scope and functions from the outset, it is proposed to examine the entire operations of an average sized QSR in Europe under current circumstances (i.e., utilization of single-use food and beverage containers and using most recent data (2019)) and future circumstances, based on policymakers' announcements, future legal requirements and industry commitments. This approach is based on data provided by QSRs operators, and it is considered reasonable due to the following key aspects: 1) usually, the size of QSRs can vary only in a limited range; 2) the composition of the average serving is independent of the size of the QSR: this means that the functional unit would remain the same, and the same differences would apply to both SU and MU systems.

In any case, there are many constraints in such complex systems, leading to a high number of possible different variables, thus a certain number of assumptions (based on primary data and realistic cases) are necessary, leading to the definition of an average situation that can be varied and tested through the sensitivity analysis.

This holistic perspective ensures comparability of both situations as the integral function(s) are assumed to remain unchanged, i.e., the purpose and business models of QSRs are maintained. Moreover, in comparative assessments it is justified and common practice to exclude identical processes if they are assumed to be not affected by the imposed change (i.e., they deliver identical quantities of services) (Hauschild, 2017). This arguably holds true for many processes associated with the current and hypothetical operation of an average QSR. Consequently, attention is given to relative changes (i.e., substitution, supplementation, displacement, enablement, induction, etc.) of involved processes and product items. Subsequent identification of systemic changes as well as the description of processes and product items is guided by this fundamental understanding. Therefore, only products and processes assumed to be altered due to the hypothetical situation in QSRs will be investigated and assessed. This means that many processes and material or energy flows associated with operating a QSR will not be assessed (e.g., production value chains of food and beverages to be served). In this context it is stressed that only the selection of processes and product items to be included in the assessment will be elaborated and justified, meaning that all other potential processes are excluded without further describing or listing them in an extensive manner.

3.2.3 System boundaries

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

- current system for take-away services from QSRs based on single-use (disposable) products made of paperboard with a PE content < 10% w/w (also referred to as single-use product system) and related transport from/to QSRs;
- expected[12] system for take-away services from QSRs based on equivalent multiple-use products (also referred to as multiple-use product system) and respective processes and operations (transport from/to QSRs, inspection, washing at home and/or in-store, take-back system).

In accordance with the ISO 14040/44 standards, the equivalence of the two distinct systems (single-use and multiple-use) is evaluated. This applies to the performance (i.e., the functions obtained from respective products), system boundaries, data quality (i.e., equivalent and appropriate implementation of foreground and background data), allocation procedures and impact assessment categories of respective product systems. Given the context of this study, the transition from single-use to multiple-use product systems for take-away services deserves particular attention.

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. Indeed, these boundaries and identified processes might be affected by different levels of uncertainties and may be subject to future modification.

Processes of the life cycle are divided in three life cycle stages: upstream, core, and downstream (see **Figure 6**).

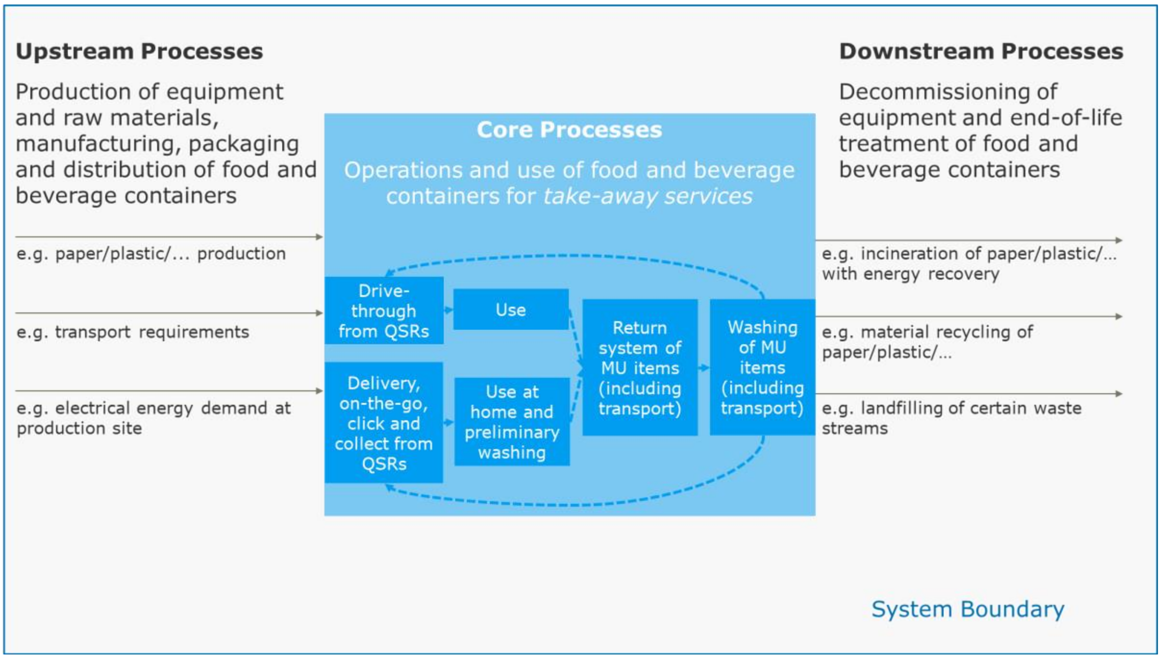

Figure 6 Schematic system boundary and differentiation between upstream, core, and downstream processes of take-away services from the perspective of a QSR (Source: own depiction)

[12] the reusable packaging system is in place and being deployed in France by QSR operators for in-store consumption and it can be assumed that the same reusable tableware system will be used for takeaway

Based on information provided by QSR operators (via specific questionnaires), as well as 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) system for take-away services could use plastic products (for MU system) as suggested also by the analysis of commercial publications related to QSRs and other types of restaurants[13,14,15,16,17]. No literature data regarding take-away services using glass/ceramic items in the specific case of QSRs have been identified.

3.2.4 Functional unit

The functional unit is:

Take-away services (drive through, on-the-go, click and collect, home delivery) of foodstuff and beverages with single-use or multiple-use tableware (including cups, lids, containers, cutlery, carriers and bags) in an average QSR for 365 days in Europe in consideration of established facilities and hygiene standards and take-away services specific characteristics (e.g., selling channels, distances, means of transport).

Based on the outcomes of the previous in-store LCA study (Ramboll, 2020) and meta-study (Ramboll, 2022), the following potentially relevant parameters been identified:

- Characteristics of SU and MU items (weight, dimensions, material);
- Number of servings;
- Number of uses for MU items;
- Additional packaging;
- Return rate;
- Return rate scheme (including: type of take-back system; Distance; Means of transport; type of preliminary washing at home; Weight optimization; Control and inspection; Application of specific taxes/fees);
- Type of professional washing;
- Additional items for QSRs effective functioning;
- Improper disposal.

In order to have robust and reliable sources of data related to these potentially relevant parameters, Ramboll carried out a specific literature review and in addition performed a specific data gathering (via datasheets, questionnaire) to QSRs operators. All collected information have been included in the following tables.

3.2.4.1 Incorporated product items

The LCA study takes into account the life cycles of:

- **8** different products for the single-use system, made of paperboard (if coated, PE content is < 10 % w/w);

[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
[17] Source: https://packagingeurope.com/news/burger-king-partners-with-loop-to-trial-reusable-packaging-for-burgers-sides-and-drinks/8146.article

- **6** different products for the multiple-use system, made of PP; and
- **3** products (cup holder, bags for transport of fries and delivery bags) considered for both single-use and multiple-use systems: even though these products are intended for single-use, it is understood from information gathered from relevant stakeholders that these items would not be replaced by equivalent function multiple-use items.

Table 11 summarises the relevant specifications of the different product items.

Table 11: Single-use and multiple-use product specifications

Function within take-away services	Single-use (SU) product item[18]	Material of SU item[19]	Dimensions/ volume of SU item[20]	Product weight of SU item[21]	Multiple-use (MU) product item[22]	Material of MU item[23]	Product weight of MU item[24]
Serving of cold drinks	Cold drink cup (PE content < 5 % w/w)	Virgin-fibre bleached board with PE coating on the reverse side / virgin-fibre board with fully coated top side and a PE coating on the reverse side	40 cl	9.8 g	Cold drink cup	PP	76 g (40 cl)
Spillover protection of cold drinks	Clip-on lid (PE content < 10 % w/w)	Virgin-fibre bleached board with partly PE coating on the reverse side	Ø89.4 mm	5.3 g	Lid for cold drink cup	PP	7 g
Carrier for cold drinks cups	Cup holder	Moulded fibre	-	13.2 g	Not replaced	Same as SU	Same as SU
Serving of burgers	Clamshell	Partially recycled cartonboard (only post-industrial white recycled fibres)	94x94x70 mm	15.6 g	Clamshell	PP	117 g (Ø150 mmx67.5 mm)
	Paper wrap	Virgin-fibre oil and grease-resistant bleached paper with ecological (soy-based) barrier coating	40x30.5 mm	29.5 g/m²			
Serving of fries and snacks	Fry bag (box)	Partially recycled cartonboard (only post-industrial white recycled fibres)	90x41x119 mm	7.5 g	Basket	PP	35 g
	Paper fry bag	Virgin-fibre oil and grease-resistant bleached paper with ecological (soy-based) barrier coating	11.2x11.2 mm	38 g/m²			
	Bag for fries' transport	Recycled brown paper bags	-	6.3 g	Not replaced	Same as SU	Same as SU
Serving of cold desserts	Ice cream cup (PE content < 5 % w/w)	Virgin-fibre bleached board with PE coating on the reverse side / virgin-fibre board with fully coated top side and a PE coating on the reverse side	Ø89.7x102 mm	9.8 g	Dessert cup	PP	54 g
Provision of cutlery	Cutlery (1 item)	Thin pressed wood (e.g., birch, bamboo)	-	3 g	Cutlery (1 item)	PP	3 g

[18] Information provided by EPPA members
[19] Information provided by EPPA members
[20] Information provided by EPPA members
[21] Information provided by EPPA members
[22] Information provided by EPPA members
[23] Information provided by EPPA members
[24] Information provided by EPPA members

Function within take-away services	Single-use (SU) product item[18]	Material of SU item[19]	Dimensions/ volume of SU item[20]	Product weight of SU item[21]	Multiple-use (MU) product item[22]	Material of MU item[23]	Product weight of MU item[24]
Bags for transport	Delivery bag	Recycled brown paper bags	32x18x26 cm	75 g	Not replaced	Same as SU	Same as SU

.

The list of main processes involved in the value chain for *take-away services* is reported in **Table 12**. These life cycle stages are used to present LCIA results.

Table 12 Processes involved in the packaging value chain for *take-away services.*

Life cycle stage	Single-Use System	Multiple-Use System
Raw material production and processing (upstream)	• cradle-to-gate production of uncoated cartonboard • cradle-to-gate production of thin greaseproof paper • cradle-to-gate production of thin pressed wood • cradle-to-gate production of PE-coated paperboard • intermediate transports from pulp producers to paper manufacturers • treatment of production wastes at paper mills	• cradle-to-gate production of multiple-use product items • intermediate transport processes • dispatch packaging
Converting (upstream)	• gate-to-gate production of single-use product items • cradle-to-gate production of auxiliary materials and products • transport from paper producers to converters • transport from suppliers of auxiliary materials and products to converters • dispatch packaging	*Included above*
Distribution of product items to QSRs (upstream)	• transport from converters to QSRs	• transport from manufacturers to QSRs
Use stage (core)	*Not applicable*	• preliminary washing/cleaning • transport back to QSRs • professional washing and drying • cradle-to-gate production of detergent, rinse agent and softener • municipal wastewater treatment
End-of-life treatment (downstream)	• transport to incineration, recycling and landfilling plant • post-consumer and post-industrial (e.g., trimmings at converters) paperboard, PE, and wood in waste incineration plant • recycling of sorted post-consumer paperboard waste from customers and production	• transport to incineration, recycling and landfilling plant • post-consumer PP in waste incineration plant • recycling of sorted PP post-consumer waste • landfilling of PP

Life cycle stage	Single-Use System	Multiple-Use System
	wastes (i.e., trimmings) from converters • landfilling of post-consumer paperboard and PE	
Avoided material production (downstream)	• cradle-to-gate pulp production (e.g., sulphate pulp, sulphite pulp, TMP, CTMP)	• cradle-to-gate PP production
Avoided energy production (downstream)	• cradle-to-consumer electricity grid mix • cradle-to-consumer thermal energy from natural gas	• cradle-to-consumer electricity grid mix • cradle-to-consumer thermal energy from natural gas

3.2.5 Geographical Scope

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., means of transport) 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).

3.2.6 Cut-off criteria and exclusions

In accordance with the LCIs of multiple-use items received from QSRs and with the LCIs and LCIAs of paperboard products received from producers and converters, the following cut-off rules and exclusions are considered:

- Items corresponding to 1% or more of total items used for take-away services (based on confidential QSRs data) are included;
- Construction of dishwashers and ancillary infrastructures are excluded;
- Materials corresponding to 1%w or more of total raw materials used are included;
- Construction of pulp and board mills and machinery are excluded;
- Symmetric transport stages related to SU and MU systems.

3.2.7 LCIA methodology and Impact categories

This study presents LCIA results with the Environmental Footprint (EF) 2.0 impact categories (European Commission, EF 2.0 reference package, June 2018)[25]. Even though EF 3.0 is now available, the choice of EF 2.0 is justified by the fact that some of the primary data collected is not compatible with EF 3.0. Mid-point impact categories are used due to the last recommendation (December 2021) of the EU Commission, which suggested to make use of EF methods to measure and communicate the life cycle environmental performance of products. **Table 13** reports the EF set of impact categories used in the model.

[25] https://eplca.jrc.ec.europa.eu/permalink/Guide_EF_DATA.pdf Note: this version of EF (2.0.) is used to be consistent to Stora Enso's LCIA results.

Table 13: List of selected EF impact categories (source: PEF guide[26])

EF Impact category	EF Impact Assessment Model	EF Impact Category indicators
Acidification	Accumulated Exceedance (AE)	mol H+ equivalent
Climate Change, total **(it includes 3 sub-categories: Climate Change, fossil, Climate Change, biogenic, Climate Change, land use and land use change)**	Radiative forcing as Global Warming Potential (GWP100)	kg CO2 equivalent
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N equivalent
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P equivalent
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235 equivalent
Ozone Depletion	Ozone Depletion Potential (ODP)	kg CFC-11 equivalent
Particulate matter	Impact on human health	disease incidence
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC equivalent
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb equivalent

Regionalized impact assessment is a relatively novel field in LCA, thus the implementation of water assessment via Water use impact category in the EF methodology could be subject to some limitations[27]. As sources of uncertainties still remain in the application of the "available water remaining" (AWaRe) methodology in the EF Water use impact category, results in this impact category of this study could be therefore seen as potentially uncertain. This can be seen as a limitation in this study. For this reason, water consumption is assessed by means of the ReCiPe 2016 midpoint (H) impact method, as reported in **Table 14**. This is chosen as it is generally recognised as a robust LCIA methodology (Dekker et al., 2019).

Table 14: Additional impact category for water consumption (ReCiPe 2016 v1.1, see Huijbregts *et al.*, 2016)

ReCiPe 2016 midpoint (H) Impact category	ReCiPe 2016 midpoint (H) Impact Assessment Model	ReCiPe 2016 midpoint (H) Impact Category indicators
Water consumption	Water consumption potential	m^3 water consumed

Some EF impact categories (i.e., ecotoxicity freshwater, human toxicity carcinogenic, human toxicity non-carcinogenic, land use[28]) are excluded since primary data of some paperboards (LCIAs) used in the SU system in this study is not compatible with these categories. This

[26] https://ec.europa.eu/environment/eussd/smgp/pdf/PEF%20webinar%20Nov%202020_Data%20and%20Impact_Final_.pdf

[27] See, e.g., https://sphera.com/wp-content/uploads/2022/02/Introduction-to-Water-Use-Assessment-in-GaBi-2022.pdf

[28] Database EN 15804 will be able to calculate LANCA results, and it might be used in the future as further improvement of the project.

approach is in line with the current PEFCR[29] guidelines for paper intermediate products, which suggest the exclusion of toxicity related impact categories and land use impact category when calculating the most relevant impact categories cumulatively contributing to at least 80% of the total environmental impact.

Moreover, biodiversity impact category is not described by the PEF methodology, and impact categories from the PEF have been chosen in this study. Therefore, no biodiversity impact category is included in this study.

3.2.8 Data quality requirements

According to ISO 14044 data quality requirements must be included for the following aspects:

- **Time-related coverage:** Primary datasets and inventories are not older than 2019. Crucial life cycle stages and processes refer to the most recent literature or otherwise publicly available information and have been discussed with market experts in order to ensure applicability. At the time of modelling latest available secondary data is implemented for background processes.
- **Geographical coverage:** In general, all data and assumptions refer to an average EU context (see section 3.2.5), as long as data availability allows. Geographical coverage is dependent on the available data. For the multiple-use system the geographical coverage is therefore dependent on available secondary data. Similarly, several life cycle stages within the single-use system are dependent on the provided primary data. Hence, upstream processes of the single-use system refer to the respective production sites of provided data. Therefore, the raw material production and processing stage entails Finland, Austria, and Slovenia. These countries are major paper producers in the EU and therefore the data is considered applicable for an average EU context. Similarly, converting data refers to production sites in Germany, Finland and France. These countries represent a typical EU average value chain for single-use product items. In addition, background processes for the converting stage are based on EU average datasets. All other life cycle stages as well as the multiple-use system are based on EU-average background data to the extent possible. In particular, processes of importance for the overall results (e.g., energy provision, recycling processes, avoided material and energy production) refer to average EU conditions. Geographical coverage of primary and secondary data is disclosed in the respective inventories in **APPENDIX 1. Life Cycle Inventory**.
- **Technological coverage:** Primary data and information covers state-of-the-art paper production and converting and is therefore considered representative of the near future. For environmentally significant processes (e.g., dishwashing) a technology mix is proposed, and underlying assumptions and data are documented transparently. Other secondary data represents average technologies used in the EU.
- **Precision:** Representative and precise primary data is used to the extent possible. The influence of unavoidable variability in key parameters (e.g., concerning electricity demand for dishwashing) is tested by means of sensitivity analyses.

[29] https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Intermediate%20paper%20product_Feb%202020.pdf

- **Completeness:** In general, completeness of data is achieved through the iterative process of data collection and modelling. Data gaps are disclosed transparently but not expected to have significant influence on the results. Validation checks (e.g., mass or energy balances) are performed.
- **Representativeness:** The degree to which data and assumptions reflects an average EU situation is addressed under time-related, geographical, and technological coverage. The study represents whole systems comprised of clearly defined product items.
- **Consistency:** Consistency in the assumptions, modelling choices, and the selection of data sources is of utmost importance for this comparative assessment. In the absence of unambiguous data or references for critical assumptions (e.g., recycling rates) equal assumptions are applied to both systems. The LCA methodology is uniformly applied to both systems and sub-systems, and it is ensured that modelling and methodological choices do not affect the results and conclusions.
- **Reproducibility:** Primary data is confidential, but context information and reference flows are disclosed to the extent possible. All other assumptions as well as implementation of secondary data is documented in a way that allows for reproduction of the underlying models.
- **Uncertainty of information:** Remaining uncertainties are addressed by means of an uncertainty analysis.

3.2.9 End-of-Life allocation approach

For the End-of-Life (EoL) allocation, the system expansion methodology (i.e., avoided burden method) is utilised as baseline in this study. A sensitivity scenario via Circular Footprint Formula is further presented.

To the aim of correctly assessing the EoL approach, a reliable point of substitution (PoS) needs to be taken into account. PoS corresponds to the point in the supply chain where secondary materials substitute primary materials. In this study, the following approaches to paper and plastic materials are considered:

- Paper product: the PoS (functional equivalence) where secondary materials substitute primary materials in the paper production process is at the stage of the process where the pulp manufactured from recovered paper is introduced (as wet pumpable pulp) to the paper machine. At this point, the recovered pulp can be assumed to replace pulp manufactured from virgin fibres. However, an integrated pulp and paper mill producing and utilising recovered pulp would not be able to produce virgin pulp (the processes and equipment requirements for recovered pulp and virgin pulp production are extremely different). The mill could however utilise market virgin pulp. The wet pumpable recovered pulp is therefore assumed to substitute dried market virgin pulp in the baseline scenario. This approach is in line with the current PEFCR[30] guidelines for paper intermediate products (see **APPENDIX 2. Life Cycle Inventory - Wastepaper recycling**).
- Plastic products: one plastic grade is considered in this study, i.e., virgin PP. The PoS for plastic product is identified at the level of recycled polymer granulate replacing virgin polymer resin of the same material, in accordance with the Plastic LCA method (Nessi *et*

[30] https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Intermediate%20paper%20product_Feb%202020.pdf

al., 2021). In this study the PoS is set at the secondary granulate after the recycling process.

3.2.10 Assumptions and limitations at systems level

In this section overarching assumptions referring to the whole study or either one or both systems are documented. Further assumptions on a product or process level are documented in the respective sections in section 4. In principle, LCIA results are relative expressions and selected impact categories covered by LCIA methods cannot display all potential environmental implications associated with respective systems. A further limitation of this study refers to the assessment of the hypothetical situation as both primary data and background data (e.g., electricity from grid) from databases are retrospective. Therefore, the hypothetical situation is primarily defined by assumptions and system characteristics. Representativeness is ensured and time-related coverage is transparently documented.

Primary and secondary data gathered from certain reference facilities or taken from databases represent specific applications and do not necessarily cover all addressed markets (i.e., average European context). Thus, site-specific implications and parameters might influence the overall results have to be taken into consideration when transferring results to other contexts (e.g., other geographical scopes).

The recommendations derived from the LCA study are solely based on the evaluation of environmental aspects. Thus, other equally relevant aspects (e.g., economic effects of transitioning from single-use to multiple-use product systems) are out of scope of this LCA study.

Additional assumptions of the ones reported in section 3.2.6 are taken:

- Bags and cup holders are considered equally present for the two systems (both in terms of materials and amount). In fact, based on relevant stakeholders' comments, these items would not change when shifting to the multiple-use system. Anyway, for sake of transparency, these items are included in the study, even though their effects are symmetrical for both SU and MU systems.
- The production value chains of food and beverages to be served are excluded from this assessment as it is assumed to be identical for both systems;
- Potential effects on the storage of food or food waste (e.g., leftovers) or waste from the preparation of the food are assumed to be equal in both systems and therefore neglected;
- Potential differences in the working time for handling used multiple-use tableware as well as labour costs due to the demand for sufficient and trained staff (e.g., to load and unload in-store dishwashing machines) are neglected for the purely environmental comparison (i.e., conservative approach to future situation);
- Space requirements for additional machinery or storage of multiple-use products are neglected for the purely environmental comparison; this also represents a conservative approach to the future situation since in multiple-use system QSRs are expected to re-arrange internal logistic and additional space may be needed;
- Packaging for auxiliary materials such as detergents and chemicals for the dishwashing process is excluded from the assessment;

- Potential plastic leakage through littering into the environment (e.g., freshwater ecosystems) cannot be adequately addressed by the underlying methodological possibilities of LCA (Federal Environment Agency Germany, 2019).
- Based on primary information of actors within the value chain of single-use products, it is acknowledged that several industry actors have made ambitious commitments concerning e.g., energy efficiency and increased sourcing of renewable electricity for respective production processes. Evidently, these commitments will have a significant impact on the actual environmental performance of the whole single-use system and are therefore vital when assessing and interpreting a hypothetical scenario. However, due to the lack of equal primary information on environmental commitments of plastic producers and/or actors involved in the hypothetical multiple-use system (e.g., dishwashing providers), the baseline assessment will solely be based on current production efficiency reflected in primary data provided by respective actors in combination with e.g., average electricity grid mix provision in the respective countries of production. This approach ensures both comparability between both systems and transferability of results to other producers and actors within both value chains. Moreover, this approach facilitates that site-specific inventories are translated into rather generic and average scenarios which can be compared in a system mostly adhering to secondary data.

3.2.11 Normalization and weighting

According to ISO 14040, normalization and weighting of midpoint impact categories are optional parts of the life cycle impact assessment procedure. However, in this study, the contribution to the total impacts is carried out by presenting "Impact categories cumulatively contributing at least 80% of the total environmental impact (excluding toxicity related impact categories)" as reported in the Product Environmental Footprint Category Rules Guidance (version 6.3).

3.2.12 Critical Review

According to ISO 14040/44, a panel review has been appointed to evaluate this study.

The review panel is composed by the following reviewers:

- Michael Sturges (lead panelist) - RISE Research Institutes of Sweden / RISE Innventia AB, Sweden – a life cycle assessment practitioner with specific experience of environmental studies relating to the packaging and food service sectors.
- Prof. Umberto Arena – University of Campania "Luigi Vanvitelli", Italy - a chemical engineer with experience of packaging systems, including LCA studies on valorization of paper and plastic waste streams.
- Frank Wellenreuther, ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH, Germany – a life cycle assessment practitioner with specific experience of environmental studies relating to packaging systems.

The complete critical review statement is reported at **Section 7** *CRITICAL REVIEW STATEMENT*

4. LIFE CYCLE INVENTORY

In this section, the main assumptions and calculations referring to the life cycle of each of the systems or single items and processes within respective systems are documented. Moreover, relevant process parameters as well as identified data gaps are disclosed. Reference flows, specific datasets for all product systems as well as necessary processes and complete LCIs for both scenarios listing input/output values is disclosed in the **APPENDIX 1. Life Cycle Inventory** (under consideration of confidentiality issues).

4.1 Product systems

The LCI covers single-use and multiple-use items fulfilling similar functions to serve food products for take-away services from QSRs. Single-use items are based on primary data provided by EPPA members and their suppliers and cover a typical set of items for take-away services. For the hypothetical multiple-use scenario, items produced from plastic are used as alternative options to fulfil similar functions compared to their established single-use equivalents. Data for the MU scenario is obtained from primary sources (QSRs) and secondary sources (literature and Ecoinvent database). **Table 11** in section 3.2.4.1 lists an overview of the items used in the single-use and multiple-use system.

4.2 Data sources and data quality assessment

This section provides a detailed and transparent description and discussion of data quality, assumptions, allocation procedures, data gaps, and accompanying calculations. Necessary data and information are collected through different sources and hence can be classified as:

- **Primary data:** data collected/measured directly by a company, e.g., raw material demand, energy (electricity, natural gas, etc.), wastes (emissions as well as solid waste) inputs and outputs for a particular process or product, as well as specific data for the use stage in take-away systems, such as distribution channels repartition, type of washing and type of dishwashers, number of reuses of a product, return rates, means of transport and distances covered. Also, data from scientific papers in Q1 journal with high level of consistency. Data are collected and maintained by subject-matter experts such as material and product engineers, research and development managers, or LCA experts.
- **Secondary data:** data collected through other types of publications, scientific literature, statistics, and LCI databases.

Primary or secondary data comprises full LCI datasets/LCIA results, input-output tables (e.g., bill of materials), and certain reference flows or values.

4.2.1 Data collection from industry

Primary data collected from manufacturers is either through LCIA results or own modelling of received input/output sheets (i.e., connecting reference flows and values with applicable datasets and flows from LCI databases) implemented in the LCA model. All data and information received from companies are checked for applicability, completeness, consistency, and plausibility. Data and information obtained are disclosed to the extent confidentiality reasons allow.

4.2.2 Data collection from quick service restaurants

Primary data and information obtained from EPPA is also reflected in the functional unit and disclosed to the extent confidentiality reasons allow. Moreover, primary information from operators is used to substantiate and validate crucial assumptions. EPPA members' market shares cover more than 65% of QSRs in Europe. The incorporation of representative data and information with regard to the functional unit, inventory data as well assumptions around the systems can be seen as a distinctive feature compared to other assessments within this field of research.

4.2.3 Data collection from literature sources and LCI databases

In case primary data is not available or accessible, secondary data from literature or LCI databases are incorporated and documented in detail. As is common practice in comprehensive LCA studies, LCI datasets (e.g., electricity from grid) are required to integrate primary information from e.g., input-output sheets for processes. Moreover, it is assured that the use of secondary data is applicable and representative in light of the goal and scope of this assessment.

4.3 **Paper and Polypropylene waste from QSRs – analysis of data and assumptions for End-of-Life**

The present LCA study compares two different serving systems, so-called:

- Single Use System: made predominantly of paper and residually of paper coated (PE) items (with PE coating <5 w/w)
- Multiple Use System: made of PP items.

It is widely acknowledged that both paper (coated or non-coated) and plastic (especially polyolefins such as PP) items are potentially recyclable. However, beside technical feasibility of recycling processes, there are several factors that can affect the overall recycling rates of these items in the take-away services, such as:

- Contamination with food and beverage residues.
- Customers' behaviour towards the correct disposal.
- Presence of suitable systems for separate collection of wastes in public places.
- Separation shares at home (which can be assimilated to a Business-to-Customer service) and in the QSRs (which works as a Business-to-Business service).
- Characteristics of the waste management network and value chain in the specific geographical context, such as:
    - Availability of suitable treatment plants.
    - Sorting and recycling rates at treatment plants.
    - Presence of a market for recycled material.

4.3.1 General fate of QSR paper and plastics waste generated by take-away orders

It can be assumed that take-away orders are taken out of QSR and consumed in public spaces and at home. As such, the main locations in which the focus waste streams are generated will correspond to these places of consumption. In addition, it cannot be ruled out that a considerable share of take-out orders is consumed in the direct vicinity of the QSR (e.g., in parking space), after which the focus waste streams are discarded in bins belonging to the QSR.

Consequently, the main waste streams from QSR take-away orders are the following:

- Mixed household waste.
- Mixed municipal waste from public spaces.
- Separated paper and plastic waste from households.
- Separated paper and plastic waste from public spaces.
- Paper and plastic waste redirected into the waste management channels.

While it is possible to estimate in a qualitative manner the fate of the focus waste streams, it will be difficult to determine the exact distribution of the shares of the focus waste streams over the different fates:

- Especially data on the share of the focus waste streams discarded in public spaces versus those discarded at home was not found.
- Reliable data on the share of separately collected plastics and paper in public spaces was not found.
- Some data on the share of the focus waste streams which is collected separately from households has been identified but these are subject to considerable uncertainties.
- Data on the share of the focus waste streams generated from take-away orders but discarded in QSR is not available.

Given the uncertainties as presented above it should be also considered that shares of separately collected plastics and paper in public spaces across the EU will vary greatly due to differences in management of public waste among Member States.

Considering the perimeter of the Study (EU average), the main publicly available data regarding recycling rate of waste streams is **data from Eurostat**[31], that refers to overall packaging waste streams (including Paper and Plastic packaging). When considering rates for the SU system, on the one side, Eurostat reports recycling rate for "paper and cardboard packaging" (**82.9%**), but it is clear that this value could be highly affected by cardboard share, which is associated to very high recycling rates, and it cannot be representative for the study. On the other hand, recycling rate for plastic packaging reported by Eurostat (**41.8%**) includes all types of polymers and both commercial/household streams, whose consideration does not completely reflect the context of this study.

Due to a lack of reliable and detailed material flow information on the current and future downstream pathways of disposed SU and MU items, assumptions are made concerning the end-of-life treatment. To do so, different sources have been examined. The more valuable information is derived from:

- Antonoupolous et al. (2021)[32]: the authors calculated the plastic waste statistics considering plants with primary data for Germany, France, Spain, Italy, Benelux, Scandinavia and Croatia, thus very representative for Europe. According with the authors, **PP waste sorting rate is indicated as equal to 57%, and re-manufacturing rate**

[31] https://ec.europa.eu/eurostat/databrowser/view/ten00063/default/table?lang=en
[32] https://www.sciencedirect.com/science/article/pii/S0956053X21001999?via%3Dihub

equal to 71%. By multiplying these two figures, it can be obtained **an overall recycling share of 40.5%**, which is in line with figures reported by Eurostat.

- Picuno et al. (2021)[33] examined specific materials recycling rates when taking into account Deposit Refund System (DRS). For plastic recycling process (including DRS stream and specifically for separate collection), they estimated for two European countries (Germany and The Netherlands) **a sorting rate equal to 77%, and a re-manufacturing rate equal to 73%**. Therefore, **an overall recycling share of about 57%.**

For SU system no specific data regarding collecting and recycling have been identified, however it is acknowledged that QSRs are involved in projects to increase the shares of separated collection and recycling of wastes. For example, different agreement between QSRs and National Federations/Consortia of Paper Packaging have been signed[34] to significantly increase (to reach 100%) the separated collection, the sorting and the recycling of wastepaper packaging for food contact (including paper coated items).

4.3.2 Symmetrical approach

In the previous in-store LCA study (Ramboll, 2020), a symmetrical approach for paper and PP was assumed: this means that hypothetical recycling and incineration share (of 30% and 70%, respectively) were assigned to the treatment of both SU and MU items. These figures considered the followings:

1. Conservative approach: low recycling rates might be more penalizing for paper.
2. Fair comparison: using the same assumption to each system.

Results of the in-store LCA study (Ramboll, 2020), about EoL phases highlighted the following:

- Efficiency of recycling has significant effect on freshwater consumption and resource depletion rather than on Climate change
- Different EoL recycling rate in general have minor effects on results of MU system (0%, 30% and 70% were tested for both systems)
- Higher recycling rate (i.e., 70%) reduced impacts for SU system mainly in the following impact categories: fine particulate matter, freshwater consumption, freshwater eutrophication, ionizing radiation, terrestrial acidification
- In general, implementing different EoL recycling rates does not alter significantly the overall comparison of the two systems.

When shifting to the present take-away LCA study, a further element should be considered, which is the share of separation at home. To the best of our knowledge, there are no sources reporting figures related to share of separation at home. However, it is generally recognised that B2B systems have better waste management, including separation compared to B2C systems.

Considering these uncertainties, it is confirmed that:

- keeping a symmetric approach for both systems is confirmed to be most appropriate for a fair comparison;

[33] https://www.mdpi.com/2071-1050/13/12/6772
[34] https://www.comieco.org/mcdonalds-seda-e-comieco-alleati-per-la-sostenibilita/

- it is worth keeping a conservative approach adopting lower recycling rate in the baseline (i.e., 30% for both systems,) even if this choice might be more penalizing for paper.

Thus, a certain amount of landfilling cannot be excluded, also by taking into account specifications provided for by applicable legislation (e.g., Directive EU 2018/850) which obliges Member States to limit the amount of municipal waste due to be landfilled to 10%.

Based on this, the EoL approach used for the baseline is a symmetrical approach for SU and MU systems, with the following shares:

- 30% recycling.
- 60% incineration.
- 10% landfilling.

In addition, for MU system there is also a residual share of items disposed of within QSRs, which is represented by those items that are returned to QSRs but are no longer usable. For these items higher recycling rates are assumed considering that take-back systems are normally organized on purpose to guarantee collection and recycling of items. Those MU items that are returned to QSRs are therefore assumed to be 70% recycled and 30% incinerated.

Beside this, a set of sensitivity analyses specifically focused on EoL shares was performed, in order to test the effects of the variation of End-of-Life shares on overall results. These sensitivity analyses are reported in **section 5.3**.

4.4 **Single-use system**

The SU system includes the following major life-cycle stages:

- Raw material production and processing (upstream);
- Converting (upstream);
- Distribution (upstream);
- Use (core);
- End-of-life treatment (downstream).

The life cycle inventory for this system includes the product items listed in **Table 11** in section 3.2.4.1.

4.4.1 Raw material production and processing (upstream)

Primary LCI data for pulp and paper products obtained in the In-store LCA study among EPPA members has been updated for this study. Therefore, this study takes into account the most recent data from producers located in countries representative for the pulp and paper market situation in Europe (e.g., Sweden, Finland, Austria).

Primary data for pulp and paper products are implemented through two different approaches. For certain pulp and paper products proprietary LCA models (LCIA impact results) are directly implemented into the LCA model. This approach concerns the pulp and paper products listed in **Table 15**. Further details are disclosed in **APPENDIX 1. Life Cycle Inventory**.

Table 15: Primary data for paper making implemented by means of proprietary LCA models (LCIA impact results)

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Chemical pulp (softwood, bleached)	Primary data	Confidential	Finland	1 t pulp	2021
PE-coated paperboard (different variants and specifications)	Primary data	Confidential	Finland	1 t board	2021

Further paper grades which serve as inputs to distinct converting processes are modelled based on primary data obtained from manufacturers in Europe. The respective paper products are listed in **Table 16**. Further details on the implemented inventory data and modelling choices are disclosed in **APPENDIX 1. Life Cycle Inventory**.

Table 16: Primary data for paper making implemented by means of inventory data and own modelling

Provider process name	Classification	Source	Geographical coverage	Reference value	Recycled content	Reference year
Thin greaseproof paper with soy-based coating	Primary data	Confidential	Austria	1 t paper	0% recycled content	2020
High-brightness paperboard	Primary data	Confidential	Austria	1 t paperboard	80% recycled content	2019

Some paperboard products listed in **Table 16** have recycled content. Therefore, recycled pulp obtained from wastepaper treatment can be assumed as used as input of the paperboard manufacturing. Recycled pulp in this study is modelled following the approach of the PEFCR for recycled input material, with the following processes that are included in the model:

- collection of wastepaper for recycling, and transport to a sorting facility
- sorting into paper grades, and transport to a recycling facility
- wastepaper recycling into recycled fibres.

For the baseline scenario, the following additional assumptions are made (i.e., raw material production/processing):

- Upstream processes refer to the respective geographical context of the paper mill or manufacturer; thus, representing Finland and Austria. These geographies can be considered representative for an average European supply chain, since they are in line with the geographical distribution of paper pulp production in Europe described by the *Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board* (2015) (Suhr *et al.*, 2015);

- Paper trimmings at paper mills and other generated wastes (e.g., unspecified non-hazardous/hazardous waste for further processing, metal scrap, sewage sludge, waste heat) are accounted for in the upstream processes;
- Although some paper producers claim 100% green electricity, it is assumed that heat energy and electricity are sourced from the grid, thus representing average conditions in the respective geographies as indicated in the inventories (**APPENDIX 2. Life Cycle Inventory - Wastepaper recycling**);
- Intermediate transport from paper producers to converters is modelled according to primary data provided by converters.

4.4.2 Converting (upstream)

The manufacturing of SU product items (converting process) is modelled based on the most recent primary data obtained from converters among EPPA members based in Germany, Finland, and France (see **Table 17**). For wooden cutlery, secondary data is implemented.

Table 17: Sources of primary data for the converting processes

Provider process name	Classification	Source	Geographical coverage	Reference year
Cold drink cup	Primary data	Seda	Germany	2020
Clip on Lid	Primary data	Seda	Germany	2020
Cup holder	Primary data	Hutamaki	Finland	2022
Clamshell	Primary data	Seda	Germany	2020
Paper wrap	Primary data	CEE Schisler	France	2019
Fry bag	Primary data	Seda	Germany	2020
Paper fry bag	Primary data	CEE Schisler	France	2019
Ice Cream Cup	Primary data	Seda	Germany	2020
Wooden cutlery	Secondary data	Paspaldzhiev *et al.* (2018)	Europe	2017
Paper bags	Primary data	CEE Schisler	France	2022

For the baseline scenario the following additional assumptions are made:

- All converting processes refer to the respective geographical context of the converter´s site location. Thus, inventories reflect technologies and processes taking place in Finland, Germany, and France. These locations as well as specific converting processes, as already mentioned above, are representative of an average European supply chain in this market. In order to make the converting processes and environmental effects as representative as possible, EU-average background processes (e.g., for electricity or thermal energy) are selected in the models;
- Types and amounts of packaging materials (cardboard and PE foils) for all single-use product items (except for wooden cutlery) are based on primary data from converters;

4.4.3 Distribution (upstream)

Transport from converters to QSRs is assumed to represent an average distance from the location of the respective converter to a central location in Europe such as France or Germany (i.e., 400 km for converters based in FR, 800 km for converters based in DE, 2.700 km for converters based in FI). The transport demands are based on the specific product and packaging weights required to fulfil the functional unit. These assumptions are implemented with the dataset indicated in **APPENDIX 1. Life Cycle Inventory**.

4.4.4 Use stage (core)

The use stage within the single-use system is only represented by the transportation of the items to points of consumption. This happens with different means of transport (car, scooter, bike, public transport, or by walking).

The average distance for take-away services is usually between 2 km and 5 km (based on literature data (Allen, Piecyk and Piotrowska, 2018; Corr, 2019; Allen *et al.*, 2021) and on confidential QSRs data). However, since these trips are symmetrical for SU and MU systems, they are excluded from the analysis.

4.4.5 End-of-life treatment (downstream)

Two types of wastepaper are taken into account: pre-consumer and post-consumer. Pre-consumer wastepaper is related to waste generated during converting, such as trimmings for the manufacturing of SU products. It further includes EoL treatment of corrugated board boxes used for shipment of SU products to QSRs. Post-consumer wastepaper is the waste generated at end of life of SU products, after use.

For pre-consumer wastepaper, standard procedure at converting sites is to recycle fibres (B2B level). Therefore, 100% recycling share of these trimming is assumed. The same assumption is made for corrugated board boxes used internally for transporting SU product items to QSr. For pre-consumer waste plastics used as packaging material for shipment, the same assumption is made.

For post-consumer wastepaper, EoL shares are assigned to each product. Material at EoL is therefore either recycled (with material recovery) or incinerated (with energy recovery). It is assumed that 30% of paper waste material fractions are materially recycled by means of recycling processes (see section 4.3).

4.4.5.1 Recycling

In this study, wastepaper recycling depends on the type of wastepaper treated. Two types of materials are considered: non-coated paperboard (including corrugated grades of shipment boxes), coated paperboards used in SU products (including pre-consumer trimmings for their manufacturing).

For non-coated paperboard and corrugated grades, the approach for modelling wastepaper recycling is given in detail in **APPENDIX 2. Life Cycle Inventory - Wastepaper recycling**. The resultant LCI describes the recycling of wastepaper from placing the recovered wastepaper into the pulper to recovered pulp, and it refers to 1 ton of recovered pulp.

For coated paperboard, a specific LCI for wastepaper recycling (confidential data) was described in the in-store LCA study by Ramboll on behalf of EPPA (Ramboll, 2020). This is primary gate-to-gate inventory data of a dedicated recycling process for plastic (PE)-coated paperboard products.

Data for both wastepaper recycling processes is given in **Table 18**.

Table 18: Sources of primary data for coated/uncoated paper recycling implemented by means of inventory data and own modelling

Provider process name	Classification	Source	Geographical coverage	Reference year
Wastepaper recycling, corrugated grades	Hybrid data (primary and secondary)	Calculations and expert judgment	Europe	2021
Recycling of sorted paperboard from post-consumer waste PE-coated paper	Primary data	Confidential	Europe	2019

Product waste is assumed to be transported over a distance of 100 km to a waste recycling facility via lorry (> 32 tons, EURO 4).

Avoided emissions (credits)

Credits for avoided material production (when recycling) and credits for avoided energy production (when incinerating) are taken into account in this study.

To model the avoided environmental emissions in the corrugated board packaging product systems, the following approach is taken:

- It is assumed that the recycled pulp as output of the wastepaper recycling is substituted by virgin pulp
- It is assumed that credits for avoided emissions of virgin pulp products are assigned by considering EU average paper grades. When factoring in further industry statistics, the resulting shares of avoided pulp products per ton of recovered pulp are as follows[35]: 78% chemical pulp, 22% mechanical and semi-chemical pulp.
- The substitute for chemical pulp is assumed to be sulphate pulp.
- As substitute for pulp, it is assumed that it consists of one third stone groundwood pulp, one third thermo-mechanical pulp and one third chemi-thermomechanical pulp.

4.4.5.2 Incineration

60% of wastepaper as well as all PE from coating associated with certain SU products within the system are assumed to be incinerated with energy recovery (see section 4.3). **APPENDIX 1. Life Cycle Inventory** presents dataset used in the model. Other minor constituents of the single-use waste products (e.g., inks, glue) are neglected during the EoL treatment. Hence, no environmental impacts or credits are accounted for.

[35]Market pulp consumption was reported by CEPI in 2021 report ("Total pulp consumption by grade and market pulp consumption"), see https://www.cepi.org/wp-content/uploads/2021/07/Key-Stats-2020-FINAL.pdf

Avoided emissions (credits)

When the material is incinerated, electricity and heat is produced and recovered. The potential benefits of the recovered energy lays in replacing electricity and heat that would have been produced from other sources. To model the avoided electricity and heat production, the average consumption electricity grid mix at European level. Inputs for the model are shown in **APPENDIX 1. Life Cycle Inventory**.

Product waste is assumed to be transported over a distance of 100 km to a waste incineration facility via lorry (>32 tons, EURO 4).

4.4.5.1 Landfilling

As deeply investigated in section 4.3, it is not possible to estimate the share of separation at home, nor exact recycling rates for paper products resulting from the analysed system. Based on discussion reported in section 4.3, and considering figures reported by analysed sources and related uncertainties, a symmetrical approach for SU and MU systems is confirmed to be most appropriate for a fare comparison, also including a 10% of landfilling, by taking into account specifications provided for by applicable legislation (e.g., Directive EU 2018/850) which obliges Member States to limit the amount of municipal waste due to be landfilled to 10%.

4.5 Multiple-use system

The multiple-use system includes the following life-cycle stages (in general, equal to the single-use system):

- Raw material production and processing (upstream);
- Converting (upstream);
- Distribution (upstream);
- Use (core);
- End-of-life treatment (downstream).

The life cycle inventory for this system includes the product items listed in **Table 11** in section 3.2.4.1.

4.5.1 Raw material production and processing (upstream)

The production phase of multiple-use items is modelled using secondary data reflecting the cradle-to-gate production of items from raw materials. It therefore includes also the conversion towards final multiple-use items. Key assumptions for this step are:

- Compared to the primary data in the single-use system, the following input processes are considered for multiple-use items:
    - Production and manufacturing of raw materials and product items (e.g., plastic granulate production and injection moulding to final product including intermediate transport);
    - Generic processes for manufacturing packaging materials (e.g., paper corrugated board, PE foil for wrapping);

A detailed overview of the individual items and their weights can be obtained from **Table 11**. Further details on the implemented inventory data and modelling choices are disclosed in **APPENDIX 1. Life Cycle Inventory**.

4.5.2 Converting (upstream)

Due to the simplified modelling of multiple-use items based on secondary data from LCI databases, conversion of raw materials to final products is already included in the raw material production stage described above.

4.5.3 Distribution of final products (upstream processes)

Transport from producers to QSRs is modelled following the suggestion by Plastic LCA method (Nessi *et al.*, 2021), considering production in Europe and in particular:

- 230 km by truck (>32 t, EURO 4);
- 280 km by train (average freight train);
- 360 km by ship (barge).

More details are reported in **APPENDIX 1. Life Cycle Inventory**.

4.5.4 Use stage and reuse (core process)

This stage is modelled by considering the phases of transport from QSR to point of consumption, preliminary washing, transport back to QSRs and professional washing and drying in QSRs before reuse.

The following key assumptions are made for the baseline scenario of the multiple-use system:

- Transport from QSR to point of consumptions is symmetrical for SU and MU systems (see also **section 4.4.4**). It is then excluded from the analysis.
- An average scenario for preliminary washing is used to reflect different possible processes. It considers an equal share of handwashing, dishwashing, cold rinsing and dry wiping, and is applied to half of total items taken back to QSRs (with the exception of those bought by means of drive through, which are assumed to be returned directly after consuming food and beverages as conservative assumption, see further details in **Table 20**).
- The phase of transport back to QSR is considered, being this exclusive of the MU system.
- For returning MU items to QSRs, a decentralized take-back mechanism is considered, where MU items are returned to collection points by consumers.
- For on-the-go, click and collect and delivery, it is assumed an average distance between QSR and point of consumption of 3 km (as reported by QSRs in specific data gathering questionnaires prepared by Ramboll). For drive through, as conservative assumption, it is assumed that food and beverages are consumed near the QSR and MU items are returned directly after consumption of food and beverages, covering a distance of 1 km.
- It is then assumed that trips for returning MU items to QSRs can provide a multifunctionality (i.e., a trip not only intended to return MU items, but also intended for other reasons external to the system boundaries), however multifunctionality may be highly affected by consumers' activities, decisions, and behaviour. There are limited

studies that provide analytics on behaviour toward take-back program. In this study the impacts associated with these trips are only partially allocated to the system, assuming - in the baseline - that only 50% of consumers make the average distances described above specifically for returning the MU items. According to this scenario, 1/2 of trips for take-back are neglected (e.g., 1 out of 2 people return MU items in case of buying of another menu). Given the unpredictability of customers' behaviour more conservative scenarios have been also tested with sensitivity analysis.

- Average reuse rate of 50 reuses and average return rate of 50%[36] are considered as reported by confidential QSRs data (gathered by means of specific questionnaires prepared by Ramboll to assure reliability of potentially key figures). Reuse rate and return rate also include potential replacement reasons such as damages, stains, theft or loss.
- Washing, rinsing and drying processes are performed in-house (in QSRs) by means of hood-types dishwashers (as reported by confidential QSRs data); inputs to these processes are based on literature values for water, energy, detergent and rinse agent demand (per item basis). An average scenario for dishwashers is used to reflect different grades of devices' efficiencies (see further details below and in **Table 21**).
- State-of-the-art detergent, rinse agent and softener compositions are assumed (although data gaps exist in the exact chemical composition and demands on a per item basis).
- Average rewashing rate for all items of 10% is considered: this assumption is to consider the presence of persistent residues that might remain after washing (Antony and Gensch, 2017). The presence of persistent residues is a peculiarity of take-away systems, since items could be returned in a long time frame (e.g., weeks) after food consumption, which leads to food/beverages encrustations. For this reason, the rewashing rate value has been increased to 10% (the original publication reports a 5% rewashing rate referring to items that are washed immediately after their use) to consider this further constraint of the system. However, the exact rate will depend on organisational structures in a QSR (e.g., time between serving of tableware and washing; pre-rinsing of tableware by hand, time frame before returning MU items).

Transport back to QSRs

As already described above, the number of trips considered to take-back MU items to QSRs and related distances covered have been included in accordance with defined system boundaries (see 3.2.3 System boundaries). When taking into account the trips to take-back MU items, it is assumed that they can start from/end in different points (e.g., the customer can be already in the street near the QSR or can consume food in the nearby area). Moreover, these trips can provide a multifunctionality (i.e., a trip not only intended to return MU items, but also intended for other reasons external to the system boundaries), thus the impacts associated with these trips are only partially allocated to the system, assuming a trip half of the average delivery distance, as explained in the following:

- For on-the-go, click and collect and delivery, it is assumed an average distance between QSR and point of consumption of 3 km (as reported by QSRs in specific data gathering questionnaires prepared by Ramboll). For drive through, as conservative assumption, it is assumed that food and beverages are consumed near the QSR and MU items are returned directly after consumption of food and beverages, covering a distance of 1 km.

[36] These assumptions are based on primary data gathered from QSRs operators.

- It is then assumed that trips for returning MU items to QSRs can provide a multifunctionality (i.e., a trip not only intended to return MU items, but also intended for other reasons external to the system boundaries), however multifunctionality may be highly affected by consumers' activities, decisions, and behaviour. There are limited studies that provide analytics on behaviour toward take-back program. In this study the impacts associated with these trips are only partially allocated to the system, assuming - in the baseline - that only 50% of consumers make the average distances described above specifically for returning the MU items. According to this scenario, 1/2 of trips for take-back are neglected (e.g., 1 out of 2 people return MU items in case of buying of another menu). Given the unpredictability of customers' behaviour more conservative scenarios have been also tested with sensitivity analysis.

Trips to reach QSR and to go back are excluded since they are symmetrical for SU and MU systems.

Table 19 reports the shares of means of transport for returning MU items to QSRs, considering different selling channels. The exact shares of total sales in each single channel are not disclosed due to confidentiality of the primary data provided by QSRs operators.

For on-the-go and click and collect, no information is available related to the specific means of transport utilised. For this reason, as conservative assumption, an equal share of cars, scooters, bike, public transport and trips by walking are considered. The same assumption is assumed for the take-back of MU items bought by means of delivery.

Table 19: Shares of means of transport for returning MU items to QSRs, considering different selling channels

Selling channel	Share of total sells	Means of transport	Share of total means of transport in the specific selling channel
Drive through	Confidential	Car	100%
On-the-go, click and collect	Confidential	Car	One fifth
		Scooter	One fifth
		Bike	One fifth
		Public transport	One fifth
		Walking	One fifth
Delivery*	Confidential	Car	One fifth
		Scooter	One fifth
		Bike	One fifth
		Public transport	One fifth
		Walking	One fifth

* For the delivery selling channel, items are mostly delivered by means of scooters and bikes (as reported by primary data from QSRs and from literature data), but since the take-back system is performed by customers, the same means of transport assumed for on-the-go and click and collect are assumed for this phase.

Details related to Ecoinvent processes considered for modelling this phase are reported in **APPENDIX 1. Life Cycle Inventory**, with the obvious exception of walking, which not entail any environmental burden. Manufacturing of means of transport is excluded from the analysis.

Preliminary washing

For the preliminary cleaning/washing stage of MU items, different methods were identified. Different companies working with reusable meal containers encourage the customers to either not clean them or only clean them shortly by rinsing with cold water (Verburgt, 2021). However, this also depends on customers behaviour. It is therefore possible that the customer will thoroughly clean the meal containers already after use anyway, even though they will also be professionally cleaned. However, in order to reflect different possibilities, the following assumptions are taken into account:

- Preliminary washing is not considered for MU items not returning to QSR (i.e., those for which the return rate does not apply).
- Among the items returning to QSR (i.e., those for which the return rate does apply), preliminary washing is considered just for 50% of items. This is a conservative assumption considered to reflect the possibility that a share of items is returned without a preliminary washing.
- For drive through selling channel, it is assumed that preliminary washing is not performed, since MU items are assumed to be used nearby the QSR and directly took-back.

For the modelling of this stage, four different system configurations were taken into account:

1. Handwashing
2. Dishwashing
3. Dry wiping (with paper towels)
4. Cold water rinsing

For handwashing, the data were obtained from research by Verburgt (2021) and Potting and van der Harst (2015) and complemented with data from Joseph *et al.* (2015) and data from Martin, Bunsen and Ciroth (2018). It is expected that hot water and detergent are required for handwashing an item, and that paper towels are used for drying it. Data reported in these studies have been recalculated with reference to the average volume of items considered in this study. Thus, 1.5 L of water, 0.09 kWh for heating the water (based on an 85% efficiency natural gas boiler), 1.5 g of detergents and 5.8 g of paper towels are required. The treatment of wastewater required as a result of washing the container was added, assuming that the amount needs to be the same as the water input according to Martin, Bunsen and Ciroth (2018).

For dishwashing, data were obtained from research by Verburgt, (2021) and Potting and van der Harst (2015). It is expected that a dishwasher uses 0.27 L of water, 0.03 kWh of electricity, 0.28 g of detergent and 0.03 g of rinse agent per item (with reference to the average volume of items in this study). The treatment of wastewater required as a result of washing the items was also added (Martin, Bunsen and Ciroth, 2018). Data for this process are different from those reported in the following for professional washing, since it is expected a sensible difference between dishwashers for domestic use and those for professional use.

For dry wiping, it is expected that the same amount of paper towels is required as included in the handwashing option.

Data for cold water rinsing were based on research by Binstock, Gandhi and Steva, (2013). **Table 20** provides an overview of the collected inventory data for the four options. The final reference process is the average of the four considered options.

Details related to the modelling of this phase can be found in **APPENDIX 1. Life Cycle Inventory**.

Table 20: Technical specifications of preliminary washing methods (LCI data).

	Handwashing (including rinsing)	Dishwashing	Dry wiping	Cold rinsing	Average preliminary washing process
Energy demand [kWh/item]	0.09	0.03	0*	0*	0.03
Water demand [l/item]	1.5	0.27	0*	1.5	0.81
Detergent [g/item]	1.5	0.28	0*	0*	0.43
Rinse agent [g/item]	-	0.03	0*	0*	0.01
Paper towels [g/item]	5.8	0*	5.8	0*	2.9
Wastewater treatment [l/item]	1.5	0.27	0*	1.5	0.81
Source	Based on (Joseph *et al.*, 2015; Potting and van der Harst, 2015; Martin, Bunsen and Ciroth, 2018; Verburgt, 2021)	Based on (Potting and van der Harst, 2015; Bosch, 2020; Verburgt, 2021)	Based on (Joseph *et al.*, 2015; Potting and van der Harst, 2015; Verburgt, 2021)	Based on (Binstock, Gandhi and Steva, 2013; Martin, Bunsen and Ciroth, 2018; Verburgt, 2021)	
NOTE: data have been calculated with reference to the average volume of items considered in this study. *the considered value is zero since the parameter is not applicable for the specific washing method.					

Professional washing and drying

In commercial dishwashers, washing is performed with standard temperature (generally higher than 65°C), followed by a rinsing process performed at temperatures higher than 85°C for hygiene reasons (Ferco, 2009). Washing can be performed with different dishwasher types, ranging from undercounter devices to hoods or conveyor-based dishwashers. Generally, two types of commercial dishwashers are considered suitable to be used (and installed) in QSRs in an in-house washing scenario: undercounter and hood-type dishwashers. In general, undercounter dishwashers are smaller, cheaper, with longer cycle time and higher energy and water demand than hood-type machines (Rüdenauer et al., 2011).

Based on data provided by QSRs operators, the type of dishwashers to be installed and used for washing MU items is hood-type. To reflect the different options of hood-type dishwashers in QSRs and the different levels of efficiencies, an average washing scenario is assumed for the baseline comparison. This average washing scenario consists of three options of hood-type dishwashers based on the fabrication year (2011, 2017, 2021), resulting in different demands for electricity, water and chemicals.

Due to limited existing experience with washing processes of multiple-use items in QSRs and limited data availability for washing demands on a per item-basis, each option is weighted equally to define an overall average washing scenario for the in-house washing process.

With respect to drying of tableware after dishwashing, it is often performed using residual heat from rinsing. For plastic items however, drying with residual heat only is not sufficient, but a dedicated drying phase for plastic products is required to ensure completely dried items after washing (e.g., through a combination of drying and ventilation). This is essential for hygiene reasons as omitting the drying phase may lead to cross-contamination or bacterial development in moist environments. Literature information identified for the hood-type dishwashers focuses on ceramic products only. Thus, it must be assumed that plastic item washing and drying in QSRs requires additional energy for a dedicated drying process. According to literature data, drying accounts for approximately 30% of the overall energy demand for washing and drying[37]. Therefore, energy demands reported in literature for the hood-type devices are assumed to reflect 70% and are increased by 30% to model in-house dishwashing of plastic-based multiple-use items, with the exception of Winterhalter dishwashers, which possess dedicated plastic washing and drying programmes that ensure plastic items are completely dry. The reported energy demands are therefore considered sufficient for drying PP products in a QSR context.

Data for modelling detergent, rinse agent and softener demands are retrieved from literature as far as available on a per item basis. Chemical composition is based on (Rüdenauer *et al.*, 2011) and was combined with expert judgement to reflect regulatory and efficiency developments since 2011[38]. Resulting compositions for detergent and rinse agent used to model the washing process of multiple-use items are listed in **APPENDIX 1. Life Cycle Inventory**

The different washing options, along with their LCI data and the resulting overall average used for the baseline comparison, are summarised in **Table 21**. Inputs for the washing and drying processes are energy demand (kWh/item), water demand (litres/item), detergent, rinse agent and softener demand (g/item). More details related to the modelling of this phase can be found in **APPENDIX 1. Life Cycle Inventory**.

[37] 30% is an approximation based on: 26% reported by EC, JRC (2007), Best Environmental Practice in the tourism sector; 33% reported for Meiko Flight Conveyor Dishwasher by Slater (2017), Energy Efficient Flight Conveyor Dishwashers; 32% reported for Hobart Flight Conveyor Dishwasher by Slater (2017), Energy Efficient Flight Conveyor Dishwashers.
[38] Expert judgement was done by in-house chemists with experience in the sector. Reported compositions for 2011 were deemed outdated due to regulatory restrictions of potassium use.

Table 21: Technical specifications of dishwashers for the inhouse washing and drying scenario (LCI data).

	Hood-type dishwasher			Average washing process
Reference year	2011	2017	2021	
Energy demand* [kWh/item]	0.024	0.014	0.014	0.017
Water demand [l/item]	0.16	0.08	0.23	0.16
Combined detergent, rinse agent and softner demand [g/item]**	0.50	0.17	0.44	0.37
Source	Based on (Rüdenauer *et al.*, 2011)	Based on (Antony and Gensch, 2017)	Based on Winterhalter (2021)	

* Including assumption for energy demand for drying, see details below

** 90% of the total is detergent and softener demand, 10% rinse agent demand

4.5.5 End-of-Life Treatment (downstream processes)

The following key assumptions are made for the treatment and disposal of multiple-use items after they reach their end of life:

- Items are separately collected and disposed of in dedicated containers (without implications for environmental impacts);
- Items are expected to be transported by waste collection company to waste treatment facility (100 km transport distance via lorry is assumed);
- It is not possible to estimate the share of separation at home, nor exact recycling rates for PP products resulting from the analysed system. Based on discussion reported in paragraph 4.3, and considering figures reported by analysed sources and related uncertainties, a symmetrical approach for SU and MU systems is confirmed to be most appropriate for a fare comparison, also including a certain amount of landfilling, by taking into account specifications provided for by applicable legislation (e.g., Directive EU 2018/850) which obliges Member States to limit the amount of municipal waste due to be landfilled to 10%.

  Based on this, the EoL approach used for the baseline is a symmetrical approach for SU and MU systems, with the following shares:

  - 30% recycling.
  - 60% incineration.
  - 10% landfilling.

Sensitivity analyses are performed with different EoL shares.

- In addition, for MU system there is also a residual share of items disposed of within QSRs, which is represented by those items that are returned to QSRs but are no longer usable. For these items higher recycling rates are assumed considering that take-back systems are normally organized on purpose to guarantee collection and recycling of items. Those MU items that are returned to QSRs are therefore assumed to be 70% recycled and 30% incinerated.
- Packaging waste (corrugated board box and PE stretch foil used in upstream for transport from manufacturing to QSR) is sent to recycling.

Recycling process of polypropylene has been modelled by implementing data from Cardamone, Ardolino and Arena (2021). Even though the original publication refers specifically to plastics from Waste of Electrical and Electronic Equipment (WEEE), using these data can be considered a more realistic assumption since secondary data from Ecoinvent refer to formal/informal recycling process in India, which does not reflect current recycling processes in Europe. Main consumption data are reported in **APPENDIX 1. Life Cycle Inventory**, assuming a sorting and re-manufacturing overall efficiency of 90% (Cardamone et al., 2021). Data for water consumption is an average value from Schwarz *et al.* (2021) and Perugini, Mastellone and Arena (2005).

In order to account for environmental benefits associated with the recycled material and recovered energy during recycling and incineration processes, secondary plastic granulate and electricity as well as thermal energy are implemented as avoided burdens. Details can be found in **APPENDIX 1. Life Cycle Inventory.**

5. LIFE CYCLE IMPACT ASSESSMENT RESULTS AND INTERPRETATION

By using the baseline model, impact results are provided, and main contributors to the results are presented for each impact category, allowing for a comparison between the two systems. Moreover, a contribution analysis is facilitated by showing contributions for each life cycle stage within the respective systems. For each impact category, the most important emissions are reported, as well as the most relevant sources of impacts on LCI level.

Analysis of relevant findings for the comparative assertion follows a consistent terminology[39] as presented in **Table 22**.

Table 22: Terminology for results interpretation

Relative difference in %	Terminologies in comparative assertion and interpretation of results
<5%	**marginal** *difference (i.e., uncertainty threshold)*
5-10%	**minor** *difference*
10-20%	**noticeable** *difference*
20-30%	**moderate** *difference*
30-50%	**significant** *difference*
>50%	**very significant** *difference*

By using classification on terminology of **Table 22**, overall results are given in **Table 23**. In the following comparative analysis of the environmental emissions Climate Change is considered as a single impact category. Therefore, the comparative analysis is presented by highlighting differences of SU and MU only for Climate Change total, by excluding a comparison of its three constituents. Yet, in the contribution analysis, investigation on shares of impacts is extended further to the three constituents of Climate Change, total (*Climate change, biogenic; Climate change, fossil; Climate change, land use and land use change*).

The baseline comparison of SU and MU shows that the SU system has lower impacts in all impact categories

Table 23: Summary of aggregated total impacts of the baseline scenario and discussion of the insights through the sensitivity analyses.

Impact category	SU system - Baseline Scenario	MU system - Baseline Scenario	Comments
EF-Acidification [mol H+ equivalents]	77.5	167.6	The **single-use system** shows **very significant** benefits (MU is + 54%)
EF-Climate change, total [kg CO2-Equivalents]	20,811	39,788	The **single-use system** shows **significant** benefits (MU is + 48%)
EF-Eutrophication, freshwater [kg N equivalents]	5.48	9.28	The **single-use system** shows **significant** benefits (MU is + 41%)

[39] The terminology used for interpretation is based on relative difference in %, where the system with associated highest impact for each category is set to 100% and the other system is normalized to this value.

Impact category	SU system - Baseline Scenario	MU system - Baseline Scenario	Comments
EF-Eutrophication, marine [kg P equivalents]	37.8	49.6	The **single-use system** shows **moderate** benefits (MU is + 24%)
EF-Eutrophication, terrestrial [mol N equivalents]	254.5	449.3	The **single-use system** shows **significant** benefits (MU is + 43%)
EF-Ionising radiation, human health [kBq U235 equivalents]	3,976	4,318	The **single-use system** shows **minor** benefits (MU is + 8%)
EF-Ozone depletion [kg CFC11 equivalents]	0.00276	0.00561	The **single-use system** shows **very significant** benefits (MU is + 51%)
EF-Particulate matter [disease incidence]	0.00083	0.00188	The **single-use system** shows **very significant** benefits (MU is + 56%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	69.8	213.5	The **single-use system** shows **very significant** benefits (MU is + 67%)
EF-Resource use, fossils [MJ]	314,931	581,979	The **single-use system** shows **significant** benefits (MU is + 46%)
EF-Resource use, minerals and metals [kg Sb equivalents]	0.06	0.32	The **single-use system** shows **very significant** benefits (MU is + 82%)
ReCiPe 2016 Midpoint (H)-Water consumption	136.8	224.5	The **single-use system** shows **significant** benefits (MU is + 39%)

Figure 7 shows the relative impacts of both system per impact category – the system with associated highest impact for each category is set to 100%, and the other system is normalized to this value, to facilitate the visualization and the difference between the results.

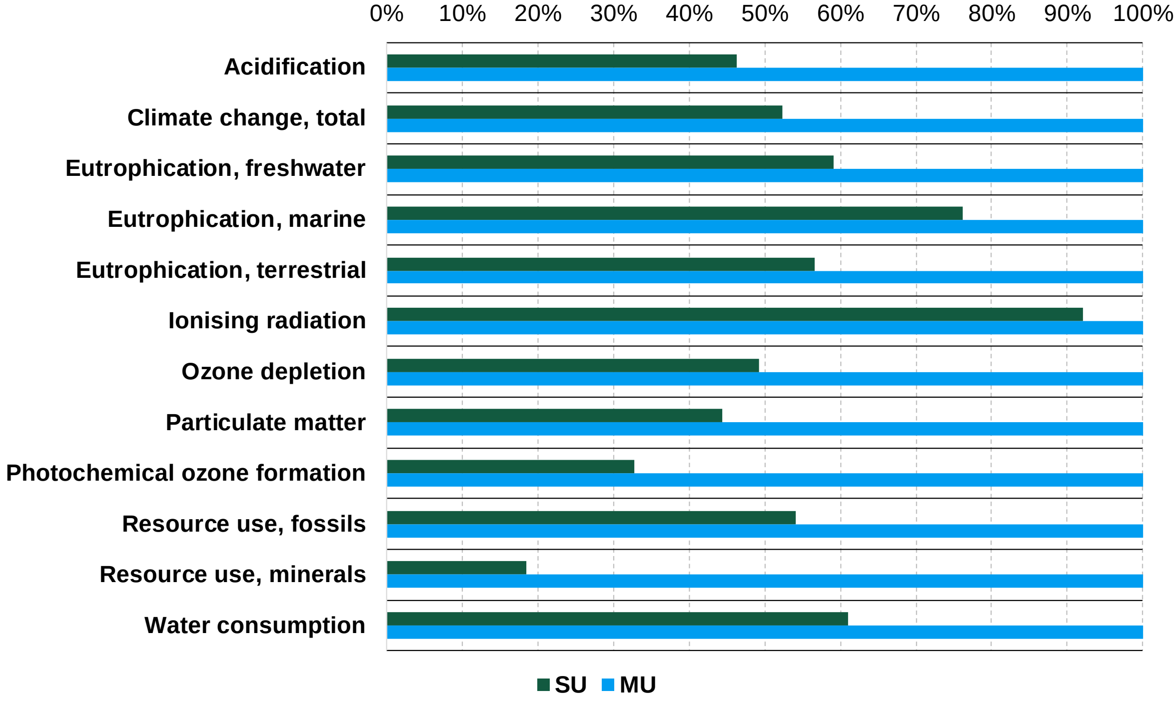

Figure 7 Results of both SU and MU systems, normalized to the highest impacts per impact category

5.1 Contribution analysis

The contribution of each life cycle stage is reviewed for all assessed impact categories in **Figure 8** (SU system) and **Figure 9** (MU system) below. The contribution analysis shows that the **environmental hotspots of the two systems (SU and MU) predominantly occur in different life cycle phases in the two systems (see the full report for more details)**:

- environmental impacts in the SU system are predominantly driven by the **Raw material extraction** and **Converting** life cycle stages,
- environmental impacts in the MU system are predominantly driven by **Use phase transport** and **Washing** life cycle stages.

Please refer to **APPENDIX 5. Results of contribution analysis in tabular form** for the result in table form.

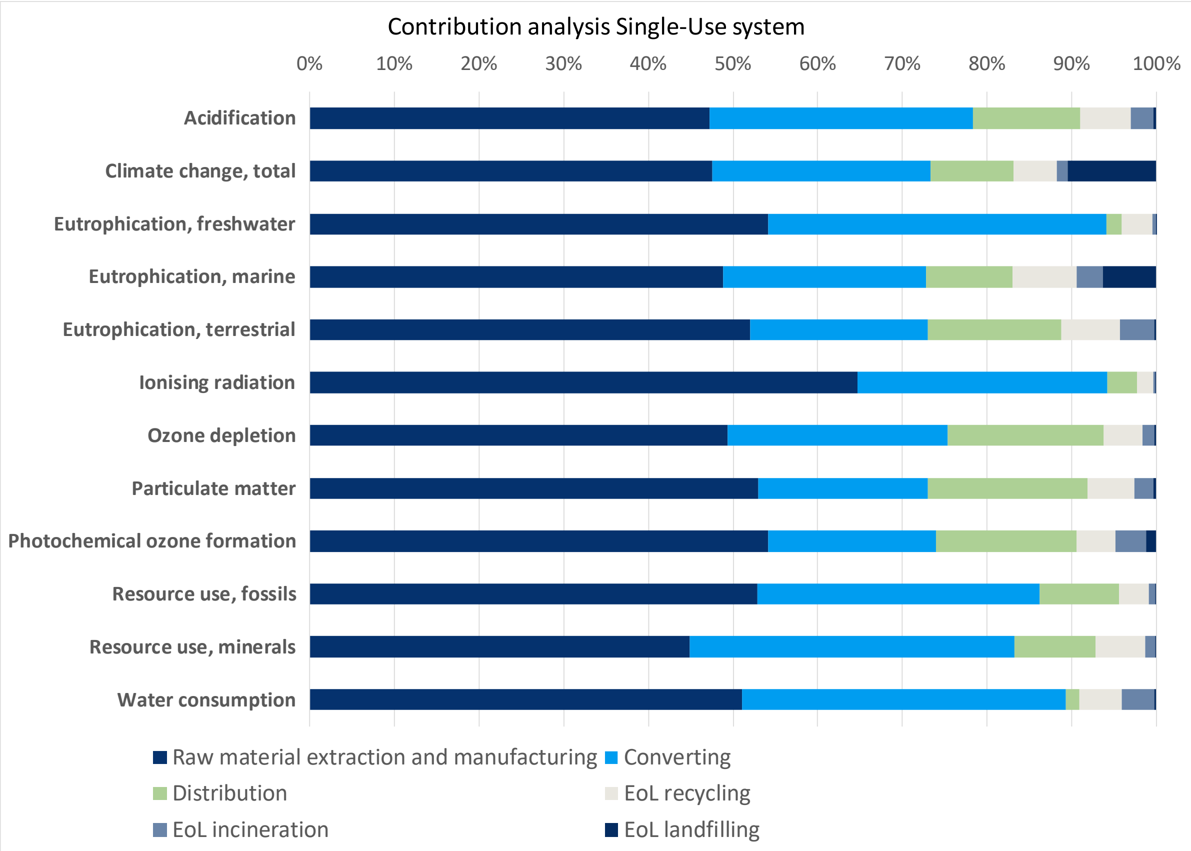

Figure 8 Contribution analysis of SU system (credits are excluded)

Figure 8 shows results of the contribution analysis of life cycle stages by excluding credits for SU system. Therefore, only impacts are considered. The potential environmental impacts of the SU system are largely driven by Paper manufacturing, which includes **Raw material extraction and manufacturing** and **Converting** (more than 70% in all impact categories). Next to paper manufacturing, the **Distribution** life cycle stage plays an important role in all categories (between 10-20% in all impact categories). In general, Ionizing radiation category is influenced by nuclear power share in the electrical grid mix for manufacturing paperboards, especially in northern countries of EU and in France. This would be also relevant for the converting process, which is mainly driven by the consumption of electrical energy.

Other life cycle stages contribute from around 5% (in Ionizing radiation) to around 18% (in Climate Change, total), and therefore represent a minor part in the total life cycle. It can be noted that potential environmental emissions are distributed with the same contributions in the different impact categories. In particular, the EoL life cycle stage contributes from 1% (Ionizing radiation) to around 10% (Water consumption). The latter is mainly due to water used in the recycling process for producing virgin pulp at the end of such process.

The contribution analysis for the MU system is given in **Figure 9**.

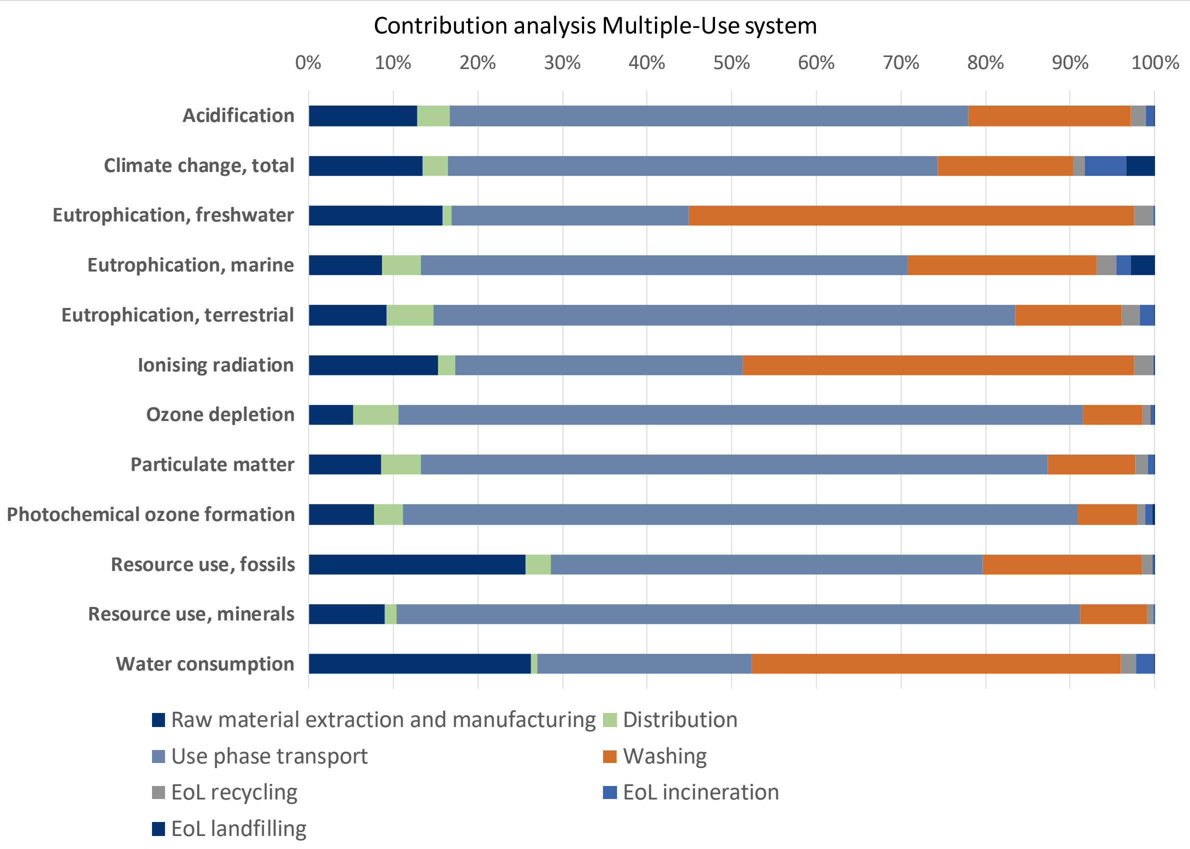

Figure 9 Contribution analysis of MU system (credits are excluded)

Figure 9 shows results of the contribution analysis of life cycle stages by excluding credits for MU system. Therefore, only impacts are considered. The potential environmental impacts of the MU system are largely driven by **Use phase transport** with a contribution from 77% (in *Ozone depletion* and *Resource use, minerals and metals* categories) to 20% (in *Water consumption* category). This depends mostly on the contribution of EURO4 cars in all considered selling channels, whose impacts are always strongly higher than those of all other means of transport.

The second most relevant life cycle stage is the **Washing** (particularly for *Eutrophication freshwater, Ionising radiation* and *Water consumption* impact categories), which contributes from 45% (*Eutrophication, freshwater* category) to 7% (in *Ozone depletion, Photochemical ozone formation* and *Resource use, minerals and metals* categories). This is linked to water and energy consumption, especially for handwashing performed for preliminary washing at home.

Other life cycle stages (**Raw material extraction and manufacturing** and **End-of-Life**) play a limited role, with the exception of *Resource use, fossils* and *Water consumption* impact categories, for which Raw material extraction and manufacturing has impact around 25% of total, due to resource and energy use for productive process of polypropylene.

5.2 Contribution to the total impacts (PEF method)

In order to present the contribution to the total impacts, the Product Environmental Footprint Category Rules Guidance (version 6.3) reports a methodology for "Impact categories cumulatively contributing at least 80% of the total environmental impact (excluding toxicity related impact categories)". Note that also Water consumption impact category is excluded, since it has been calculated with a different LCIA methodology (ReCiPe 2016 Midpoint (H)). Following this procedure, the results show:

- **SU system**: Based on the normalized and weighted results, and excluding the toxicity related impacts, the most relevant impact categories are *Acidification, Climate Change, total, Particulate matter, Photochemical ozone formation, human health* and *Resource use, fossils* for a cumulative contribution of 81.5% of the total impact (**Table 24**).
- **MU system**: Based on the normalized and weighted results, and excluding the toxicity related impacts, the most relevant impact categories are *Climate Change, total, Particulate matter, Photochemical ozone formation, human health, Resource use, fossils* and *Resource use, minerals and metals* for a cumulative contribution of 84.6% of the total impact (**Table 25**).

Most relevant categories common to both systems are indicated in the **brown cells**, while most relevant categories for only one system are indicated in **orange cells**.

Table 24 Impact categories cumulatively contributing at least 80% of the total environmental impact for SU system

Single-use system - Impact category	Contribution to the total impact (%), excluding toxicity impact categories
EF 2.0 Acidification [Mole of H+ eq.]	5.7%
EF 2.0 Climate Change - total [kg CO2 eq.]	36.4%
EF 2.0 Eutrophication, freshwater [kg P eq.]	3.9%
EF 2.0 Eutrophication, marine [kg N eq.]	2.6%
EF 2.0 Eutrophication, terrestrial [Mole of N eq.]	3.4%
EF 2.0 Ionising radiation, human health [kBq U235 eq.]	3.1%
EF 2.0 Ozone depletion [kg CFC-11 eq.]	0.5%
EF 2.0 Particulate matter [Disease incidences]	7.6%
EF 2.0 Photochemical ozone formation, human health [kg NMVOC eq.]	5.4%
EF 2.0 Resource use, fossils [MJ]	26.3%
EF 2.0 Resource use, mineral and metals [kg Sb eq.]	5.1%

Table 25 Impact categories cumulatively contributing at least 80% of the total environmental impact for MU system

Multiple-use system - Impact category	Contribution to the total impact (%), excluding toxicity impact categories
EF 2.0 Acidification [Mole of H+ eq.]	5.8%
EF 2.0 Climate Change - total [kg CO2 eq.]	32.8%
EF 2.0 Eutrophication, freshwater [kg P eq.]	3.1%
EF 2.0 Eutrophication, marine [kg N eq.]	1.6%
EF 2.0 Eutrophication, terrestrial [Mole of N eq.]	2.9%
EF 2.0 Ionising radiation, human health [kBq U235 eq.]	1.6%
EF 2.0 Ozone depletion [kg CFC-11 eq.]	0.5%
EF 2.0 Particulate matter [Disease incidences]	8.1%

EF 2.0 Photochemical ozone formation, human health [kg NMVOC eq.]	7.7%
EF 2.0 Resource use, fossils [MJ]	22.9%
EF 2.0 Resource use, mineral and metals [kg Sb eq.]	13.09%

5.3 Sensitivity analysis

The following sections present the performed sensitivity analyses, investigating the influence of critical parameters on the results and the comparative analyses. In this regard, only one parameter (or assumption) is changed per system. This is aimed at keeping transparency and ensure traceability of results. Critical assumptions and their potential effect on the baseline comparison are evaluated, and detailed results are presented per sensitivity scenario and compared to the relevant related counterpart. The performed sensitivity scenarios are based on both the contribution analysis of the baseline comparison and the identified variability regarding critical parameters. As a result, certain potentially sensitive parameters or assumptions are excluded from the quantitative sensitivity analysis as they are found to impact both scenarios equally and hence do not influence the comparative assertion.

5.3.1 Scenarios

Table 26 gives an overview of all production and product related sensitivity analysis presented with different scenarios. To maintain transparency and ensure traceability of results, only one parameter (e.g., number of reuses) or assumption (e.g., EoL fate: shares of recycling, incineration and landfill) has been changed per each sensitivity analysis.

Table 26: Summary of sensitivity analyses (SU: SU system paper based, MU: multiple-use system plastic based)

Domain of parameter change	Baseline scenario	Sensitivity analysis
Take-back system (MU)	Number of reuses = 50	**S01**: Number of reuses = 100
	Return rate = 50%	**S02:** Return rate **=** 70%
	1/2 trips to return MU items are neglected (multifunctional approach)	**S03**: 4/5 trips to return MU items are neglected (i.e., 4 out of 5 people return MU items in case of buying of another menu)
Washing phase (MU)	Preliminary washing at home	**S04**: no preliminary washing at home
	Hood-type dishwasher	**S05**: External washing with band transport dishwasher
End-of-life (both systems)	30% recycling, 60% incineration, 10% landfill (both systems)	**S06:** 30% recycling, 70% incineration (both systems)
		S07: 60% recycling, 30% incineration, 10% landfill (both systems)
		S08: Eurostat data: for SU: 82.9% recycling, 7.8% incineration, 9.3% landfill

Domain of parameter change	Baseline scenario	Sensitivity analysis
		for MU: 41.8% recycling, 33.5% incineration, 24.7% landfill
	System expansion (i.e., avoided burden) allocation approach	**S09:** Cut-off 50:50 allocation approach

The sensitivity scenarios are explained in the following sections. The assumptions around these parameters can vary depending on the analysed system, thus more conservative figures are chosen in order to test the robustness of results when varying these parameters.

Take-back system parameters (S01, S02 and S03)

Number of reuses and return rate in the baseline are chosen based on primary data collected directly from QSRs operators. In the sensitivity analysis, these figures are incremented to simulate a more efficient take-back system. For the number of reuses, a value of 100 reuses is evaluated. This is retrieved from the in-store LCA study (Ramboll, 2020) and represent an average of different figures reported in literature. Even though this value might be too high for a take-away system, it is tested as it can be a key parameter.

With respect to the return rate, 70% is tested. It is understood from discussion with QSRs operators that 70% is the desired return rate for in-store consumption (thus probably too high for take-away system). In fact, based on real data the return rate of in-store is significantly lower than 70%, but it is tested as it can be a key parameter.

The assumptions around the trips to return MU items already provide a conservative approach in the baseline, by considering multifunctionality of trips (as described in **section 4.5.4**). In the sensitivity, these figures are further reduced, considering that 4/5 of total trips to return MU items are neglected. However, results of this scenario reflect a very conservative approach, according to which 4 out of 5 people return MU items in case of buying of another menu

Washing phase (S04 and S05)

For the preliminary cleaning/washing stage of MU items at home, different methods were identified and described in the baseline. However, different companies working with reusable meal containers encourage the customers to either not clean them or only clean them shortly by rinsing with cold water (Verburgt, 2021). Moreover, this also depends on customers behaviour. For this reason, a scenario without preliminary washing at home is tested.

Regarding the external washing with band transport dishwasher in the MU system (S05), this scenario explores the effects of washing multiple-use items at an external service-provider instead of in-house in QSRs. Therefore, items are assumed to be collected and transported to external washing facilities after each use. Washing and rinsing at the service-provider takes place using a band transport dishwasher[40], and it is assumed to represent best-available-technique (BAT). Information is provided by Profimiet[41] and data is reported for PP cup washing in the year 2020, including a dedicated drying module to achieve highest hygiene standards.

[40] This type of dishwasher can handle over 8000 plates per hour.
[41] PROFIMIET GmbH, personal communication

Table 27 shows the relative differences of the energy, water and chemicals demands for the external washing process. Further underlying key assumptions for this scenario can be summarised as follows:

- Additional transport to and from service provider is assumed to be 100 km (via lorry);
- Additional weights for packaging using reusable racks are accounted for;
- Production and disposal of racks for transport is excluded;
- Dedicated service providers with respective equipment in place are existing and therefore no new dishwashers need to be produced and installed[42];

All other assumptions of the baseline scenario (e.g., reuse rates of multiple-use items) remain unchanged.

Table 27: Relative differences of environmentally relevant inputs to the external dishwashing scenario in comparison to the baseline.

Parameter	External washing using a band-transport dishwasher
Energy demand [kWh/item]	0.009
Water demand [l/item]	0.062
Combined detergent, rinse agent and softener demand [g/item]	0.075

Different End-of-life fate for both SU and MU systems (S06, S07 and S08)

This scenario elaborates results by assuming different recycling rates, different incineration rates, and different landfilling rates. This is due to the uncertainty presented in the baseline scenario, (see **section 4.3**) and in order to explore further EoL scenarios, which could be of relevance in the EU context. While in the EU the recycling rate for paper and cardboard packaging waste is high (around 82.9%, see Eurostat[43]), this is not methodological clear how to extent this value to the supply chain for quick-service restaurant in a mixed scenario with B2B domain, as well as B2C domain (due to users' behaviours). Therefore, considering the take-away restaurant study focus, an assumption of 30% recycling of post-consumer paperboard waste is implemented for the baseline comparison.

The following different potential scenarios are tested:

- **Scenario S06**, with 30% recycling and 70% incineration, investigates the absence of landfilling. This is investigated as in many EU countries future landfilling ban at B2B level will be effective, and therefore this scenario could be seen as hypothetical analysis of future effects on EoL rates.
- **Scenario S07**, with 60% recycling, 30% incineration, and 10% landfill, investigates a symmetrical approach for recycling and incineration by assuming that in the future paper and plastic materials would be subjected to higher recycling rates at equal level, and by

[42] For the baseline a generic assumption of two additional dishwashers with a ten-year lifetime is taken into account via a simplified bill of materials
[43] https://ec.europa.eu/eurostat/databrowser/view/ten00063/default/table?lang=en

assuming a fixed amount of landfilling that would represents an uncertain parameter that cannot be avoid in all European countries.

- **Scenario S08**, by using Eurostat data (for SU: 82.9% recycling, 7.8% incineration, 9.3% landfill, and for MU: 41.8% recycling, 33.5% incineration, 24.7% landfill), investigates the consequences by applying a non-symmetrical approach for EoL fate. In this case, the SU system benefits from a higher share of recycling rate, which is mainly driven in Europe by corrugated paperboard. The MU system is however be affected by a lower recycling rate than the SU counterpart, but with higher recycling rate than the baseline scenario.
- **Scenario S09**, which provides a methodological variation in terms of allocation approach, shifting from the system expansion methodology (i.e., avoided burden method) to the cut-off 50:50. This latter assigns burdens and credits from the recycling processes in equal proportion to the previous and subsequent product in which the material is used (Allacker et al., 2014).

5.3.2 Visualization of the sensitivity analysis results

The following charts report the results of the sensitivity analysis for each impact category, showing them in terms of percentage difference between SU and MU systems. The charts have two parts:

- if SU system is less impacting than MU system in a selected impact category, the bars are shown in the upper part of the chart.
- if MU system is less impacting than SU system in a selected impact category, the bars are shown in the lower part of the chart.

This means that the 0% line represent the “starting point”, and any variation from that line represent the environmental performance in terms of percentage difference between SU and MU systems when varying a specific parameter (for reference, the baseline scenario is included in the chart).

If the bars are not visible, it means that both systems show a comparable performance when varying that specific parameter (i.e., the bars rely on the 0% line).

With this type of visualization, robustness can be visualized as follows:

- When a parameter is not crucial and does not change the results of the analysis, the bar of the correspondent product is visualized in the same side of the chart (either upper or lower part). This means that, to some extent and depending on the percentage variation of the results, the results due to the variation of the selected parameter could be considered robust
- When a parameter is crucial and changes the results of the analysis, for instance, the bar of the correspondent product is visualized in the opposite side of the chart (either upper or lower part).

All nominal results are given in **APPENDIX 6. Results of sensitivity analysis in tabular form.**

5.3.3 Results of the sensitivity analysis

Results of the sensitivity analysis are given in the following charts. All results in table form are given in **APPENDIX 6. Results of sensitivity analysis in tabular form.**

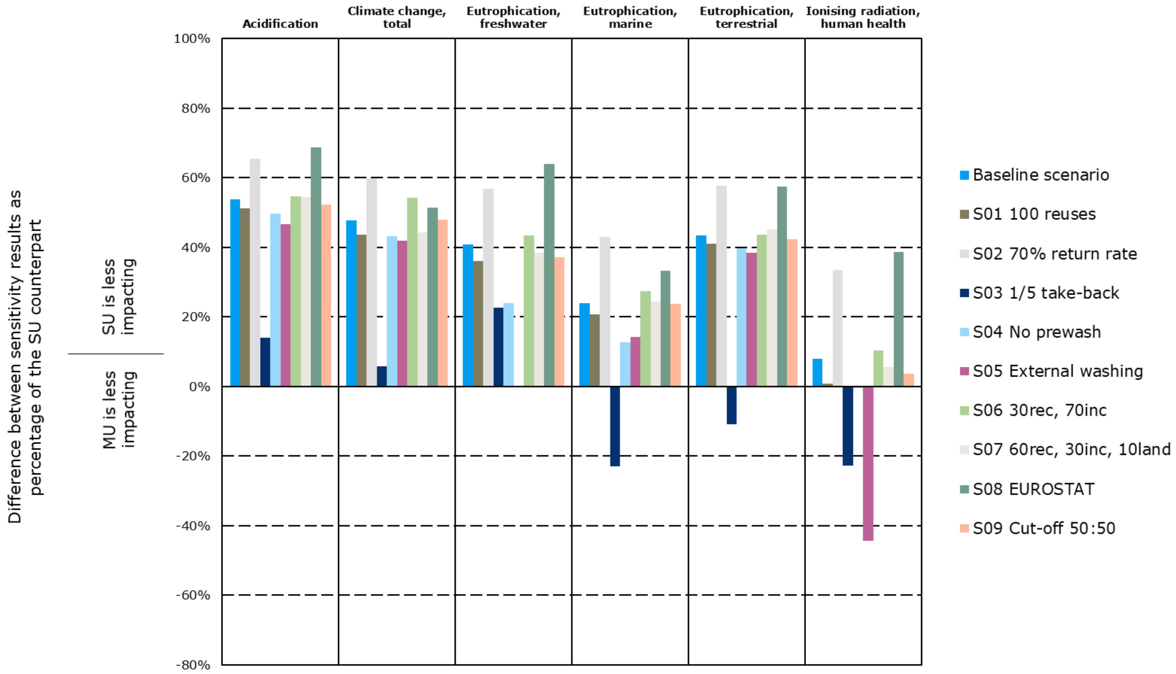

Figure 10 Sensitivity analysis – part 1/2

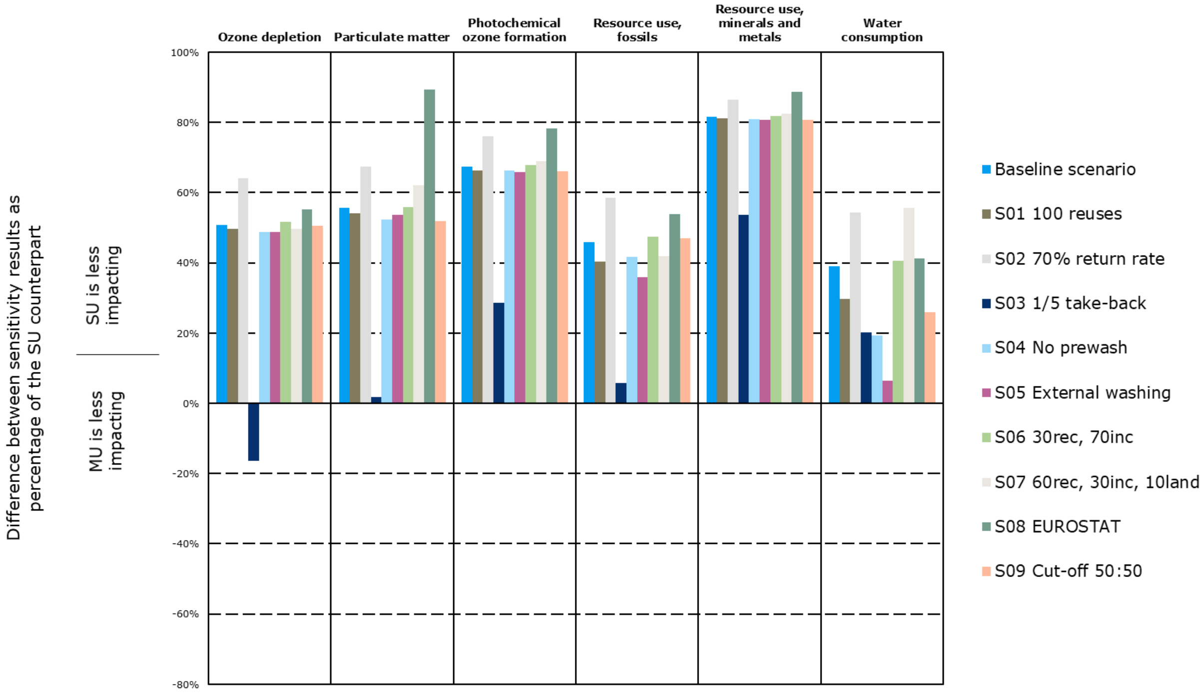

Figure 11 Sensitivity analysis – part 2/2

As shown in the charts, most of the tested scenarios provide results similar to those of the baseline, confirming a situation in which the percentage difference between SU and MU systems is in favour of SU system (i.e., overall results show that SU is less impacting). Few variations in the results can be obtained when 4/5 of total trips to return MU items are neglected (S03, whose effect is able to turn the results in favour of MU system only for *Eutrophication marine*, *Eutrophication terrestrial*, *Ionising radiation, human health*, and *Ozone depletion* categories) and when considering the external washing (S05, whose effect is able to turn the results in favour of MU system only for *Ionising radiation, human health* category).

Here below, a more detailed discussion is given by presenting a focus on the three groups of scenarios (described above) in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems (described in **section 5.2**).

Take-back system parameters in MU system (S01, S02, S03)

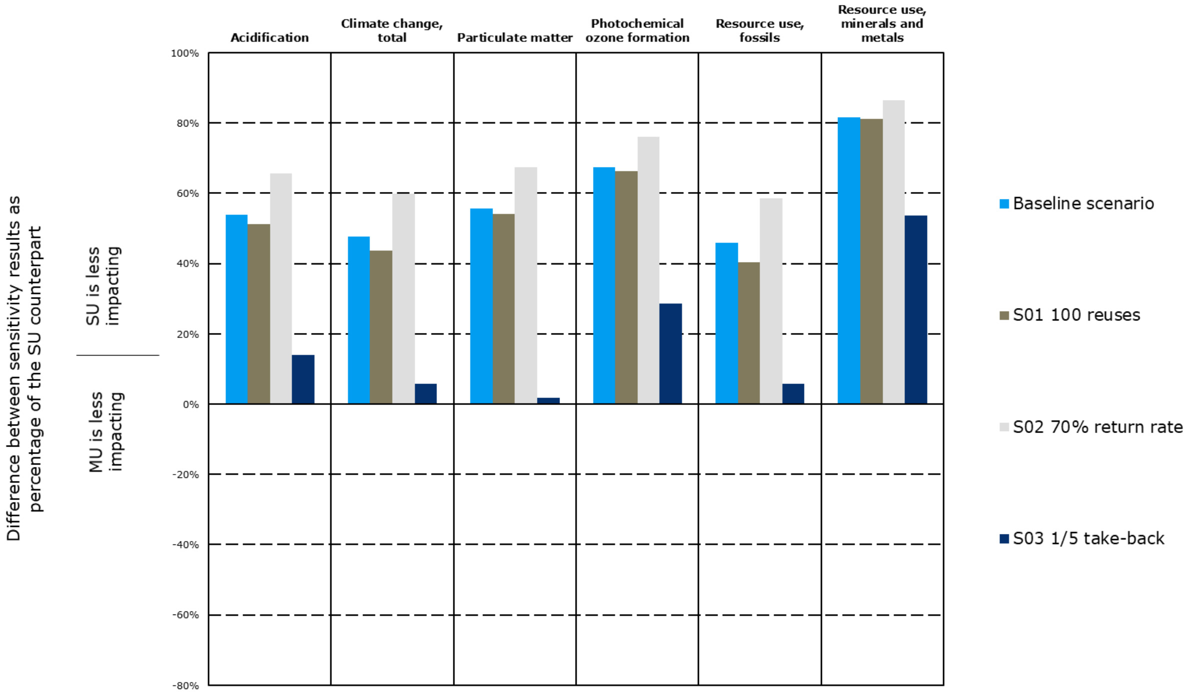

Figure 12 Sensitivity analysis for take-back system parameters in MU system in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems.

The chart of **Figure 12** reports results for the variation of the logistic parameters for MU system, showing that such variation does not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. Going into detail:

1. The variation of number of reuses to 100 is able to provide a little variation for the analysed impact categories (with the exception of *Resource use, minerals and metals*). However, this variation is very limited and does not change the overall results.
2. The variation of return rate to 70% even provides a widening of the delta between the two systems (i.e., a higher return rate implies higher impacts for the MU system). For the MU system, a higher return rate means:
    a. lower impacts for the production and end-of-life phase.
    b. higher impacts for the use phase transport preliminary washing.

   Since use phase transport and preliminary washing phases are the hotspots of MU system, increasing the return rate implies more direct and indirect environmental impacts than avoided ones.

3. The reduction of total trips for take-back, considering that 4/5 of total trips to return MU items are neglected (i.e., 4 out of 5 people returning MU items in case of buying of another menu), provides the largest improvement for MU system with some results almost comparable to those of SU system, but still not changing the results (i.e., SU system is still less impacting).

   However, results of this scenario reflect a very conservative approach, according to which 3/4 of trips for take-back are neglected.

Washing phase in MU system (S04, S05)

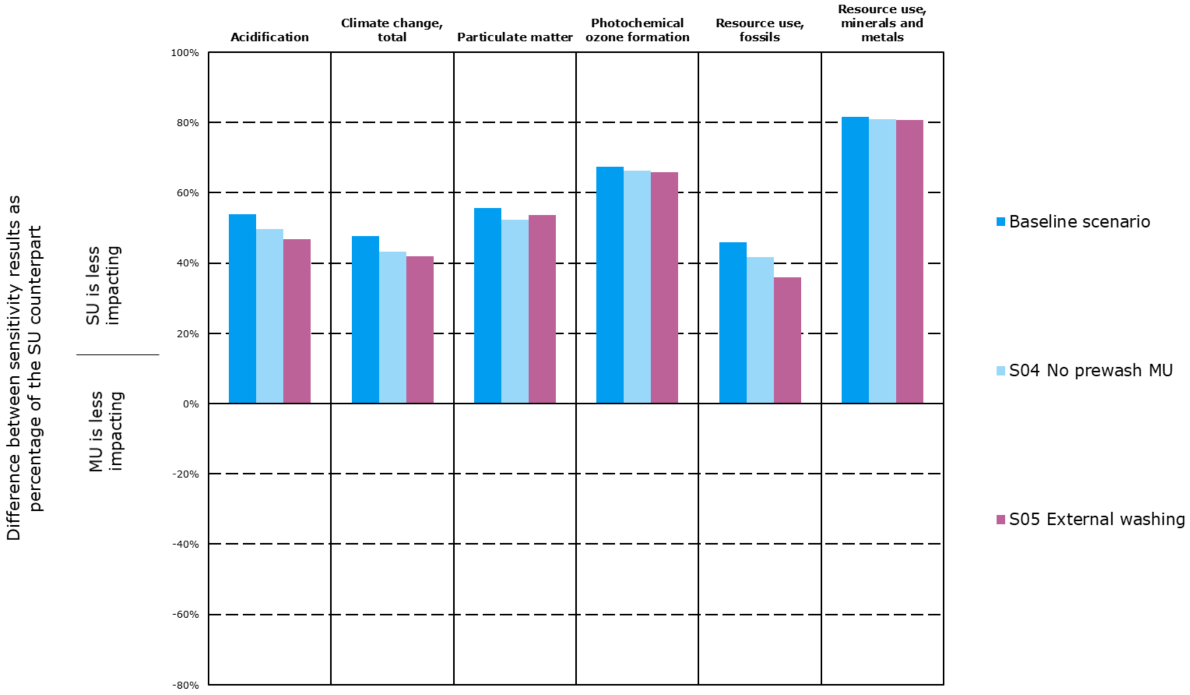

Figure 13 Sensitivity analysis for washing phase in MU system in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems.

The chart of **Figure 13** reports results for the variation of the washing phase for MU system, showing that such variation does not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. Overall, the variation provided by both scenarios in the analysed impact category is very limited.

Different End-of-life shares and allocation approach for SU and MU systems (S06, S07, S08, S09)

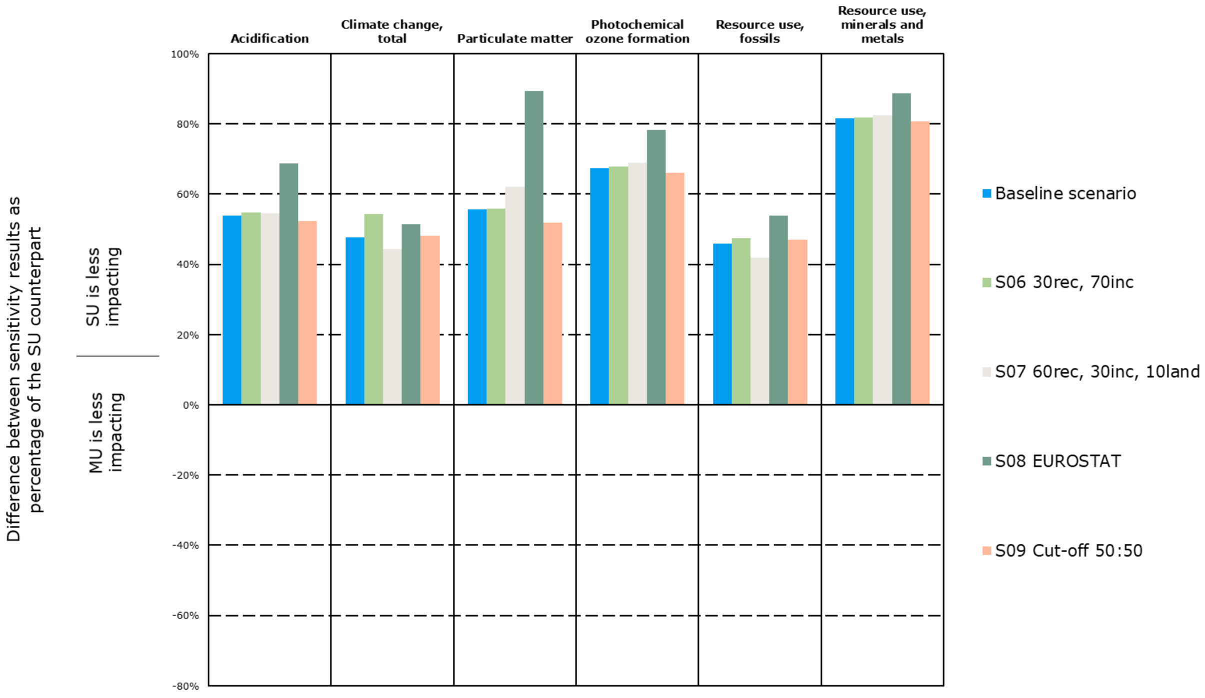

Figure 14 Sensitivity analysis for different End-of-life shares for both SU and MU systems in the impact categories cumulatively contributing at least 80% of the total environmental impact of both systems

Finally, when analysing the results of different end-of-life shares and allocation approach (**Figure 14**), again it is shown that such variations do not imply changing in the results of the analysis (i.e., the bars are visualized in the upper side of the chart, meaning that SU system is still less impacting). This also means that the results due to the variation of the selected parameters can be considered robust. The Eurostat shares gives a larger delta between the two systems (i.e., by utilising data provided by Eurostat, SU is less impacting than the baseline), even though figures by Eurostat cannot be assumed as fully representative of the analysed system, as explained in **section 4.3**.

6. CONCLUSIONS

The chapters above provide background information and results for a comparative LCA of single-use and multiple-use tableware options for take-away systems in QSRs in Europe (see description of goal and scope of the study in **section 3**). A systems perspective is used to reflect both systems and compare equal functions of single-use and multiple-use product items in an average QSR context in Europe (see **section 3.2** on QSR characteristics and the functional unit used for this LCA). The LCA is performed according to relevant ISO standards 14040 and 14044 and discusses the impacts on a set of twelve environmental impact categories (see **section 3.2.7**). In this regard it is important to emphasise that the eventual selection of the assessed impact categories is the inevitable result of primary data acquisition. More specifically, land occupation and toxicity impact categories are deemed not reliable as appropriate inventory data from suppliers' direct operations (e.g., forest operations) is lacking. The generic exclusion of potentially relevant impact categories for both systems is an unavoidable limitation of this study which needs to be taken into account when interpreting overall results and making decisions in this regard.

With regards to data quality and appropriateness for the goal and scope of this assessment, it is important to differentiate between primary and secondary data (see **section 4.2**) as well as to acknowledge environmentally decisive life-cycle stages and processes within both systems. In order to have robust and reliable sources of data related to the potentially relevant parameters, Ramboll performed a specific data gathering (via datasheets, questionnaire) to QSRs operators related to the use stage in take-away systems, such as distribution channels repartition, type of washing and type of dishwashers, number of reuses of a product, return rates, means of transport and distances covered. Moreover, primary data and information (reflected in the functional unit) for single-use system are obtained from EPPA members' which market shares cover more than 65% of QSRs in Europe. Also, data from scientific papers in Q1 journal with high level of consistency have been incorporated for both SU and MU systems.

Overall, results of the comparative assessment of the single-use and multiple-use systems show that 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 use phase transport (to take-back MU items to QSRs) and the washing of items (see results in **section 5**). To test decisive assumptions in the systems, several sensitivity scenarios are analysed (see **section5.3**).

Under consideration of obtained impact results, it can be concluded that, for the baseline comparison between SU and MU, SU system shows lower impacts in all impact categories with a relative percentage difference ranging between 8% (for *Ionising radiation* category) to 82% (for *Resource use, minerals and metals* category).

Performed sensitivity analysis shows that most of the tested scenarios provide results similar to those of the baseline, confirming a situation in which the percentage difference between SU and MU systems is in favour of SU system (i.e., overall results show that SU is less impacting). Some differences in the results can be obtained for:

- S03 scenario (according to which 4/5 of total trips to return MU items are neglected, i.e., 4 out of 5 people returning MU items in case of buying of another menu), whose effect is able to turn the results in favour of MU system only for *Eutrophication marine*, *Eutrophication terrestrial*, *Ionising radiation, human health*, and *Ozone depletion* categories.

- S05 scenario (external washing), whose effect is able to turn the results in favour of MU system only for *Ionising radiation, human health* category.

These results are partly in contrast to other LCA studies that are mainly product-focused and often reveal clearer environmental advantages for multiple-use items compared to their single-use equivalents as long as a certain minimum number of reuses is considered (see **sections 1.1.2 and 2.1.1** for the literature screening). This difference can be largely explained by the fact that previous studies are mainly relying on secondary data (in particular concerning the paper upstream value chain) whereas the study at hand implemented primary data to a large extent, in particular for the environmental hotspots of paper production and conversion in the single-use system. However, for the multiple-use system, data is based on literature information and assumptions combined with inputs from QSRs operators where possible. This is due to the fact that the return scheme multiple-use system presents a hypothetical future scenario for which no consolidated primary data exists. With regard to specific functioning of QSRs, it is mainly based on data provided by QSRs operators retrieved from in-store consumption (multiple-use items, dishwashing process, selling channels) where multiple-use scheme is already in place.

In this sense, it must be noted that considerations regarding take-back system of MU items and features of related trips (distance, multifunctionality (i.e., the fact that a trip is made specifically to return MU items or not), allocation of burdens) strongly depends on customers' behaviour and might represent a decisive factor when considering overall environmental performance of MU system. With reference to these aspects, the study tried to implement assumptions as much conservative as possible. However, the complexity around these assumptions arises from:

- the hypothetical nature of MU system for QSRs, since it is not yet fully established at industrial scale, implying a partial lack of data availability. Although based on data provided by QSRs operators MU plastic alternative might be predominant in future considering specific nature of QSR industry (i.e., high volumes, need of hygiene and food safety at the highest level).
- The unpredictability of customers' behaviour, which is in contrast with the science-driven nature of LCA, thus implying the need to make specific assumptions for the correct functioning of the system. These assumptions are clearly reported in this study to guarantee transparency of the assessment.

This study is not intended to present or interpret environmental impacts on a product level. Modelling choices, data quality and assumptions are to be seen in the light of the overarching goal and systems perspective.

The study shows that there are different potentially crucial assumptions and parameters that can have a key role in the functioning of analysed systems and associated environmental impacts. This is particularly evident with reference to the hot-spots of the system, which are:

- **Raw material extraction** and **Converting** life cycle stages for SU system: due to the geographical scope of the study (i.e., Europe), European averages are used for important (background) processes such as the electricity mix and pulp production for EoL allocation (i.e., avoided impacts associated with assumed substitution of average pulp products from virgin sources). Thus, the selection of another geographical scope could significantly change the results and comparative assertion.

- **Use phase transport** and **Washing** life cycle stages for MU system: this are again influenced by the electricity mix (and then the geographical scope), selling channels, specific means of transport, and customers' behaviour regarding several aspects (preliminary washing at home, separate collection of waste, choices regarding the take-back system.

The results of the study also point to further need for research and investigation of relevant parameters, with particular emphasis to take-back system of MU items and features of related trips: distance, multifunctionality (i.e., the fact that a trip is made specifically to return MU items or not), allocation of burdens.

7. CRITICAL REVIEW STATEMENT

Critical review statement

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Comparative Life Cycle Assessment (LCA): Single Use and Multiple Use Tableware Systems for Take-Away Services in Quick Serve Restaurants

Review background

This document forms the critical review statement for the study "Comparative Life Cycle Assessment (LCA) Single Use and Multiple Use Tableware Systems for Take-away Services in Quick Service Restaurants" as reported by Ramboll in their Technical LCA report for Project Number 330001928, dated November 2022. The report was prepared by Ramboll Italy, and was commissioned and funded by European Paper Packaging Alliance (EPPA).

The critical review has been performed by an independent panel consisting of:

- Michael Sturges (lead panellist) - RISE Research Institutes of Sweden / RISE Innventia AB, Sweden – a life cycle assessment practitioner with specific experience of environmental studies relating to the packaging and food service sectors
- Prof. Umberto Arena – University of Campania "Luigi Vanvitelli", Italy. – a chemical engineer with experience of packaging systems, including LCA studies on valorisation of paper and plastic waste streams
- Frank Wellenreuther, ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH, Germany – a life cycle assessment practitioner with specific experience of environmental studies relating to packaging systems

Critical review process

The review was performed based on the requirements of ISO14044:2006 Section 6.3, i.e., critical review by panel of relevant experts.

The critical review was iterative in nature, being performed concurrently with the LCA study. The review panel was in regular contact with the LCA study team and provided comments at the following stages of the study:

- Goal and scope document (word document and presentation to the critical review panel)

- Primary and secondary life cycle inventory data selected for the modelling (word document and presentation to the critical review panel – this included access under non-disclosure agreement to the confidential primary data used in the models)
- Draft baseline results (presentation to the critical review panel)
- Finalised baseline results and sensitivity scenarios (presentation to the critical review panel)
- Draft final report (word document)

At each stage, comments were provided using a MS Excel feedback template and were discussed in a meeting with the LCA practitioners and representatives of EPPA. The LCA team then responded to the comments and provided its feedback, also describing subsequent changes to the data, models and report, by using the appropriate section of the feedback template. The reviewers considered these responses and changes and were satisfied that appropriate clarifications and actions had been provided.

Result of the critical review

Subsequently, the study was found to be in conformance with ISO 14040 and ISO 14044.

Opinion of the reviewers

The reviewers find the study's level of quality, detail and transparency to be appropriate considering the goal and scope. In particular, they appreciate the specific data gathering implemented by the authors of the study. Subsequently, the reviewers consider the results and conclusions to be a sound and fair reflection of the potential comparative environmental impacts of the studied systems representing the use of single use and multiple use tableware for take-away services in Quick Service Restaurants. The detailed sensitivity analysis provides transparency of the uncertainties and confidence in the overall robustness of the results achieved and conclusions drawn.

As with all LCA studies, there are opportunities to improve the analysis and evaluation. In particular, for this study it would be interesting to see the results for all the Environmental Footprint impact categories, including toxicity-related impact categories and land-use. However, it is appreciated by the review panel that there are limitations to achieving this: the available primary LCI data did not support the fair comparison of toxicity related impact categories and the applicability and robustness of the land use impact category for paper products is subject to ongoing development. If further data becomes available to support fair comparison of toxicity impact categories and if the land use impact category is fully developed, then updating the analysis to include these would give further insights into the nature of any wider trade-offs between the systems not addressed by the selected impact categories, and would increase the transparency of the analysis.

However, the critical review panel appreciates that this would also add further complexity to and require additional resource for an already comprehensive study.

In conclusion, it is the opinion of the review panel that the report provides useful and realistic information for stakeholders interested in this topic.

Critical review sign-off

The reviewers certify that the statement provided is a fair reflection of their assessment and views of the study “Comparative Life Cycle Assessment (LCA) Single Use and Multiple Use Tableware Systems for Take-away Services in Quick Service Restaurants”:

Signed: Dated: 12th November 2022

Michael Sturges, RISE Research Institutes of Sweden / RISE Innventia AB, Sweden (lead panellist)

Signed: Dated: 12th November 2022

Prof. Umberto Arena – University of Campania “Luigi Vanvitelli”, Italy

Signed: Dated: 12th November 2022

Frank Wellenreuther, ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH, Germany

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APPENDIX 1. LIFE CYCLE INVENTORY

Single-Use System inventory

Single-use items are based on primary data provided by EPPA members and their suppliers and cover a typical set of items for serving one meal. Primary data collected from manufacturers is either through LCIA results or own modelling of received input/output sheets (i.e. connecting reference flows and values with applicable datasets and flows from LCI databases) implemented in the LCA model.

For the collection of the primary data via input/output sheets, the following procedure is taken:

- data collection sheets were prepared and sent to companies
- companies collected information on their production processes: paper products production (upstream - raw material production and processing), converting process (upstream - converting)
  This primary data is collected/measured directly by a company; e.g. raw material demand, energy (electricity, natural gas, etc.), wastes (emissions as well as solid waste) inputs and outputs for a particular process or product. Data are collected and maintained by subject-matter experts such as material and product engineers, research and development managers, or LCA experts of the companies.
- This collected data was checked for applicability, completeness, consistency, and plausibility. And questions to companies were sent in case of lack of data of its inconsistency. This was an iterative process.
- In case of lack of information, calculation is made. This is relevant, for example, for estimating emissions released with fuel combustion. These emissions (in the output tables of this Appendix) are calculated by using emissions factors (from literature, e.g., from Department for Business, Energy & Industrial Strategy, UK[44]). This is relevant, for example, for natural gas, petroleum liquefied gas and diesel, among other fossil fuels.

Data and information obtained are disclosed to the extent confidentiality reasons allow.

Upstream - Raw material production/processing

Chemical pulp (softwood):

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Chemical pulp (softwood)	Primary data	Confidential	Finland	1 t dry chemical pulp	2021

[44] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

For this upstream process, EF 2.0 impact assessment results based on proprietary LCA models are implemented in this assessment.

The implemented LCIA results refer to a cradle-to-gate system boundary. That is, from the point at which raw materials are extracted from the environment through to the point at which finished products are ready for distribution to customers (i.e., paper manufacturers) at the factory gate. Hence, the following major process steps are included:

- Raw material production;
- Raw material transport;
- Processing into chemical pulp (wood handling, cooking, bleaching, drying), and co-products.

Primary data is from actual process data, and incorporated secondary data is obtained from Ecoinvent 3.8 database.
Proxy data is used to fill following data gaps:

- Proxy for polyethylene glycol (commonly used defoamer)

The following allocation approach is adopted:

- Economical allocation (e.g., for turpentine, crude tall oil, thermal energy, electricity, etc.)

PE-coated paperboard:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
PE-coated paperboard	Primary data	Confidential	Finland	1 t board	2021

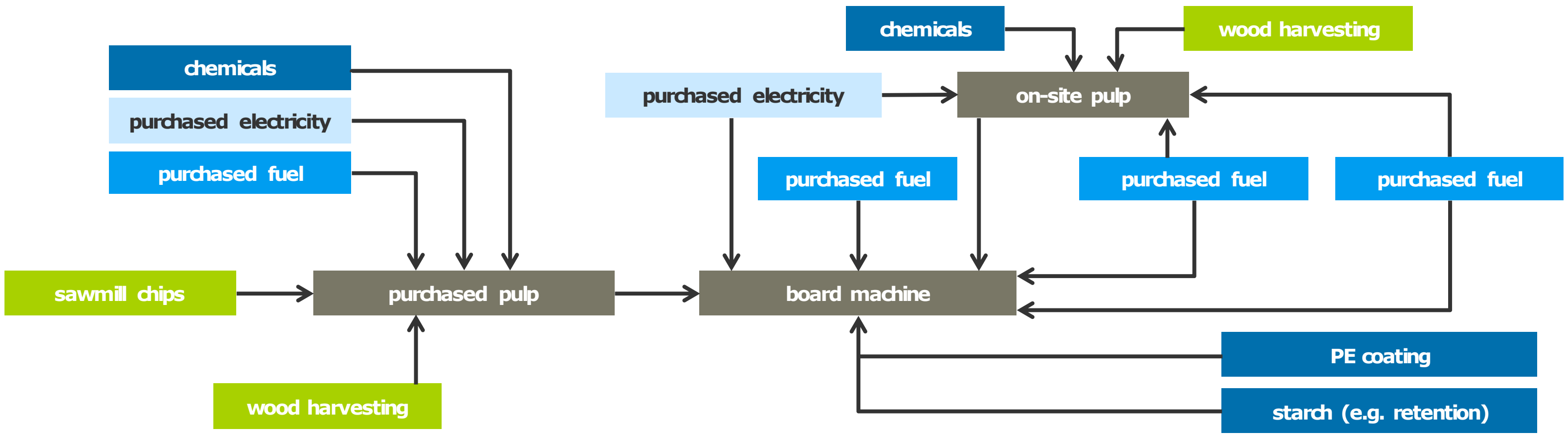
For this upstream process, EF 2.0 impact assessment results based on proprietary LCA models are implemented in this assessment.

The LCA model contains different variants and specifications of PE-coated paperboards. Depending on the single-use product different paperboard specifications are used. The exact technical specifications and used paper products are based on primary information from converters. Specific LCIA results are implemented for each variant and specification of PE-coated paper. Quantitative data for the PE-coated paper grades are confidential. For further reference and enhanced transparency of the study, some details are disclosed below.

In general, two different variants are implemented for the modelling of respective converting (product manufacturing) processes:

- Virgin-fibre bleached board and PE coating on the reverse side (in total, five different technical specifications (e.g., different grammage) of this variant are implemented);
- Virgin-fibre board with PE coating on the reverse side (in total, one technical specification of this variant is implemented).

The implemented LCIA results refer to the following production process and cradle-to-gate system boundaries:



Source: Confidential

In summary, the following main process steps and datasets are included in the provided impact results:

- Wood harvesting, wood supply from different supply regions. Specific data for wood harvesting from each region;
- Pulp and board chemicals, cut off 1%. Data from Ecoinvent 3.8;
- Fuels used in mill. Fuel production from Ecoinvent 3.8;
- Purchased electricity. Electricity sources according to site-specific supply mix. Electricity production processes from Ecoinvent, shares site-specific;
- All transport distances are primary data. Environmental data for transportations from VTT Lipasto database;
- Primary data for pulp and board production and PE coating. Primary data also for purchased pulps;
- PE data from Ecoinvent 3.8, transportation of PE primary data.

Underlying LCA models of implemented LCIA results adhere to ISO 14040/44 standards. LCIA results are based on cradle-to-gate data, including all relevant energy and material inputs (see excerpt above). Cut-off rule is 1%, with certain exemptions for chemicals/raw materials that sometimes are less than 10kg/t. Land occupation and toxicity categories are deemed not reliable and hence excluded from provided LCIA results (see also section 3.2.7). Moreover, provided LCIA data does not account for biogenic carbon.

Thin greaseproof paper with soy-based coating:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Thin greaseproof paper with soy-based coating	Primary data	Confidential	Confidential data	1 t paper	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory is confidential. It refers to cradle-to-gate system boundaries.

High-brightness paperboard:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
High-brightness paperboard	Primary data	Confidential	Confidential data	1 t paperboard	2019

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Market pulp (chemical, bleached)	Confidential data	kg	Confidential data
Recovered paper	Confidential data	kg	Confidential data
Production chemicals	Confidential data	kg	Confidential data
Production chemicals: calcium carbonate	Confidential data	kg	Confidential data
Production chemicals: kaolin	Confidential data	kg	Confidential data
Production chemicals: latex	Confidential data	kg	Confidential data
Production chemicals: binder, retention agents, starch	Confidential data	kg	Confidential data
Shrink foil (packaging material)	Confidential data	kg	Confidential data
Pallets (packaging material)	Confidential data	kg	Confidential data
Other (packaging material)	Confidential data	kg	Confidential data
Electricity from grid	Confidential data	MWh	Confidential data
Natural gas	Confidential data	kg	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Biogas (renewable) (on-site generation)	Confidential data	MWh	Confidential data
Diesel	Confidential data	kg	Confidential data
District heating (sold)	Confidential data	MWh	Confidential data
Municipal water supply	Confidential data	kg	Confidential data
Ground water	Confidential data	kg	Confidential data
Surface (river) water	Confidential data	kg	Confidential data
Sewage water (thermally polluted)	Confidential data	kg	Confidential data
Sewage water process	Confidential data	kg	Confidential data
Reject/recovered paper residues	Confidential data	kg	Confidential data
Sludge	Confidential data	kg	Confidential data
Metal scrap	Confidential data	kg	Confidential data
Wood waste	Confidential data	kg	Confidential data
Other non-hazardous waste	Confidential data	kg	Confidential data
Hazardous waste (incl. Lubricants)	Confidential data	kg	Confidential data
CO_2 fossil (to air)	Confidential data	kg	Confidential data
CO_2 biogenic (to air)	Confidential data	kg	Confidential data
CO (to air)	Confidential data	kg	Confidential data
NO_X (to air)	Confidential data	kg	Confidential data
SO_2 (to air)	Confidential data	kg	Confidential data
Dust (to air)	Confidential data	kg	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
COD (to freshwater)	Confidential data	kg	Confidential data
BOD (to freshwater)	Confidential data	kg	Confidential data
Suspended solids (to freshwater)	Confidential data	kg	Confidential data
AOX (to freshwater)	Confidential data	kg	Confidential data
Total N (to freshwater)	Confidential data	kg	Confidential data
Total P (to freshwater)	Confidential data	kg	Confidential data

Upstream – Converting

Wooden cutlery:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Wooden cutlery	Secondary data	Paspaldzhiev et al.	Europe	1 pc	2017

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Wooden utensil	Europe	kg	0.003
Paper packaging (one packaging bag for three pieces)	Europe	kg	0.001

Clamshell:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Clamshell	Primary data	Seda	Germany	1000000 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Paperboard (70% recycled content)	Austria	kg	Confidential data
Road transport for paperboard	Austria-Germany	kg*km	Confidential data
Inks	France	kg	Confidential data
Road transport for inks	France-Germany	kg*km	Confidential data
Varnish	Germany	kg	Confidential data
Road transport for varnish	Germany	kg*km	Confidential data
Glue	Italy	kg	Confidential data
Road transport for glue	Italy-Germany	kg*km	Confidential data
Electricity	Germany	kWh	Confidential data
LDPE for packaging	Germany	kg	Confidential data
Road transport for LDPE	Germany	kg*km	Confidential data
Corrugated paperboard for packaging (40% recycled content)	Germany	kg	Confidential data
Road transport for corrugated paperboard	Germany	kg*km	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Non-hazardous process waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
non-hazardous technical waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
Ammonia emissions to air (printing area)	Germany	g	Confidential data

Fry bag:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Fry bag	Primary data	Seda	Germany	1000000 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Paperboard (70% recycled content)	Austria	kg	Confidential data
Road transport for paperboard	Austria-Germany	Kg*km	Confidential data
Inks	France	kg	Confidential data
Road transport for inks	France-Germany	kg*km	Confidential data
Varnish	Germany	kg	Confidential data
Road transport for varnish	Germany	kg*km	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
gr treatment	UK	kg	Confidential data
Road transport for gr treatment	UK-Germany	kg*km	Confidential data
Glue	Italy	kg	Confidential data
Road transport for glue	Italy-Germany	kg*km	Confidential data
Electricity	Germany	kWh	Confidential data
LDPE for packaging	Germany	kg	Confidential data
Road transport for LDPE	Germany	kg*km	Confidential data
Corrugated paperboard for packaging (40% recycled content)	Germany	kg	Confidential data
Road transport for corrugated paperboard	Germany	kg*km	Confidential data
Non-hazardous process waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
non-hazardous technical waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
Ammonia emissions to air (printing area)	Germany	g	Confidential data

Clip-on lid:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Clip on lid	Primary data	Seda	Germany	1000000 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Paperboard	Finland	kg	Confidential data
Road transport for paperboard	Finland-Germany	kg*km	Confidential data
Ferry transport for paperboard	Finland-Germany	kg*km	Confidential data
Paperboard PE-coated	Finland	kg	Confidential data
Road transport for paperboard PE-coated	Finland-Germany	kg*km	Confidential data
Ferry transport for paperboard PE-coated	Finland-Germany	kg*km	Confidential data
Inks	France	kg	Confidential data
Road transport for inks	France-Germany	kg*km	Confidential data
Varnish	Germany	kg	Confidential data
Road transport for varnish	Germany	kg*km	Confidential data
Vinylic glue	Italy	kg	Confidential data
Road transport for glue	Italy-Germany	kg*km	Confidential data
Electricity	Germany	kWh	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
LDPE bags for packaging	Germany	kg	Confidential data
LDPE stretch for packaging	Germany	kg	Confidential data
Road transport for LDPE bags/stretching	Germany	kg*km	Confidential data
Corrugated paperboard for packaging (40% recycled content)	Germany	kg	Confidential data
Road transport for corrugated paperboard	Germany	kg*km	Confidential data
Non-hazardous process waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
non-hazardous technical waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
Ammonia emissions to air (printing area)	Germany	g	Confidential data

Paper wrap:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Paper wrap	Primary data	Schisler	France	1000 pcs	2019

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Thin greaseproof paper with soy-based coating	Austria	kg	Confidential data
Transport (lorry 24 t) for paper	Austria-France	kg*km	Confidential data
Inks (water - food safe contact)	France	kg	Confidential data
Transport (lorry) for inks	France	kg*km	Confidential data
Electricity	France	kWh	Confidential data
Liquid Petroleum Gas	France	kg	Confidential data
Municipal water supply	France	kg	Confidential data
Plastic film for packaging	France	kg	Confidential data
Transport (lorry) for plastic film	France	kg*km	Confidential data
Corrugated box pallet for packaging (90% recycled content)	France	kg	Confidential data
Transport (lorry) for corrugated box pallet	France	kg*km	Confidential data
Pallet for packaging	France	kg	Confidential data
Transport (lorry) for pallet	France	kg*km	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Shrink wrap for packaging	France	kg	Confidential data
Transport (lorry) for shrink wrap	France	kg*km	Confidential data
Non-hazardous waste (paper) for recycling	France	kg	Confidential data
Transport (lorry) of paper waste	France	kg*km	Confidential data
Chemical oxygen demand (COD) (emissions to water)	France	kg	Confidential data
Biochemical oxygen demand (emissions to water)	France	kg	Confidential data
2-(N-morpholino)ethanesulfonic acid (emissions to water)	France	kg	Confidential data
Greases (emissions to water)	France	kg	Confidential data
Total Kjeldahl nitrogen (NTK) (emissions to water)	France	kg	Confidential data
Total phosphorus (emissions to water)	France	kg	Confidential data
Total hydrocarbons (emissions to water)	France	kg	Confidential data

Paper fry bag:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Paper fry bag	Primary data	Schisler	France	1000 pcs	2019

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Thin greaseproof paper with soy-based coating	Austria	kg	Confidential data
Transport (lorry 24 t) for paper	Austria-France	kg*km	Confidential data
Inks (water - food safe contact)	France	kg	Confidential data
Transport (lorry) for inks	France	kg*km	Confidential data
Glue	France	kg	Confidential data
Transport (lorry) for glue	France	kg*km	Confidential data
Electricity	France	kWh	Confidential data
Liquid Petroleum Gas	France	kg	Confidential data
Municipal water supply	France	kg	Confidential data
Corrugated box pallet for packaging (90% recycled content)	France	kg	Confidential data
Transport (lorry) for corrugated box pallet	France	kg*km	Confidential data
Pallet for packaging	France	kg	Confidential data
Transport (lorry) for pallet	France	kg*km	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Shrink wrap for packaging	France	kg	Confidential data
Transport (lorry) for shrink wrap	France	kg*km	Confidential data
Non-hazardous waste (paper) for recycling	France	kg	Confidential data
Transport (lorry) of paper waste	France	kg*km	Confidential data
Chemical oxygen demand (COD) (emissions to water)	France	kg	Confidential data
Biochemical oxygen demand (emissions to water)	France	kg	Confidential data
2-(N-morpholino)ethanesulfonic acid (emissions to water)	France	kg	Confidential data
Greases (emissions to water)	France	kg	Confidential data
Total Kjeldahl nitrogen (NTK) (emissions to water)	France	kg	Confidential data
Total phosphorus (emissions to water)	France	kg	Confidential data
Total hydrocarbons (emissions to water)	France	kg	Confidential data

Ice cream cup (PE content < 5 % w/w):

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Ice cream cup	Primary data	Seda	Germany	1000000 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
PE claycoated paperboard	Finland	kg	Confidential data
Road transport for paperboard	Finland-Germany	kg*km	Confidential data
Ferry transport for paperboard	Finland-Germany	kg*km	Confidential data
Inks	France	kg	Confidential data
Road transport for inks	France-Germany	kg*km	Confidential data
Varnish	Germany	kg	Confidential data
Road transport for varnish	Germany	kg*km	Confidential data
Electricity	Germany	kWh	Confidential data
LDPE bags for packaging	Germany	kg	Confidential data
LDPE stretch for packaging	Germany	kg	Confidential data
Road transport for LDPE bags/stretch	Germany	kg*km	Confidential data
Corrugated paperboard for packaging (40% recycled content)	Germany	kg	Confidential data
Road transport for corrugated paperboard	Germany	kg*km	Confidential data
Non-hazardous process waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
non-hazardous technical waste (inks and varnish negligible) for recycling	Germany	kg	Confidential data
Ammonia emissions to air (printing area)	Germany	g	Confidential data
2-Propanol emissions to air (printing area)	Germany	g	Confidential data

Downstream – End-of-life treatment

Recycling of coated paperboard:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Recycling of sorted paperboard from post-consumer waste PE-coated paper	Primary data	Confidential	Europe	1 t	2019

For this downstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
waste paperboard, sorted	Finland	kg	Confidential data
purchased electricity	Finland	kWh	Confidential data
RDF (external)	Finland	GJ	Confidential data
heavy fuel oil	Finland	kg	Confidential data
natural gas	Finland	kg	Confidential data
RDF (external)	Finland	GJ	Confidential data
wood residuals	Finland	kg	Confidential data
H2O2	Finland	kg	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
NaOH	Finland	kg	Confidential data
Sodium silicate	Finland	kg	Confidential data
River water	UK	m^3	Confidential data
Recycled pulp	Finland	kg	Confidential data
Wastewater	UK	m^3	Confidential data
CO2 fossil	Finland	kg	Confidential data
Methane	Finland	kg	Confidential data
N2O	Finland	kg	Confidential data
NOx	Finland	kg	Confidential data
SO2	Finland	kg	Confidential data
Particulates, unspecified	Finland	kg	Confidential data
COD	Finland	kg	Confidential data
BOD	UK	kg	Confidential data
Nitrogen	Finland	kg	Confidential data
Phosphorus	Finland	kg	Confidential data
Suspended solids, unsp.	Finland	kg	Confidential data

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Carbon monoxide	Europe	kg	Confidential data
Particulates > 10µm	Europe	kg	Confidential data
Rejects, others	Europe	kg	Confidential data
Rejects, paper	Europe	kg	Confidential data
Organic sludge	Europe	kg	Confidential data

Recycling of non-coated paperboard:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Wastepaper recycling, corrugated grade	Hybrid data (primary and secondary)	Calculations and expert judgment	Europe	1 t	2021

For this downstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory can be found in Appendix 2.

Multiple-Use system inventory

Upstream – Raw materials

PP cold drink cup:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
16 oz PP cold cup	Secondary data	McDonalds /SEDA	EU	1 piece	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.08
Production	EU	kg	0.08
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009
LDPE stretch for packaging	-	kg	0.00002

PP lid for cold cup:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year

PP lid for cup	Secondary data	SEDA	EU	1 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.007
Production	EU	kg	0.007
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009
LDPE stretch for packaging	-	kg	0.00002

PP clamshell for burgers:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
PP clams for burgers	Secondary data	SEDA	EU	1 piece	2022

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.117
Production	EU	kg	0.117
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009
LDPE stretch for packaging	-	kg	0.00002

PP basket for serving fries:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
PP basket for serving fries	Secondary data	Assumption	EU	1 piece	-

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.04
Production	EU	kg	0.04
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
LDPE stretch for packaging	-	kg	0.00002

PP dessert cup:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
PP dessert cup	Secondary data	McDonalds / SEDA	EU	1 pcs	2020

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.05
Production	EU	kg	0.05
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009
LDPE stretch for packaging	-	kg	0.00002

Thick washable plastic cutlery:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Thick washable plastic cutlery	Secondary data	Antony and Gensch 2017	EU	1 pcs	2017

For this upstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Polypropylene	EU	kg	0.003
Production	EU	kg	0.003
Corrugated paperboard for packaging (40% recycled content)	-	kg	0.0009
LDPE stretch for packaging	-	kg	0.00002

Use phase

Detergent for washing:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Detergent for washing	Secondary data	Rüdenauer et al. 2011, Antony & Gensch 2017; own research	EU	1 kg	2011, 2017, 2020

For this use phase process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Potassium tripolyphospate solution, 50 % (mass fraction)*	EU	kg	0.1
Potassium hydroxide, 50 % (mass fraction)	-	kg	0.36
Sodium silicate (water glass)	EU	kg	0.23
Oxidising agent	-	kg	0.02
De-ionised water	EU	kg	0.29

*Softener

Rinse agent for washing:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Rinse agent for washing	Secondary data	Rüdenauer et al. 2011, Antony & Gensch 2017; own research	EU	1 kg	2011, 2017, 2020

For this use phase process, a full inventory (input-output sheet) is implemented in this assessment.
The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Citric acid-monohydrate, crystalline	-	kg	0.05
Non-ionic surfactants, fatty alcoholC12/C14 + 5 EO + 4 PO	EU	kg	0.2
Sodium cumolsulphonate	EU	kg	0.05
De-ionised water	EU	kg	0.7

Downstream – End-of-life treatment

Recycling of PP items:

Recycling process of polypropylene has been modelled by implementing data from Cardamone, Ardolino and Arena (2021). Even though the original publication refers specifically to plastics from Waste of Electrical and Electronic Equipment (WEEE), using these data can be considered a more realistic assumption since secondary data from Ecoinvent refer to formal/informal recycling process in India, which does not reflect current recycling processes in Europe. Main consumption data are reported in the following tables, assuming a sorting and re-manufacturing overall efficiency of 90% (Cardamone et al., 2021). Data for water consumption is an average value from Schwarz *et al.* (2021) and Perugini, Mastellone and Arena (2005).

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Recycling of PP items	Secondary data	Cardamone et al., 2021	Europe	1 kg	2021

For this downstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory below refers to cradle-to-gate system boundaries:

Original process/flow	Location/ origin	Input/ Output unit	Input/ Output value
Electricity for sorting and re-manufacturing	EU	kWh	0.381
Tap water	EU	l	2
PP recycled	-	kg	0.9
Wastewater treatment	EU	l	2

Recycling of non-coated paperboard:

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Wastepaper recycling, corrugated grade	Hybrid data (primary and secondary)	Calculations and expert judgment	Europe	1 t	2021

For this downstream process, a full inventory (input-output sheet) is implemented in this assessment.

The implemented LCI inventory can be found in Appendix 2.

APPENDIX 2. LIFE CYCLE INVENTORY - WASTEPAPER RECYCLING

To represent an appropriate recycling scenario as well as to account for environmental credits of recycling, gate-to-gate inventory data of a dedicated recycling process for wastepaper recycling is implemented for all case studies. This data is provided by CEPI[45] and FEFCO[46], and it was compiled as part of a project to determine the life cycle inventories for producing pulp from recovered fibres for various applications. This data, which is a pre-publication dataset, was compiled by RISE during 2021 by adapting data present in the FEFCO LCI database (CEPI and FEFCO, 2018) and considering information presented in the "Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board" (Suhr *et al.*, 2015). This data was checked by a major producer of recycled corrugated case materials, considering operational experience.

For the calculation of the repulping of wastepaper, FEFCO's LCI (CEPI and FEFCO, 2018) is divided in two inputs: one related to the pulp production, and the other related to the paper machine. For the first input, 150 kWh electricity per ton of pulp is considered (see Table 6.1 in Suhr *et al.*, 2015). For the second input, 550 kWh electrical energy demand per ton is considered (see Table 7.11 in Suhr *et al.*, 2015), and 403 kWh thermal energy demand per ton (see Table 2.9 in Suhr *et al.*, 2015). By using these shares, the total share of purchased electricity demand for recovered pulp production is estimated at around 37 kWh/ton with a self-generated energy demand estimated at around 526 kWh/ton. Therefore, the share of fossil fuels used for internal energy demand is estimated at around 552 MJ/ton. The latter is therefore assumed to be required to have 1 ton of fibre in an integrated mill process. Wastepaper is therefore recycled to wet pumpable pulp, which is identified as output of this process. The resultant Life Cycle Inventory (LCI, see Table 28) describes the recycling of wastepaper from placing the recovered wastepaper into the pulper to recovered pulp. The reference is 1 ton of recovered pulp (*wet pumpable pulp*).

Table 28: LCI of wastepaper to pulp recycling (reference: 1 ton of wet pumpable pulp) – "dm" indicates dry matter

Input	Value (unit)
Wastepaper input	1100 kg
Natural gas	480,70 MJ
Electrical energy	37 kWh
Heavy fuel oil	0,15 MJ
Light fuel oil	0,96 MJ
Diesel	0,08 MJ

[45] CEPI: Confederation of European Paper Industries (https://www.cepi.org/)
[46] FEFCO: The Federation of Corrugated Board Manufacturers (https://www.fefco.org/)

Coal	58,85 MJ
Lignite	11,20 MJ
Biofuel (bark, scrap wood, tall oil)	2,36 MJ
Hydrogen peroxide	0,0127 kg (dm)
Starch (corn and wheat)	29,7 kg (dm)
Starch (modified)	0,30 kg (dm)
Water	3,5 m^3
Output	**Value (unit)**
Dust to air	8,57E-04 kg
CO2 fossil to air	60,036 kg
CO2 biogenic to air	6,763 kg
CO to air	0,017 kg
NOX (as NO2) to air	0,077 kg
SOX (as SO2) to air	0,015 kg
Wastewater	3,5 m^3
TSS to freshwater	0,22 kg
COD to freshwater	0,44 kg
AOX to freshwater	3,00E-04 kg
BOD5 to freshwater	0,12 kg
Total P to freshwater	3,25E-03 kg
Total N to freshwater	0,03 kg
TOC to freshwater	0,21 kg
Organic sludges - 35% dry content	28 kg
Rejects, paper (50% dry content)	23 kg

Rejects, other (50% dry content)	46 kg

APPENDIX 3. DOCUMENTATION OF THE BACKGROUND DATA

Background data[47] is presented in this appendix. Documentation for all ecoinvent datasets is available at: https://ecoquery.ecoinvent.org/. Tables in this appendix reports providers used in the model, data classification, source of the data, and geographical coverage. As the study is focused on Europe, priority is given to that geographical coverage (in ecoinvent is called RER – Europe). If datasets are not available for this average geography, specific datasets (e.g., located in Switzerland, Germany, etc.) are used. The most representative dataset is used, in accordance with the assumptions made in the modelling, and reported in this document.

It should be noted that in this appendix datasets are reported in two forms: a form without "market for" or a form with "market for"[48]. Datasets without "market for" are implemented with respective transport distances and means of transport separately. A generic entry (i.e., transport, freight, lorry >32 metric ton, EURO4) is used for this purpose. Datasets that are indicated with "market for", which are used in case of lack of transport information, represent an average geography and include transport distances. All these datasets are checked against their respective transport distances and emissions to avoid double counting[49].

Fuels and energy

European averages for fuel inputs and electricity grid mixes are retrieved from ecoinvent 3.8 datasets. These are in line with the assumptions made in the study.

Provider process	Data classification	Source	Geographical coverage
Single-use system			
market group for electricity, medium voltage	secondary data	Ecoinvent 3.8	Europe (RER)
market for natural gas, low pressure	secondary data	Ecoinvent 3.8	CH
market for biomethane, high pressure	secondary data	Ecoinvent 3.8	CH
market group for diesel	secondary data	Ecoinvent 3.8	Europe (RER)

[47] For a definition of "background data", see: JRC. (2010). ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance. Luxembourg: Joint Research Centre.
[48] For a detailed explanation see https://ecoinvent.org/the-ecoinvent-database/market-activities/ and https://ecoinvent.org/glossary-terms/
[49] „a market activity may contain exchanges that model the average transportation of the product, direct emissions caused by the transportation, as well as an input from the market itself, which represents losses that occur during transportation and storage of the product." Source: https://ecoinvent.org/glossary-terms/

Provider process	Data classification	Source	Geographical coverage
market for heat, district or industrial, natural gas	secondary data	Ecoinvent 3.8	Europe without Switzerland
liquefied petroleum gas production, petroleum refinery operation	secondary data	Ecoinvent 3.8	Europe without Switzerland
heat production, natural gas, at industrial furnace low-NOx >100kW	secondary data	Ecoinvent 3.8	Europe without Switzerland
market group for heavy fuel oil	secondary data	Ecoinvent 3.8	Europe (RER)
market group for diesel, low-sulfur	secondary data	Ecoinvent 3.8	Europe (RER)
market for hard coal	secondary data	Ecoinvent 3.8	Europe, without Russia and Turkey
market group for light fuel oil	secondary data	Ecoinvent 3.8	Europe (RER)
market for lignite	secondary data	Ecoinvent 3.8	Europe (RER)
Multiple-use system			
market group for electricity, medium voltage	secondary data	Ecoinvent 3.8	Europe (RER)
market for natural gas, low pressure	secondary data	Ecoinvent 3.8	CH
market for biomethane, high pressure	secondary data	Ecoinvent 3.8	CH
market group for diesel	secondary data	Ecoinvent 3.8	Europe (RER)
market for heat, district or industrial, natural gas	secondary data	Ecoinvent 3.8	Europe without Switzerland
liquefied petroleum gas production, petroleum refinery operation	secondary data	Ecoinvent 3.8	Europe without Switzerland
heat production, natural gas, at industrial furnace low-NOx >100kW	secondary data	Ecoinvent 3.8	Europe without Switzerland
market group for heavy fuel oil	secondary data	Ecoinvent 3.8	Europe (RER)
market group for diesel, low-sulfur	secondary data	Ecoinvent 3.8	Europe (RER)

Provider process	Data classification	Source	Geographical coverage
market for hard coal	secondary data	Ecoinvent 3.8	Europe, without Russia and Turkey
market group for light fuel oil	secondary data	Ecoinvent 3.8	Europe (RER)
market for lignite	secondary data	Ecoinvent 3.8	Europe (RER)

Upstream (raw materials and manufacturing)

Provider process	Data classification	Source	Geographical coverage
Single-use system			
municipal waste collection service by 21 metric ton lorry	Secondary data	Ecoinvent 3.8	CH
treatment of waste paperboard, unsorted, sorting	Secondary data	Ecoinvent 3.8	Europe without Switzerland
corrugated board box production	secondary data	Ecoinvent 3.8	Europe (RER)
ethylene vinyl acetate copolymer production	secondary data	Ecoinvent 3.8	Europe (RER)
packaging film production, low density polyethylene	secondary data	Ecoinvent 3.8	Europe (RER)
market for tap water	secondary data	Ecoinvent 3.8	Europe without Switzerland
alkyd paint production, white, water-based, product in 60% solution state	secondary data	Ecoinvent 3.8	Europe (RER)
printing ink production, offset, product in 47.5% solution state	secondary data	Ecoinvent 3.8	Europe (RER)
fatty alcohol production, petrochemical	secondary data	Ecoinvent 3.8	Europe (RER)
N,N-dimethylformamide production	secondary data	Ecoinvent 3.8	Europe (RER)
graphic paper production, 100% recycled	secondary data	Ecoinvent 3.8	Europe (RER)

Provider process	Data classification	Source	Geographical coverage
plywood production	secondary data	Ecoinvent 3.8	Europe (RER)
Multiple-use system			
polypropylene production, granulate	secondary data	Ecoinvent 3.8	Europe (RER)
injection moulding	secondary data	Ecoinvent 3.8	Europe (RER)
corrugated board box production	secondary data	Ecoinvent 3.8	Europe (RER)
packaging film production, low density polyethylene	secondary data	Ecoinvent 3.8	Europe (RER)
municipal waste collection service by 21 metric ton lorry	Secondary data	Ecoinvent 3.8	CH
treatment of waste paperboard, unsorted, sorting	Secondary data	Ecoinvent 3.8	Europe without Switzerland
ethylene vinyl acetate copolymer production	secondary data	Ecoinvent 3.8	Europe (RER)
market for tap water	secondary data	Ecoinvent 3.8	Europe without Switzerland
alkyd paint production, white, water-based, product in 60% solution state	secondary data	Ecoinvent 3.8	Europe (RER)

Transport (distribution and transport means in all life cycle stages)
Transport in this study is modelled by truck (>32 t, EURO 4), train (average freight train) and ship (barge).

Provider process	Data classification	Source	Geographical coverage
Single-use system			
transport, freight, inland waterways, barge	Secondary data	Ecoinvent 3.8	Europe (RER)
transport, freight, lorry >32 metric ton, EURO4	Secondary data	Ecoinvent 3.8	Europe (RER)
transport, freight, lorry 16-32 metric ton, EURO4	Secondary data	Ecoinvent 3.8	Europe (RER)
Multiple-use system			

Provider process	Data classification	Source	Geographical coverage
transport, freight, lorry >32 metric ton, EURO4	Secondary data	Ecoinvent 3.8	Europe (RER)
transport, freight train	Secondary data	Ecoinvent 3.8	Germany
transport, freight, inland waterways, barge	Secondary data	Ecoinvent 3.8	Europe (RER)

Use stage

Provider process	Data classification	Source	Geographical coverage
transport, passenger car, EURO 4	Secondary data	Ecoinvent 3.8	Europe (RER)
transport, regular bus	Secondary data	Ecoinvent 3.8	Switzerland
transport, passenger, motor scooter	Secondary data	Ecoinvent 3.8	Switzerland
transport, passenger, bicycle	Secondary data	Ecoinvent 3.8	Switzerland
market for soap	Secondary data	Ecoinvent 3.8	GLO
market group for tap water	Secondary data	Ecoinvent 3.8	Europe (RER)
market for tissue paper	Secondary data	Ecoinvent 3.8	GLO
market group for municipal solid waste	Secondary data	Ecoinvent 3.8	Europe (RER)
treatment of wastewater, from residence, capacity 1.1E10l/year	Secondary data	Ecoinvent 3.8	Switzerland
market for citric acid	secondary data	Ecoinvent 3.8	GLO
market for potassium hydroxide	secondary data	Ecoinvent 3.8	GLO
market for sodium silicate, solid	secondary data	Ecoinvent 3.8	Europe (RER)
market for sodium perborate, monohydrate, powder	secondary data	Ecoinvent 3.8	GLO
market for water, deionised	secondary data	Ecoinvent 3.8	Europe (RER)

Provider process	Data classification	Source	Geographical coverage
market for ethoxylated alcohol	secondary data	Ecoinvent 3.8	Europe (RER)
market for sodium cumenesulphonate	secondary data	Ecoinvent 3.8	GLO
market group for tap water	secondary data	Ecoinvent 3.8	Europe (RER)
market for wastewater, average	secondary data	Ecoinvent 3.8	Europe without Switzerland

End-of-life treatment

Provider process	Data classification	Source	Geographical coverage
Single-use system			
treatment of waste paperboard, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of waste polyethylene, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of waste wood, untreated, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of waste paperboard, unsorted, sorting	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for wastewater, average	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for waste wood, untreated	Secondary data	Ecoinvent 3.8	Europe (RER)
market for sludge from pulp and paper production	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for scrap steel	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for municipal solid waste	Secondary data	Ecoinvent 3.8	Europe (RER)
market for hazardous waste, for incineration	Secondary data	Ecoinvent 3.8	Europe without Switzerland

Provider process	Data classification	Source	Geographical coverage
treatment of waste polyethylene, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of waste paperboard, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of biowaste, municipal incineration with fly ash extraction	Secondary data	Ecoinvent 3.8	CH
market for bark chips, wet, measured as dry mass	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for hydrogen peroxide, without water, in 50% solution state	Secondary data	Ecoinvent 3.8	Europe (RER)
market for sodium hydroxide, without water, in 50% solution state	Secondary data	Ecoinvent 3.8	Global
market for sodium silicate, spray powder, 80%	Secondary data	Ecoinvent 3.8	Europe (RER)
market for maize starch	Secondary data	Ecoinvent 3.8	Global
Multiple-use system			
market group for tap water	secondary data	Ecoinvent 3.8	Europe (RER)
transport, freight, lorry >32 metric ton, EURO4 | transport, freight, lorry >32 metric ton, EURO4 | Cutoff, S - RER	secondary data	Ecoinvent 3.8	Europe (RER)
treatment of waste polypropylene, municipal incineration | waste polypropylene | Cutoff, S - CH	secondary data	Ecoinvent 3.8	Europe (RER)
treatment of waste paperboard, unsorted, sorting	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for wastewater, average	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for municipal solid waste	Secondary data	Ecoinvent 3.8	Europe (RER)
market for hazardous waste, for incineration	Secondary data	Ecoinvent 3.8	Europe without Switzerland
treatment of waste polyethylene, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of waste paperboard, municipal incineration	Secondary data	Ecoinvent 3.8	CH
treatment of biowaste, municipal incineration with fly ash extraction	Secondary data	Ecoinvent 3.8	CH

Provider process	Data classification	Source	Geographical coverage
market for bark chips, wet, measured as dry mass	Secondary data	Ecoinvent 3.8	Europe without Switzerland
market for hydrogen peroxide, without water, in 50% solution state	Secondary data	Ecoinvent 3.8	Europe (RER)
market for sodium hydroxide, without water, in 50% solution state	Secondary data	Ecoinvent 3.8	Global
market for sodium silicate, spray powder, 80%	Secondary data	Ecoinvent 3.8	Europe (RER)
market for maize starch	Secondary data	Ecoinvent 3.8	Global

Avoided emissions (credits)

The following table presents 4 datasets used in the model for the avoided emissions of pulp and 2 datasets for avoided energy emissions. These datasets represent average European electricity and steam generation. For electrical generation, medium voltage is assumed, while for steam generation, natural gas production is assumed.

Provider process	Data classification	Source	Geographical coverage
Single-use system			
Sulfate pulp production, from softwood, unbleached	Secondary data	Ecoinvent 3.8	Europe (RER)
Stone groundwood pulp production	Secondary data	Ecoinvent 3.8	Europe (RER)
Thermo-mechanical pulp (TMP) production	Secondary data	Ecoinvent 3.8	Europe (RER)
Chemo-thermomechanical pulp (CTMP) production	Secondary data	Ecoinvent 3.8	Europe (RER)
Market group for electricity, medium voltage	Secondary data	Ecoinvent 3.8	Europe (RER)
Market group for heat, district or industrial, natural gas	Secondary data	Ecoinvent 3.8	Europe (RER)
polyethylene production, low density, granulate	Secondary data	Ecoinvent 3.8	Europe (RER)
Multiple-use system			
Sulfate pulp production, from softwood, unbleached	Secondary data	Ecoinvent 3.8	Europe (RER)

Provider process	Data classification	Source	Geographical coverage
Stone groundwood pulp production	Secondary data	Ecoinvent 3.8	Europe (RER)
Thermo-mechanical pulp (TMP) production	Secondary data	Ecoinvent 3.8	Europe (RER)
Chemo-thermomechanical pulp (CTMP) production	Secondary data	Ecoinvent 3.8	Europe (RER)
Market group for electricity, medium voltage	Secondary data	Ecoinvent 3.8	Europe (RER)
Market group for heat, district or industrial, natural gas	Secondary data	Ecoinvent 3.8	Europe (RER)
polyethylene production, low density, granulate	Secondary data	Ecoinvent 3.8	Europe (RER)
polypropylene production	Secondary data	Ecoinvent 3.8	Europe (RER)

APPENDIX 4. PRIMARY DATA FROM QSRS

Stage	Parameter	System (SU/MU)	Assumption (value or range)
Production and use	Type and amount of items	SU/MU	Confidential
Share of selling channels	On-the-go	SU/MU	Confidential
	Click and collect		Confidential
	Drive through		Confidential
	Delivery		Confidential

Use	Number of reuses of MU items	MU	50
Use	Return rate	MU	50%
Use (on-the-go, click and collect, delivery)	Average distance and means of transport	SU/MU	Confidential
Use (drive through)	Average distance	SU/MU	Confidential
Use (professional washing)	Type of washing and type of dishwashers	MU	In-store, hood-type

APPENDIX 5. RESULTS OF CONTRIBUTION ANALYSIS IN TABULAR FORM

SU: Impact categories	Raw material extraction and manufacturing	Converting	Distribution	EoL recycling	EoL incineration	Credits material	Credits energy
EF-Acidification [mol H+ equivalents]	38%	25%	10%	5%	2%	11%	9%
EF-Climate change, biogenic [kg CO2-Equivalents]	50%	41%	0%	0%	0%	6%	2%
EF-Climate change, fossil [kg CO2-Equivalents]	42%	22%	9%	5%	1%	7%	13%
EF-Climate change, land use and land use change [kg CO2-Equivalents]	55%	43%	0%	0%	0%	1%	1%
EF-Climate change, total [kg CO2-Equivalents]	43%	23%	9%	5%	1%	7%	13%
EF-Eutrophication, freshwater [kg N equivalents]	39%	29%	1%	3%	0%	11%	16%
EF-Eutrophication, marine [kg P equivalents]	45%	22%	9%	7%	3%	9%	5%

EF-Eutrophication, terrestrial [mol N equivalents]	44%	18%	13%	6%	3%	11%	6%
EF-Ionising radiation, human health [kBq U235 equivalents]	49%	22%	3%	1%	0%	9%	15%
EF-Ozone depletion [kg CFC11 equivalents]	42%	22%	16%	4%	1%	5%	10%
EF-Particulate matter [disease incidence]	42%	16%	15%	4%	2%	19%	2%
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	46%	17%	14%	4%	3%	11%	6%
EF-Resource use, fossils [MJ]	42%	26%	7%	3%	1%	7%	14%
EF-Resource use, minerals and metals [kg Sb equivalents]	36%	31%	8%	5%	1%	14%	5%
ReCiPe 2016 Midpoint (H)- Water consumption	34%	25%	1%	3%	3%	26%	8%

MU: Impact categories	Raw material extraction and manufacturing	Distribution	Use phase transport	Washing	EoL recycling	EoL incineration	EoL landfilling	Credits material	Credits energy
EF-Acidification [mol H+ equivalents]	12%	3%	56%	17%	2%	1%	0%	6%	4%
EF-Climate change, biogenic [kg CO2-Equivalents]	1%	0%	1%	13%	2%	0%	82%	1%	0%
EF-Climate change, fossil [kg CO2-Equivalents]	13%	3%	54%	14%	1%	5%	0%	5%	5%
EF-Climate change, land use and land use change [kg CO2-Equivalents]	5%	0%	5%	87%	0%	0%	0%	1%	1%
EF-Climate change, total [kg CO2-Equivalents]	12%	3%	52%	14%	1%	4%	3%	5%	5%
EF-Eutrophication, freshwater [kg N equivalents]	14%	1%	24%	45%	2%	0%	0%	5%	9%
EF-Eutrophication, marine [kg P equivalents]	8%	4%	53%	21%	2%	2%	3%	5%	2%
EF-Eutrophication, terrestrial [mol N equivalents]	9%	5%	64%	12%	2%	2%	0%	5%	2%

EF-Ionising radiation, human health [kBq U235 equivalents]	13%	2%	29%	39%	2%	0%	0%	5%	11%
EF-Ozone depletion [kg CFC11 equivalents]	5%	5%	77%	7%	1%	0%	0%	2%	4%
EF-Particulate matter [disease incidence]	8%	4%	68%	10%	1%	1%	0%	7%	1%
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	7%	3%	75%	7%	1%	1%	0%	4%	2%
EF-Resource use, fossils [MJ]	22%	3%	43%	16%	1%	0%	0%	9%	6%
EF-Resource use, minerals and metals [kg Sb equivalents]	9%	1%	77%	7%	1%	0%	0%	4%	1%
ReCiPe 2016 Midpoint (H)-Water consumption	21%	1%	20%	34%	1%	2%	0%	15%	6%

APPENDIX 6. RESULTS OF SENSITIVITY ANALYSIS IN TABULAR FORM

Impact categories	Baseline scenario		S01	S02	S03	S04	S05	S06		S07		S08		S09	
			Take-back parameters			Washing phase		End-of-Life							
			100 reuses	70% return rate	1/5 take-back	No prewash	External washing	30rec, 70inc		60rec, 30inc, 10land		EUROSTAT		Cut-off 50:50	
	SU	MU	MU	MU	MU	MU	MU	SU	MU	SU	MU	SU	MU	SU	MU
Acidification	77.48	167.58	158.73	224.77	90.14	153.77	145.59	75.57	166.60	75.25	165.39	52.67	167.89	81.92	171.67
Climate change, total	20812	39789	36877	51793	22092	36680	35808	17445	38175	21912	39398	19319	39689	21150	40679
Eutrophication, freshwater	5.48	9.28	8.59	12.71	7.09	7.20	5.48	5.16	9.11	5.77	9.38	3.44	9.56	5.98	9.50
Eutrophication, marine	37.78	49.63	47.71	66.17	29.11	43.25	44.03	34.81	48.01	37.03	48.97	33.00	49.41	38.40	50.35
Eutrophication, terrestrial	254.51	449.31	431.38	602.42	226.74	422.64	414.24	252.18	448.21	242.50	442.36	190.72	447.50	263.78	457.06
Ionising radiation, human health	3976	4318	4010	5971	3076	3954	2213	3780	4215	4145	4393	2760	4494	4263	4429
Ozone depletion	2.8E-03	5.6E-03	5.5E-03	7.7E-03	2.31E-03	5.4E-03	5.4E-03	2.7E-03	5.6E-03	2.8E-03	5.7E-03	2.5E-03	5.7E-03	2.8E-03	5.6E-03
Particulate matter	8.3E-04	1.9E-03	1.8E-03	2.6E-03	8.48E-04	1.7E-03	1.8E-03	8.3E-04	1.9E-03	6.8E-04	1.8E-03	2.0E-04	1.8E-03	9.4E-04	1.9E-03
Photochemical ozone formation	69.83	213.50	207.17	289.97	97.64	206.64	204.29	68.26	212.70	65.38	210.40	46.50	212.60	73.55	217.15
Resource use, fossils	314931	581979	527025	758225	334076	540584	491280	301757	575174	335471	577950	272587	590390	326777	615436
Resource use, minerals and metals	0.06	0.32	0.31	0.44	0.13	0.31	0.31	0.06	0.32	0.06	0.32	0.04	0.32	0.06	0.33
Water consumption	136.82	224.50	194.80	299.77	171.16	169.34	146.11	131.97	221.98	83.22	187.28	125.16	213.04	186.52	251.79

APPENDIX 7. CONCLUSIONS OF THE META-STUDY CONDUCTED BY RAMBOLL ON BEHALF OF EPPA (RAMBOLL, 2022)

On behalf of European Paper Packaging Alliance, Ramboll has conducted a meta-study (Ramboll, 2022) 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)"[50]**.** 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 tableware 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.**

[50] *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 29 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 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 29 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 (+)
Resource use, fossils	Additional packaging (+) Transport to home (+)	Additional packaging (+) Transport to home (+)

	Possible increase in improper disposal (+)	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.