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COMPARATIVE LIFE CYCLE ASSESSMENT (LCA)

SINGLE-USE AND MULTIPLE-USE DISHES SYSTEMS FOR IN-STORE CONSUMPTION IN QUICK SERVICE RESTAURANTS

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COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) SINGLE-USE AND MULTIPLE-USE DISHES SYSTEMS FOR IN-STORE CONSUMPTION IN QUICK SERVICE RESTAURANTS

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ABBREVIATIONS

BAT	Best Available Technology
CTMP	Chemo-thermomechanical pulp
EoL	End-of-Life
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MU	Multiple-Use
PE	Polyethylene
PE-LD	Low-density Polyethylene
PP	Polypropylene
QSR	Quick service restaurant
SU	Single-Use

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EXECUTIVE SUMMARY

Ramboll has been appointed by the European Paper Packaging Alliance (EPPA[1]) as technical consultant for conducting a comparative Life Cycle Assessment (LCA) study between a single use dishes system and equivalent multiple-use dishes in Quick Service Restaurants (hereafter "QSRs") in accordance with ISO standards 14040 and 14044 as a basis for discussion with authority representatives on the current legal developments within the European Union plus the United Kingdom regarding circular economy and waste prevention.

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

This assessment is embedded in an ongoing debate around the environmental performance of single-use and multiple-use products and it is focused on a systemic approach (comprehensive dishes options for in-store consumption in QSR) which is used to reflect both systems and compare equal functions of single-use and multiple-use product items in an average.
The main goal of the LCA study is to use a systems-based approach to **compare the environmental performance of single-use and multiple-use dishes options for in-store consumption in QSR in Europe.**

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

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

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

The distinctive feature 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 for the first time through a system approach the environmental performance of single-use and multiple-use dishes options for in-store consumption in QSR in Europe and not focused on the environmental performance of a single product;

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[1] EPPA is an association representing suppliers and manufacturers of renewable and sustainable paper board and paper board packaging for Food and Foodservice Industry. They include, e.g., Seda International Packaging Group, Huhtamaki, AR Packaging, Smith Anderson, CEE Schisler Packaging Solutions, Stora Enso, Metsä Board, Mayr-Melnhof Karton, WestRock, Iggesund/Holmen, Reno De Medici and Paper Machinery Corporation.

- **Robustness and reliability of the investigated system**: the incorporation of representative data and information with regards to the functional unit, inventory data as well assumptions around the systems.
  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. This is particularly relevant since previous LCA studies based on secondary data for paper upstream processes are not anymore representing state-of-the art for the investigated single-use system.

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

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

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

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

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

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

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;
- 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;

- End-of-life (paper products):
    - 30% paper recycling and 70% incineration with energy recovery for paper;
    - Transport of waste from QSR to incineration facility is assumed to be 100 km

Multiple-use system:

- PP manufacturing in Europe;
- Average reuse PP rate of 100 reuses is considered. Reuse rates also include potential replacement reasons such as damages, stains, theft or loss. The latter reasons are considered to be relatively important in QSRs as higher volumes of product items are involved than in regular restaurants;
- Dishwashing process:
    - An average scenario for in-house dishwashers is used to reflect different grades of devices' efficiencies;
    - Internal washing is assumed with a separate drying module because of hygienic requirements and increased efforts for drying of PP products based on literature information, 30% of total energy demand of washing and drying comes from drying; thus energy demands for washing reported in literature were increased by +30% if the device does not perform sufficient drying for PP products;
    - State-of-the-art detergent and rinse agent compositions are assumed;
    - Average rewashing rate for all items of 5% is considered, this assumption is made to avoid persistent residues that might remain after washing;
    - Production of simplified dishwashers is considered (generic assumption of two additional devices to be installed inside a QSR to perform in-house washing; ten-year lifetime of the dishwasher).
- End-of-life (PP products):
    - 30% material recycling and 70% incineration with energy recovery;
    - Transport of waste from QSR to waste treatment facility is assumed to be 100 km.

For the EoL assumption of the baseline scenarios it should be noted that generic plastic packaging shows EU average recycling figures (about 40%)[2] lower than paper packaging (about 85%[3]). For data symmetry reasons in the comparison and due to the lack of product-specific recycling rates, 30% material recycling and 70% incineration with energy recovery are assumed for both baseline scenarios, provided that appropriate sorting of post-consumer waste fractions is facilitated at the EoL stage. Sensitivity analyses are performed for 0% recycling and 100% incineration with energy recovery and for 70% material recycling and 30% incineration with energy recovery for both systems.

The aggregated total impacts of the baseline systems are summarised in the following Table 1.

Table 1: Life cycle impact assessment results of the baseline comparison of the single-use and multiple-use systems.

ReCiPe 2016 (H) Indicator	Single-use system - Baseline Scenario	Multiple-use system - Baseline Scenario
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	9008	24954
Fine Particulate Matter Formation [kg PM2.5 eq.]	5.2	12.2

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[2] https://ec.europa.eu/eurostat/databrowser/view/ten00063/default/table?lang=en

[3] https://ec.europa.eu/eurostat/databrowser/view/ten00063/default/table?lang=en

ReCiPe 2016 (H) Indicator	Single-use system - Baseline Scenario	Multiple-use system - Baseline Scenario
Fossil depletion [kg oil eq.]	2827	9565
Freshwater Consumption [m3]	61	224
Freshwater Eutrophication [kg P eq.]	2.9	0.6
Ionizing Radiation [kBq Co-60 eq. to air]	2110	1323
Metal depletion [kg Cu eq.]	55	49
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.010	0.009
Terrestrial Acidification [kg SO2 eq.]	23	39

These results for the baseline scenario are[4]:

- For **Climate Change**, the single-use system shows very significant climate change benefits (i.e. impacts of multiple-use baseline scenario are 177% higher than in the single-use baseline scenario).
- For **Fine Particulate Matter Formation**, the single-use system shows very significant environmental benefits (i.e. impacts of multiple-use baseline scenario are 132% higher than in the single-use baseline scenario).
- For **Fossil Depletion**, there are very significant benefits for the single-use system (i.e. impacts of multiple-use baseline scenario are 238% higher than in the single-use baseline scenario).
- For **Freshwater Consumption**, there are very significant environmental benefits for the single-use system (i.e. impacts of multiple-use baseline scenario are 267% higher than in the single-use baseline scenario).
- For **Freshwater Eutrophication**, there are very significant benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 81% lower than in the single-use baseline scenario).
- For **Ionizing Radiation**, there are significant environmental benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 37% lower than in the single-use baseline scenario).
- For **Metal Depletion**, there are noticeable environmental benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 12% lower than in the single-use baseline scenario).

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[4] Terminology used for interpretation based on relative difference in % based on the respective indicated single-use system as reference value (e.g. baseline scenario): <5%: **marginal** difference (i.e. uncertainty threshold); 5 to 10%: **minor** difference; 10-20%: **noticeable** difference; 20-30%: **moderate** difference; 30-50%: **significant** difference; >50%: **very significant** difference

- For **Stratospheric Ozone Depletion**, there are noticeable environmental benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 11% lower than in the single-use baseline scenario).
- For **Terrestrial Acidification**, there are very significant environmental benefits for the single-use system (i.e. impacts of multiple-use baseline scenario are 72% higher than in the single-use baseline scenario).

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 are generated during the upstream production of the items whereas the main contributor to the impacts of the multiple-use system is the use phase, i.e. the washing of items. To test decisive assumptions in the systems, several sensitivity scenarios were analysed. Uncertainties of the method and the results were considered.

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

1. Single-use system: Different recycling rates of post-consumer paperboard (0%; 70%);
2. Multiple-use system: Different recycling rates of post-consumer PP items (0%; 70%);
3. Multiple-use system: Varied demand for multiple-use items (30% higher; 30% lower);
4. Multiple-use system: Optimised washing scenario;
5. Multiple-use system: External washing with band transport dishwasher;
6. Multiple-use system: Alternative multiple-use items (dishes made from ceramic (500 or 250 reuses), glass (500 or 250 reuses), stainless steel (1000 reuses) and PP (100 reuses);
7. Both systems: Different EoL allocation approach for avoided energy and material production (50:50)

Under consideration of identified uncertainties and sensitivities of impact results, the following **conclusions** can be drawn from the comparative assessment[4]:

- For **Climate Change**, the single-use system shows very significant benefits considering the comparison of the baseline scenarios. When including the different sensitivity scenarios, only in cases where very efficient dishwashing processes are implemented either through solely using efficient hood-type dishwashers or in an external dishwashing scenario do the environmental benefits for the single-use system become smaller and range from very significant to minor. Therefore, the environmental benefits for the single-use system in terms of climate change impacts are consistent throughout all considered scenarios.
- For **Fine Particulate Matter Formation**, the single-use system shows very significant environmental benefits in the baseline comparison. Minor benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits. Therefore, the comparison between the single-use and the multiple-use system is dependent on underlying assumptions.
- For **Fossil Depletion**, there are very significant benefits for the single-use system in the baseline comparison. Minor environmental benefits for the single-use system may occur in cases where very efficient dishwashing processes are implemented either through solely

using efficient hood-type dishwashers or in an external dishwashing scenario. Therefore, the environmental benefits for the single-use system in terms of fossil depletion impacts are consistent throughout all considered scenarios.

- For **Freshwater Consumption**, there are very significant environmental benefits for the single-use system considering the baseline comparison. Moderate environmental benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits.
- For **Freshwater Eutrophication**, there are exclusively very significant benefits for the multiple-use system in the baseline and the different scenarios. Therefore, the environmental benefits for the multiple-use system in terms of freshwater eutrophication impacts are consistent throughout all considered scenarios.
- For **Ionizing Radiation**, there are significant environmental benefits for the multiple-use system in the baseline comparison. Only noticeable environmental benefits for the multiple-use system are identified when increased post-consumer paper recycling and full crediting at the EoL stage is assumed. Therefore, the environmental benefits for the multiple-use system in terms of ionizing radiation impacts are consistent throughout all considered scenarios.
- For **Metal Depletion**, there are noticeable environmental benefits for the multiple-use system in the baseline comparison. However, minor up to very significant environmental benefits are shown for the single-use system when compared to a multiple-use system comprising alternative product items made of ceramic, glass, and steel. Therefore, the comparison between the single-use and the multiple-use system for the potential metal depletion impact is dependent on underlying assumptions.
- For **Stratospheric Ozone Depletion**, there are noticeable environmental benefits for the multiple-use system in the baseline comparison. Very significant environmental benefits for the multiple-use system are identified for the hypothetical scenarios entailing optimised or external washing processes. Therefore, the environmental benefits for the multiple-use system in terms of stratospheric ozone depletion impacts are consistent throughout all considered scenarios.
- For **Terrestrial Acidification**, there are very significant environmental benefits for the single-use system in the baseline comparison. Noticeable environmental benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits. Therefore, the comparison between the single-use and the multiple-use system for the potential terrestrial acidification impact is dependent on underlying assumptions.

These results are partly in contrast to other LCA studies found in literature screening 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. This difference can largely be 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 extend, 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 conventions combined with selected industry and expert inputs where possible. This is due to the fact that the multiple-use system presents a hypothetical future scenario for which no primary data exists (i.e. specific functioning of QSRs is mainly based on conventions) and, as regards the upstream production of multiple-use items, no primary data is available in the context of this LCA study.

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. As a consequence, the impact result may not be used for product development, production process improvement, or any product-related decisions.

The geographical location of production and use is potentially crucial and in particular the energy mix at the location of production and use has significant influence on the associated environmental impacts. Consequently, the geographical context is also a decisive factor for the results of this study. 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. In particular for the multiple-use system, where major impacts are generated by the use of electricity for the washing process, the selection of another geographical scope could significantly change the results and comparative assertion.

In the light of a potential introduction of multiple-use systems it needs to be borne in mind that this also constitutes a paradigm shift of the environmental monitoring and management. **While the single-use system is characterised by rather centralised large, industrialised operators with continuous environmental improvement systems in place, the environmental implications of a hypothetical multiple-use system may be characterised by decentralised and less organised actors.** This shift may cause a lack of both environmental management systems and data availability and reliability to steer further environmental strategies.

The results of the study also point to further need for research and investigation of relevant parameters and processes, amongst others related to certain impact categories in LCA methods as well as further need for research on the assumptions, conventions and parameters relating to current and hypothetical multiple-use system.

External review

This executive summary is based on an ISO-compliant full LCA report that was subject to a third-party review.

EXECUTIVE ANNEX

Quick Service Restaurants (QSRs) are at the core of utilized product items and accompanying processes (e.g. transport, dishwashing) in this assessment. Therefore, it is crucial that the established functioning of a QSR restaurant is maintained despite the fundamental change related to the use of reusable food and beverage containers for in-store consumption. In line with the goal and envisaged systems approach of this assessment and current or hypothetical future operations in QSRs being in the foreground of this assessment, this LCA seeks to differentiate between upstream, core, and downstream processes which are inextricably linked to the functional unit (see Figure 1).

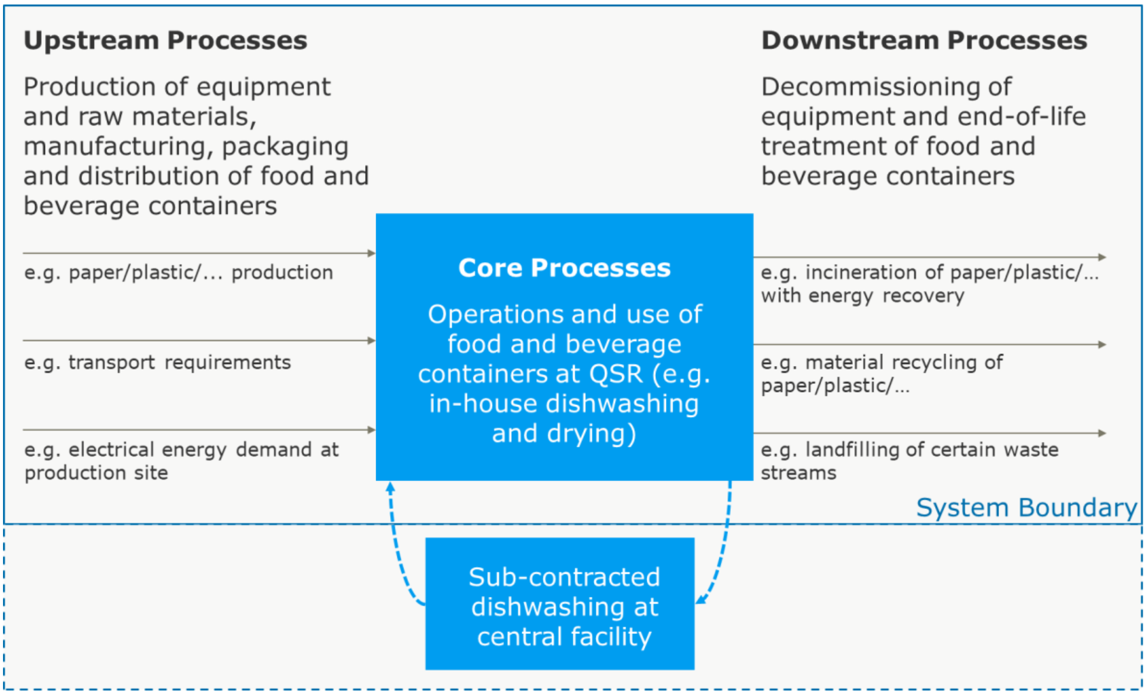

Figure 1: Schematic system boundary and differentiation between upstream, core, and downstream processes from the perspective of a QSR (Source: own depiction)

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 EoL treatment of the items whereas the main contributor to the impacts of the multiple-use system is the use phase, i.e. the washing of items. 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 2 is implemented in the assessment.

Table 2: Primary data for paper making implemented in the assessment

Process name	Classification	Source	Geographical coverage	Reference value	Reference year
Chemical pulp (softwood)	Primary data	Confidential	Finland	1 t dry chemical pulp	2019
PE-coated paperboard (different variants and specifications)	Primary data	Confidential	Finland	1 t board	2020
Thin greaseproof paper with soy-based coating	Primary data	Confidential	Austria	1 t paper	2020
High-brightness cartonboard	Primary data	Confidential	Austria	1 t cartonboard	2019
Brown kraft cartonboard	Primary data	Confidential	Slovenia	1 t cartonboard	2019

For this assessment it is assumed that all single-use products are entirely made of virgin paper. In this regard it is important to remember that actually a significant share of some paper products listed above comes from post-industrial paper waste. Consequently, this assumption reflects a conservative approach and avoids the risk of double counting of the credits associated with energy or material recovery at the EoL stage. In line with this approach, EoL credits are assigned based on the assumption that an equivalent virgin paper product is displaced in the market by the recovered material.

The production stage of single-use product items (i.e. converting stage) 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 3 is implemented in the assessment.

Table 3: Primary data for paper converting implemented in the assessment

Process name	Classification	Source	Geographical coverage	Reference value	Reference year
Hot drink cup	Primary data	Huhtamaki	Finland	1 t dry weight product	2018
Cold drink cup	Primary data	Seda	Germany	1000000 pcs	2020
Clamshell	Primary data	Seda	Germany	1000000 pcs	2020
Fry bag	Primary data	Seda	Germany	1000000 pcs	2020
Salad box	Primary data	Seda	Germany	1000000 pcs	2020
Clip on Lid	Primary data	Seda	Germany	1000000 pcs	2020
Ice Cream Cup	Primary data	Seda	Germany	1000000 pcs	2020
Paper wrap	Primary data	CEE Schisler	France	1000 pcs	2019
Paper fry bag	Primary data	CEE Schisler	France	1000 pcs	2019

In order to represent an appropriate recycling scenario as well as to account for environmental credits of recycling, primary gate-to-gate inventory data of a dedicated recycling process for plastic (PE)-coated as well as uncoated paperboard products is implemented. For the subsequent environmental credits from material recycling, inventory data of the manufacturing of intermediate paper products until the point of substitution through respective material outputs of the recycling process are implemented as indicated in Table 4.

Table 4: Industry statistics and secondary data for avoided pulp production

Industry statistics for the resulting shares of avoided pulp products per ton of recovered pulp (in total 100 %)	Provider process	Data classification	Source	Geographical coverage
49 %	Market for sulfate pulp, bleached	Secondary data	Ecoinvent 3.6	Europe (RER)
2 %	Market for sulfate pulp, unbleached	Secondary data	Ecoinvent 3.6	Europe (RER)
2 %	Sulfite pulp production, bleached*	Secondary data	Ecoinvent 3.6	Europe (RER)
24 %	Thermo-mechanical pulp (TMP) production*	Secondary data	Ecoinvent 3.6	Europe (RER)
24 %	Chemo-thermomechanical pulp (CTMP) production*	Secondary data	Ecoinvent 3.6	Europe (RER)

* implemented data is adjusted to reflect energy efficiency gains in the industry

Further details on the use phase (including washing) of the multiple-use system

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. Both types of dishwashers show different ranges of efficiencies in terms of energy, water and chemicals demand. For the baseline scenario it is assumed that already installed devices in QSRs will be maintained until their end of life and will be supplemented by new devices. To reflect the different options of dishwashers in QSRs and the different levels of efficiencies, an average washing scenario is assumed for the baseline comparison. Given the board geographical scope of this assessment (EU average) this assumption is further justified. This average washing scenario consists of two options of undercounter dishwashers (conservative and optimised performance) and two options of hood-type dishwashers (conservative and optimised performance), resulting in four options with 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. These four options along with their LCI data and the resulting overall average used for the baseline comparison are summarised in Table 5. The two undercounter dishwasher options presented in Table 5 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. 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 two hood-type devices are assumed to reflect 70% and are increased by 30% to model in-house dishwashing of plastic-based multiple-use items.

Table 5: Technical specifications of dishwashers for the inhouse washing scenario (LCI data).

	Undercounter dishwasher		**Hood-type dishwasher**		**Average washing process**
	Conservative	Optimised	Conservative	Optimised	
Reference year	2011	2020	2011	2017	
Energy demand* [kWh/item]	0.043	0.027	0.024	0.014	0.027
Water demand [l/item]	0.80	0.23	0.16	0.08	0.318
Combined detergents and rinse demand [g/item]**	0.80	0.20	0.50	0.17	0.417
Source	Based on (Rüdenauer *et al.*, 2011); (CIRAIG, 2014)	Based on Miele[6]; (CIRAIG, 2014; Paspaldzhiev *et al.*, 2018)	Based on (Rüdenauer *et al.*, 2011); (Paspaldzhiev *et al.*, 2018)	Based on (Antony and Gensch, 2017)	

* including assumption for energy demand for drying

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

Baseline comparison and sensitivity analyses results

The following paragraphs show the results of the baseline comparison per impact category, including details on the distribution of impact over different life cycle stages. In addition, results of the sensitivity analyses for the respective impact categories are provided.

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[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] Source: Miele Website (accessed 26.10.2020), commercial dishwashers: https://www.miele.co.uk/professional/product-selection-commercial-dishwashers-429.htm

a) Climate Change

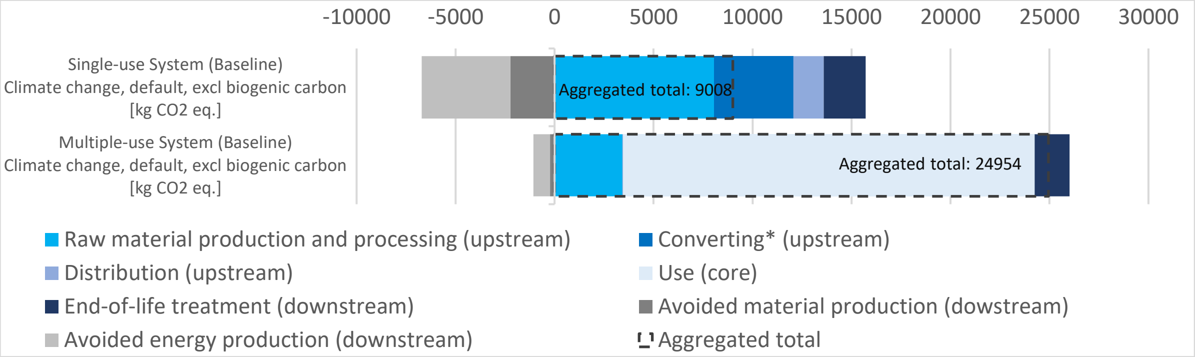

Figure 2: Baseline comparison results for the impact category Climate Change (excl. biogenic carbon) in kg CO_2 eq.

Single-use system

The potential climate change impacts of the single-use system are largely driven by paper manufacturing (about 90% of the aggregated total and half of the positive impact contributions, i.e. from raw material stage until EoL treatment). Next to paper manufacturing, the electricity demand for converting plays an important role in this category (assumed as EU-28 average grid mix). While paper manufacturing adds significant climate impacts, it is important to bear in mind that the total climate change impact is also significantly affected by the assigned climate change credits through material recycling and incineration with energy recovery (i.e. calculated negative impacts due to assumed avoidance of primary production of pulp or energy). Avoided climate change impacts through recycling and energy recovery correspond to about 75% of the aggregated total. The resulting climate change credits are, in turn, mainly associated with the avoided energy production, i.e. avoided production of electricity and thermal energy from natural gas in Europe.

Multiple-use system

The single main contributor to climate change impact in the multiple-use baseline scenario is the electricity demand of the washing process. Overall, the use phase accounts for 83% of the total aggregated impact. Another 14% are generated from the upstream production of multiple-use products and 7% from the EoL treatment of the item, although again a credit of 4% is associated with EoL treatment (credits for material and energy).

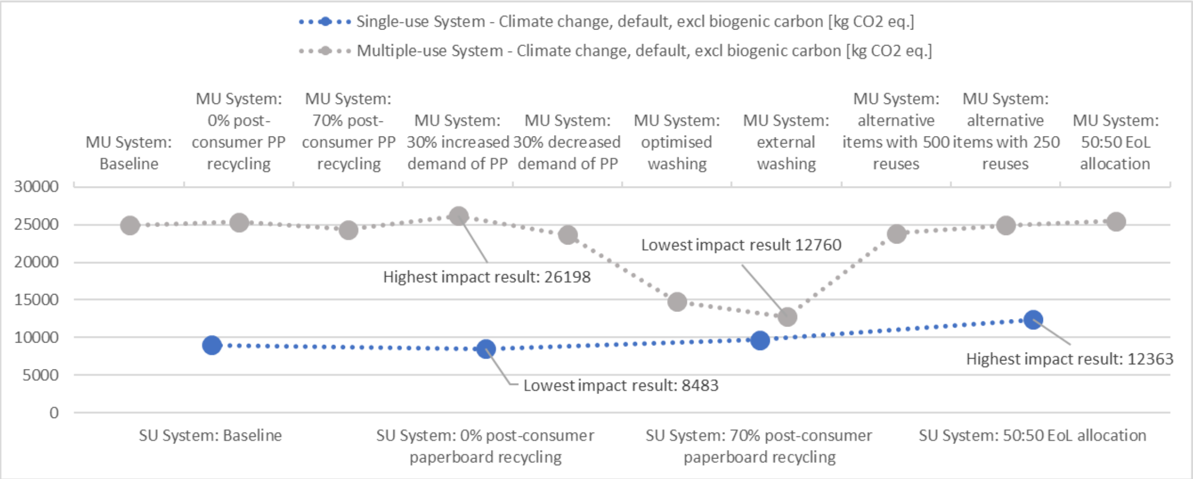

Figure 2: Summary of aggregated results for the impact category Climate Change of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the single-use system predominantly and on average shows **very significant** climate change benefits, apart from a scenario where very efficient dishwashing processes are implemented either through solely using efficient hood-type dishwashers or in an external dishwashing scenario. Only in these cases do the relative differences in climate change impacts become smaller (i.e. ranging from **significant benefits** for the single-use system to **minor benefits** for the single-use system).

b) Fine Particulate Matter Formation

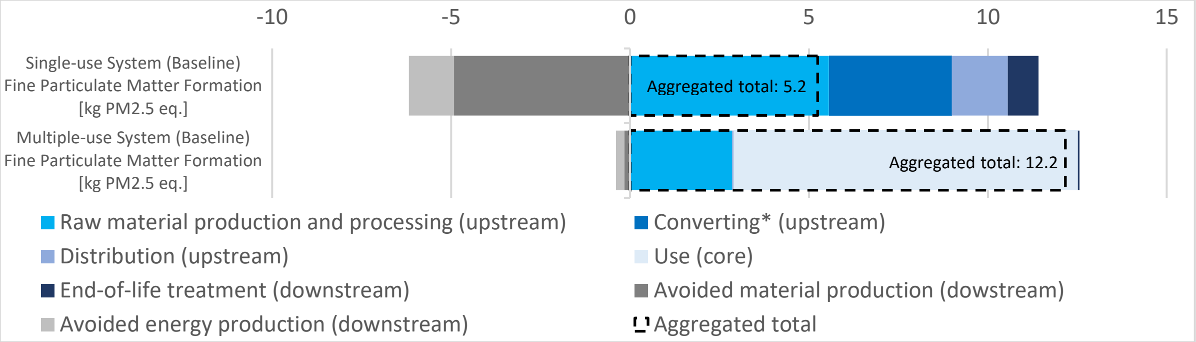

Figure 3: Baseline comparison results for the impact category Fine Particulate Matter Formation in kg PM2.5 eq.

Single-use system

Next to significant contributions from the paper manufacturing stage (both paper-based products as well as cardboard for packaging), converting (more than 60% of the aggregated total) and transport emissions during final distribution of single-use product items to QSR locations (about 30% of the aggregated total) are the main contributors to the total impacts associated with the baseline scenario of the single-use system. The resulting aggregated total impact is, again, significantly affected by the credits associated with material recycling and energy recovery. Overall, the incorporated credits are as high as the aggregated impacts of the single-use system in this category.

Multiple-use system

Similarly to the climate change impact category, 79% of the aggregated total for fine particulate matter are associated with the washing process, dominated by its electricity demand (i.e. EU-28 average grid mix). Upstream multiple-use items cradle-to-gate production accounts for 23% of the aggregated total impact.

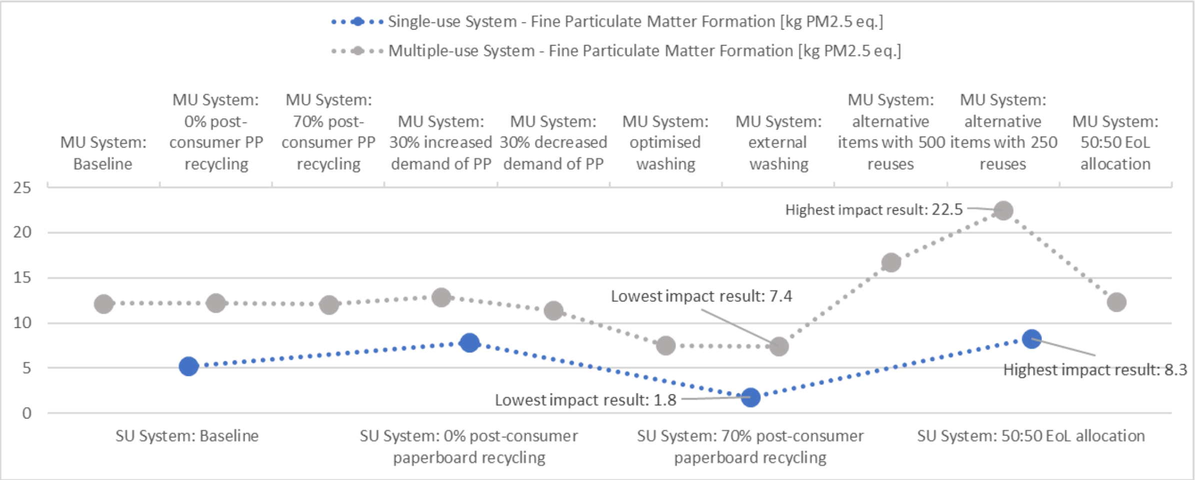

Figure 4: Summary of aggregated results for the impact category Fine Particulate Matter Formation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the majority of the considered scenarios confirm the tendency of the baseline comparison, i.e. on average the single-use system shows **very significant** environmental benefits for fine particulate matter formation. **Minor** benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits.

c) Fossil Depletion

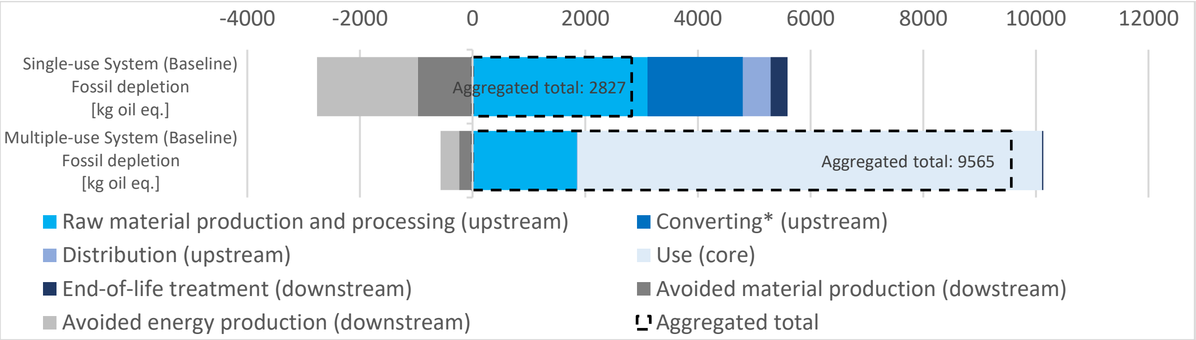

Figure 5: Baseline comparison results for the impact category Fossil depletion in kg oil eq.

Single-use system

The largest contributors to the baseline scenario of the single-use system are paper manufacturing and electricity demand for converting which is based on the EU-28 average grid mix. However, these contributions are again significantly counteracted by credits from material recycling and energy recovery, together corresponding to about 50% of the total positive impact contributions (see contributions from upstream, core, and EoL treatment).

Multiple-use system

With regard to the baseline scenario of the multiple-use system, fossil depletion is dominated by the electricity demand (i.e. EU-28 average grid mix) for washing and the washing phase accounts for 86% of the aggregated total impact. Upstream multiple-use items production is responsible for 19% of the aggregated total impact to fossil depletion.

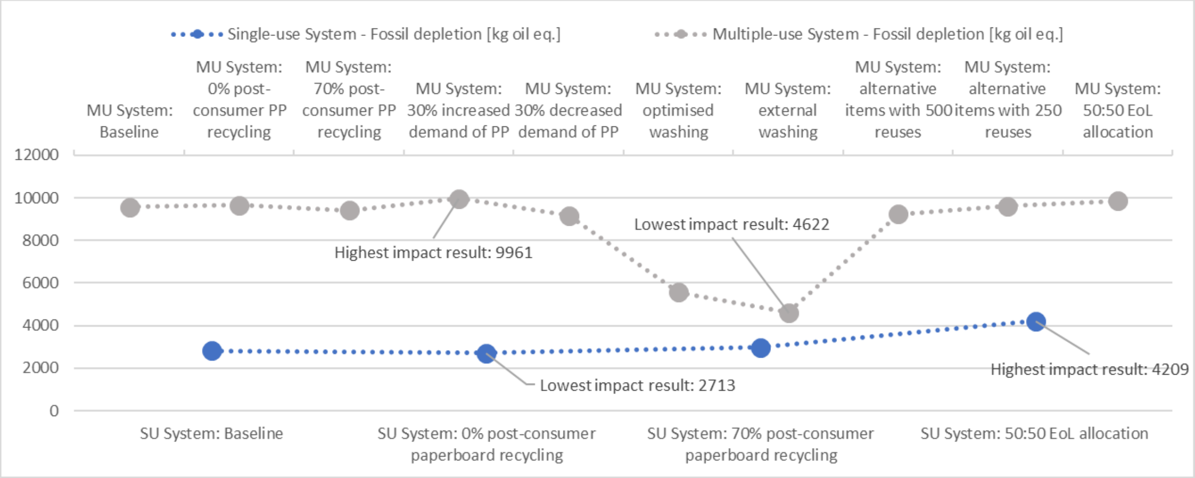

Figure 6: Summary of aggregated results for the impact category Fossil Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, reported results mainly and on average suggest **very significant** benefits for the single-use system with regard to fossil depletion. Only when assuming an efficient external washing scenario in combination with a different assumption concerning the EoL stages of both systems, the relative difference between the two systems becomes smaller (i.e. ranging from **very significant** benefits for the single-use system to **noticeable** benefits for the single-use system).

d) Freshwater Consumption

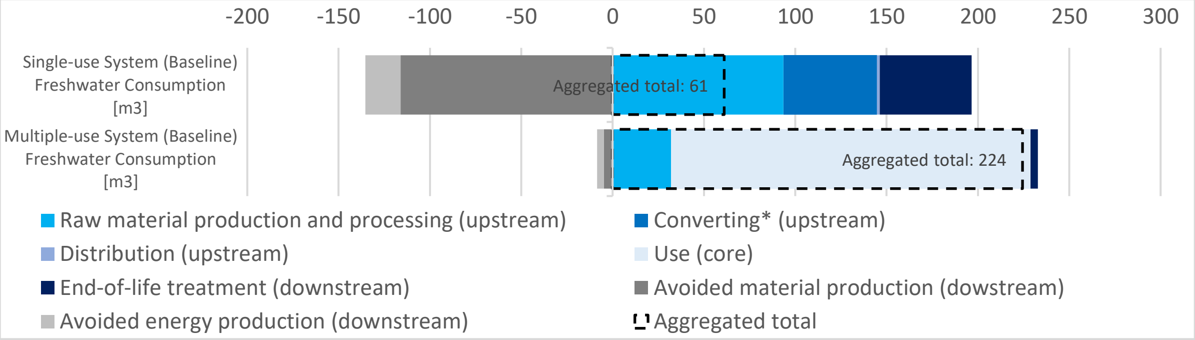

Figure 7: Baseline comparison results for the impact category Freshwater Consumption in m³

Single-use system

Paper manufacturing and electricity demand for converting and the paper incineration process (see contribution from End-of-life treatment) are significant contributors in the baseline scenario of the single-use system. Despite the relatively high impact from the actual incineration process, freshwater consumption credits associated with energy recovery and recycling more than outweighs these impacts (in particular credits from avoided primary production of bleached sulphate pulp).

Multiple-use system

The main contributor to freshwater consumption in the baseline scenario of the multiple-use system is the water demand of the washing process. However, the net effect is rather small as a most of the water is only used temporarily and made available again through a wastewater treatment process. Other significant contributions to freshwater consumption arise again from electricity demand of the washing process and upstream items production as well as from chemicals production for the washing process.

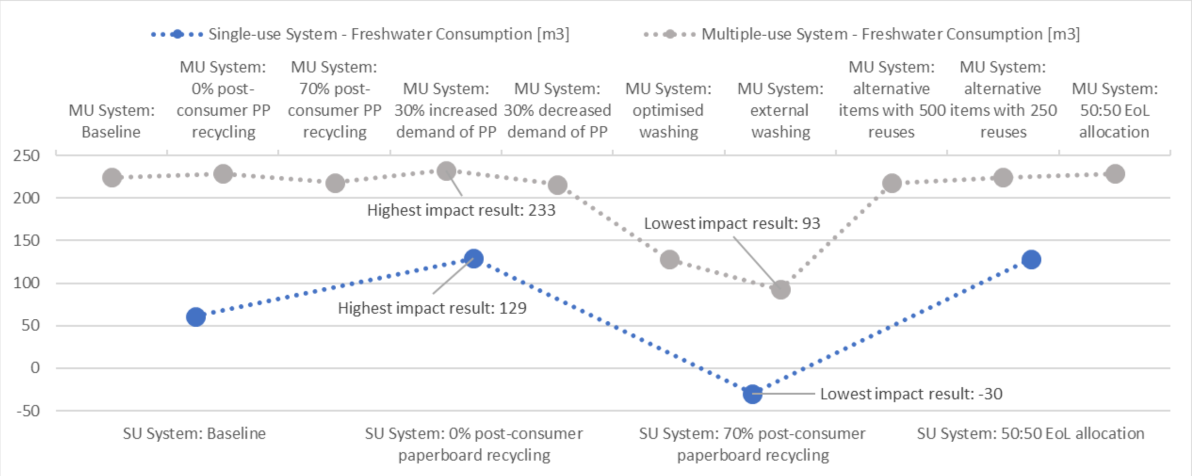

Figure 8: Summary of aggregated results for the impact category Freshwater Consumption of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the comparison between the single-use and the multiple-use system is dependent on underlying assumptions. However, there is a tendency that on average the single-use system shows **very significant** environmental benefits in terms of freshwater consumption. **Moderate** environmental benefits for the multiple-use system are solely identified in hypothetical situations where the effects of post-consumer paper recycling are less prevalent (i.e. 0% post-consumer recycling and/or different EoL allocation assumption) and optimised or external washing is fully adopted. In general, it is important to bear in mind inherent uncertainties relating to the adopted impact assessment method and, in particular, the freshwater consumption indicator.

e) Freshwater Eutrophication

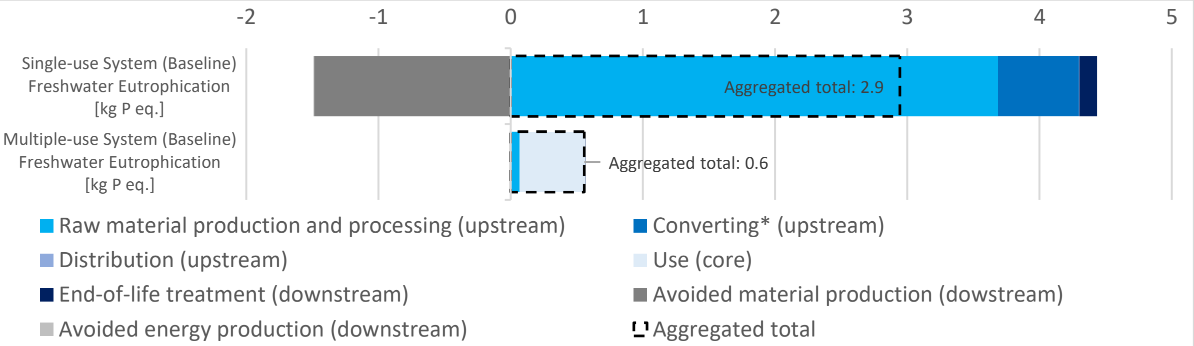

Figure 9: Baseline comparison results for the impact category Freshwater Eutrophication in kg P eq.

Single-use system

The resulting impact of the baseline scenario of the single-use system is predominantly influenced by paper manufacturing. Credits from avoided primary production of pulp contributes significant credits (i.e. negative impacts) to this impact category.

Multiple-use system

The single main contributor to freshwater eutrophication in the baseline scenario of the multiple-use system is wastewater treatment as a result of the washing process (see use phase). Combined with the contributions from the electricity demand of the washing process and the production of chemicals for the detergent, 89% of the aggregated total impact are generated by the use phase of the multiple-use system. The upstream production of items is another significant contributor with a share of 12% of the total aggregated impact.

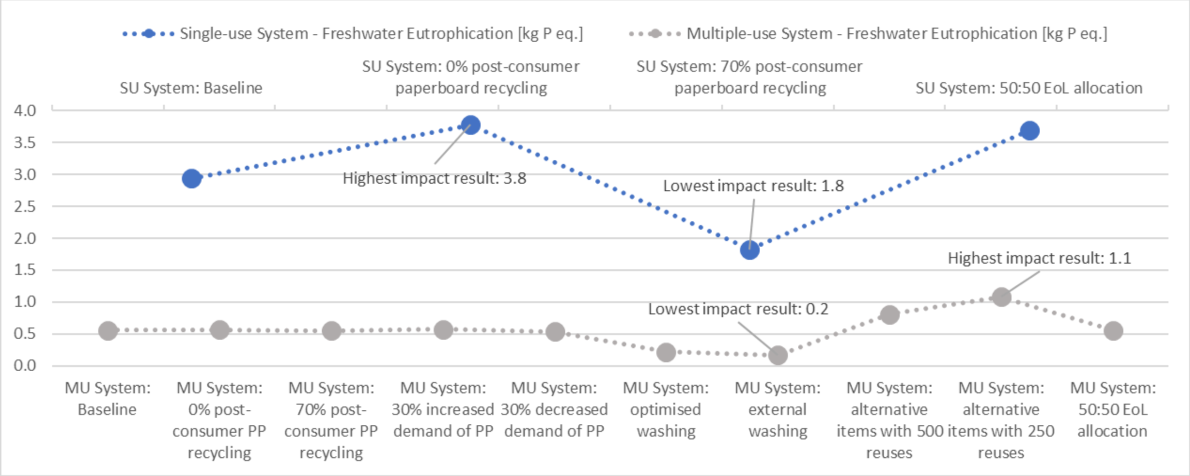

Figure 10: Summary of aggregated results for the impact category Freshwater Eutrophication of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, reported results exclusively suggest **very significant** benefits for the multiple-use system with regard to freshwater eutrophication.

f) Ionizing Radiation

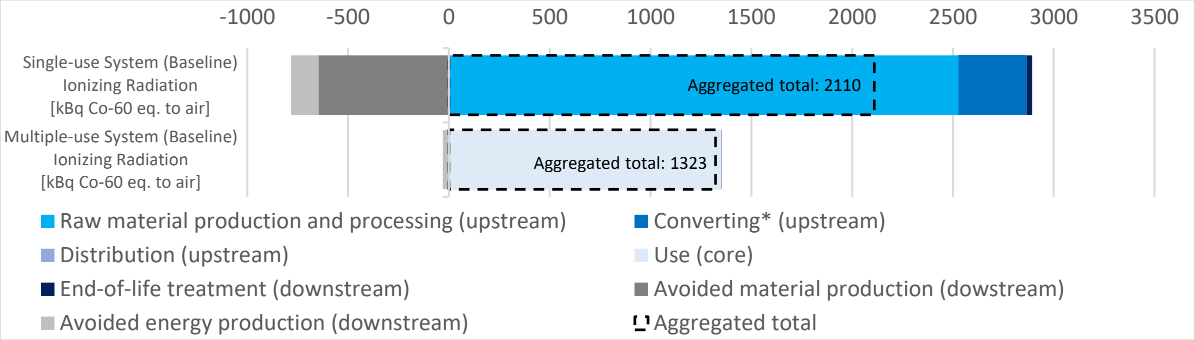

Figure 11: Baseline comparison results for the impact category Ionizing Radiation in kBq Co-60 eq. to air

Single-use system

The resulting impact in the baseline scenario of the single-use system is almost entirely affected by both the paper manufacturing and subsequent credits from material recycling. The latter corresponds to almost 40% of the aggregated total.

Multiple-use system

In the baseline scenario of the multiple-use system, ionizing radiation is dominated by the electricity demand (i.e. EU-28 average grid mix) of the washing process in the use phase, which accounts for almost 102% of the aggregated total impact. Around 2% of these impacts are offset due to the credits from EoL treatment.

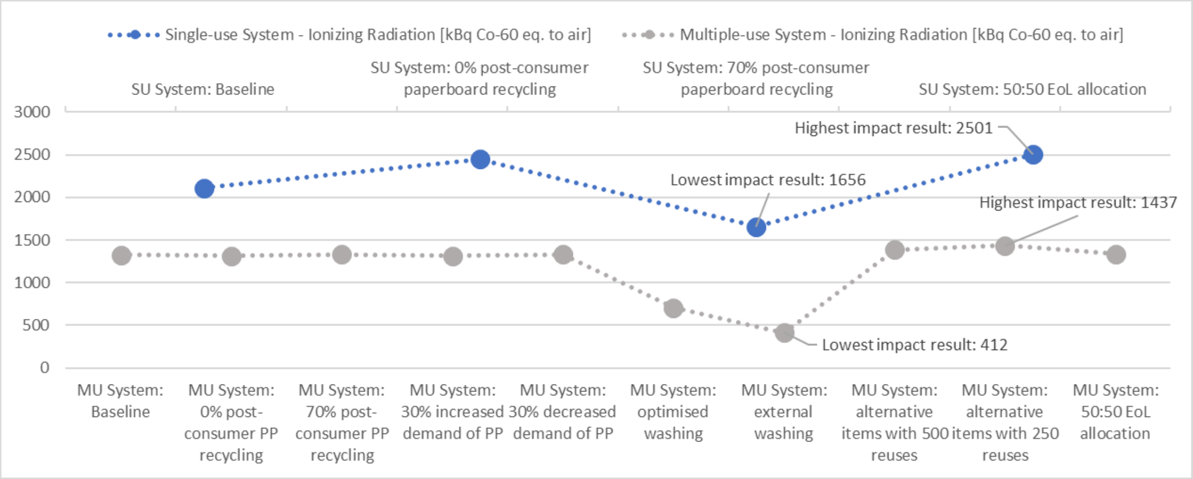

Figure 12: Summary of aggregated results for the impact category Ionizing Radiation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, there are on average **significant** environmental benefits for the multiple-use system with regard to ionizing radiation. Only **noticeable** environmental benefits for the multiple-use system are identified when increased post-consumer paper recycling and full crediting at the EoL stage is assumed.

g) Metal Depletion

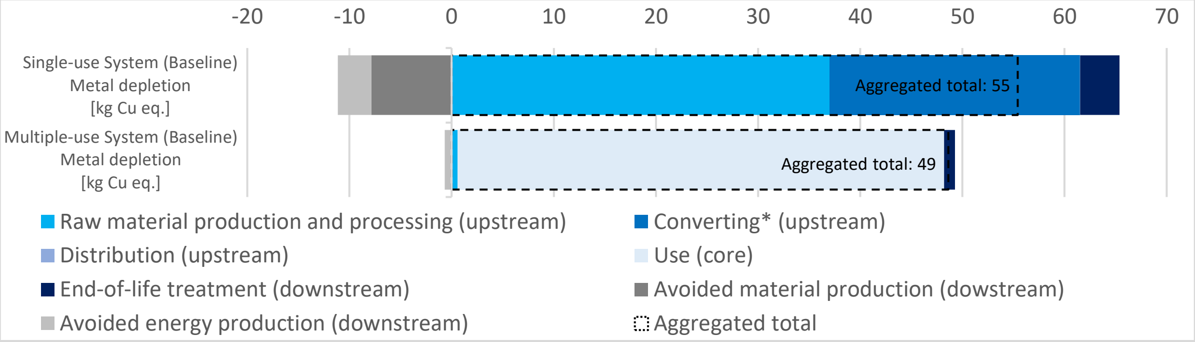

Figure 13: Baseline comparison results for the impact category Metal Depletion in kg Cu eq.

Single-use system

The main contributors in the baseline scenario of the single-use system are chemicals/fillers and varnishes/paints during paper manufacturing and converting. Noteworthy credits are resulting from energy recovery and material recycling (corresponding to about 20% of the aggregated total).

Multiple-use system

The main contributor to metal depletion in the baseline scenario of the multiple-use system is the electricity demand of the washing process, followed by the water demand for washing and the production of chemicals and additional dishwashers. The combined impacts of the processes in the use phase account for 98% of the total impact. Smaller contributions come from the upstream items production and the EoL treatment of these items.

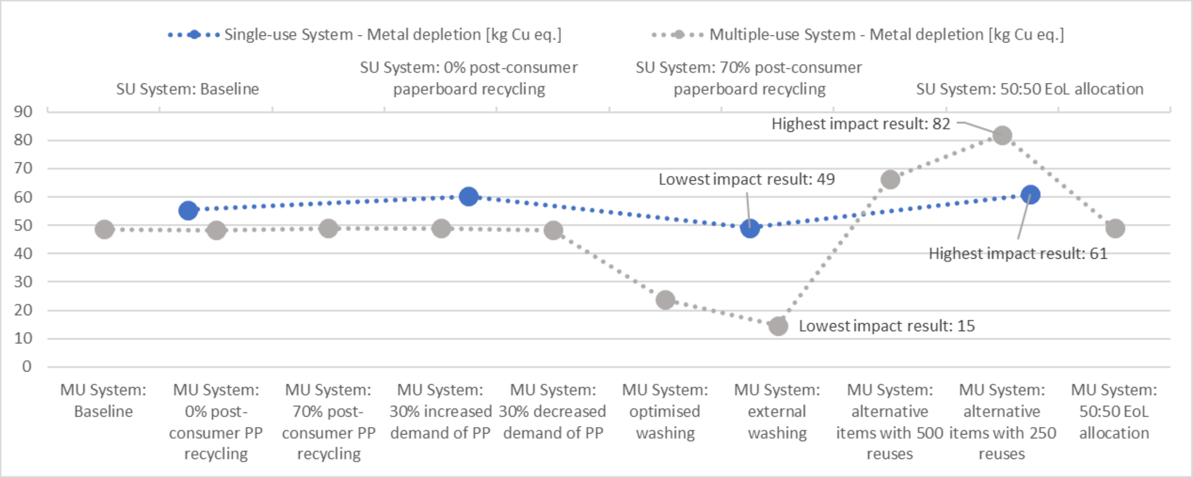

Figure 14: Summary of aggregated results for the impact category Metal Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the multiple-use system shows on average **noticeable** environmental benefits with regard to metal depletion. However, **minor** up to **very significant** environmental benefits are shown for the single-use system when compared to a multiple-use system comprising alternative product items partially made of ceramic, glass, and steel.

h) Stratospheric Ozone Depletion

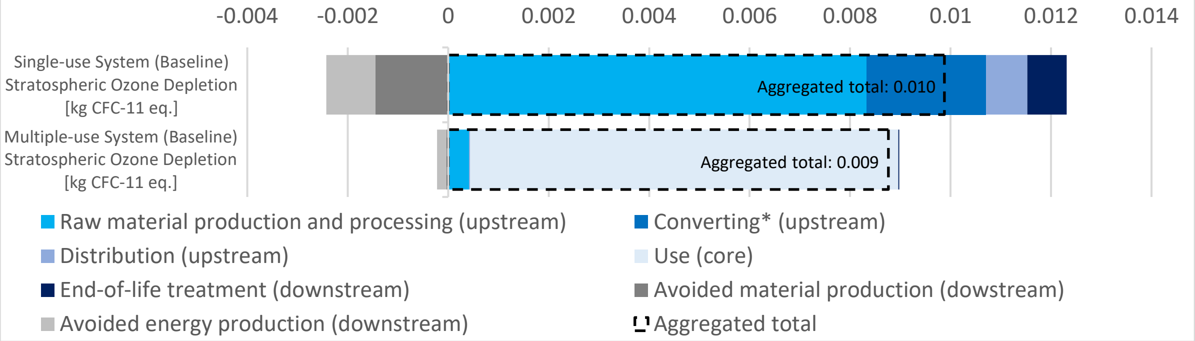

Figure 15: Baseline comparison results for the impact category Stratospheric Ozone Depletion in kg CFC-11 eq.

Single-use system

Looking at the baseline scenario of the single-use system, this impact category is almost entirely influenced by certain paper manufacturing processes. Credits from recycling and energy recovery are less significant in this category compared to other impact categories.

Multiple-use system

With regard to the baseline scenario of the multiple-use system, the stratospheric ozone depletion is again dominated by the electricity demand of the washing process, followed by municipal wastewater treatment and the production of chemicals for washing. Thus, the use phase generates 97% of the total aggregated impact.

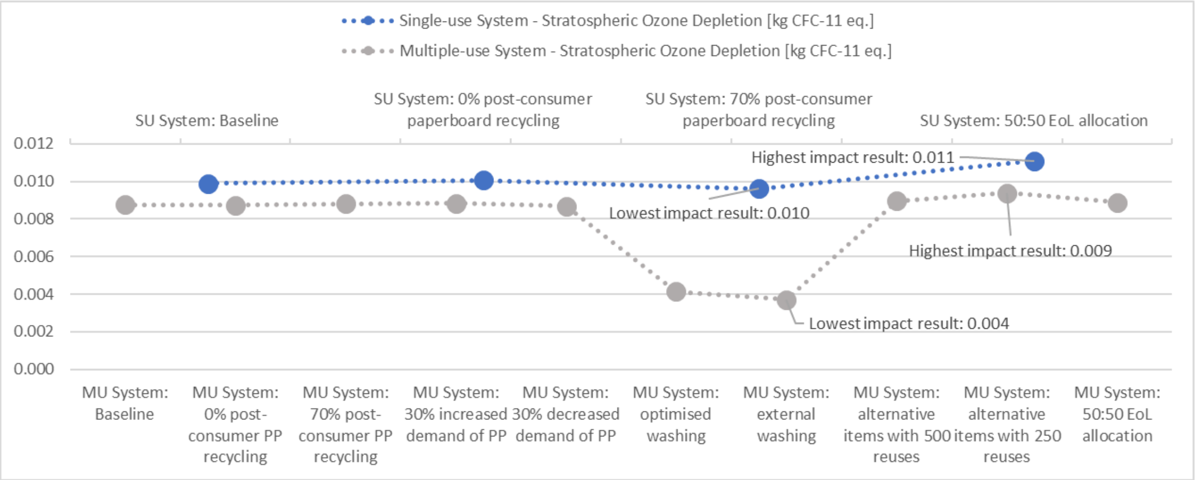

Figure 16: Summary of aggregated results for the impact category Stratospheric Ozone Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the multiple-use system on average shows **moderate** environmental benefits in terms of stratospheric ozone depletion. **Very significant** environmental benefits for the multiple-use system are identified for the hypothetical scenarios entailing optimised or external washing processes.

i) Terrestrial Acidification

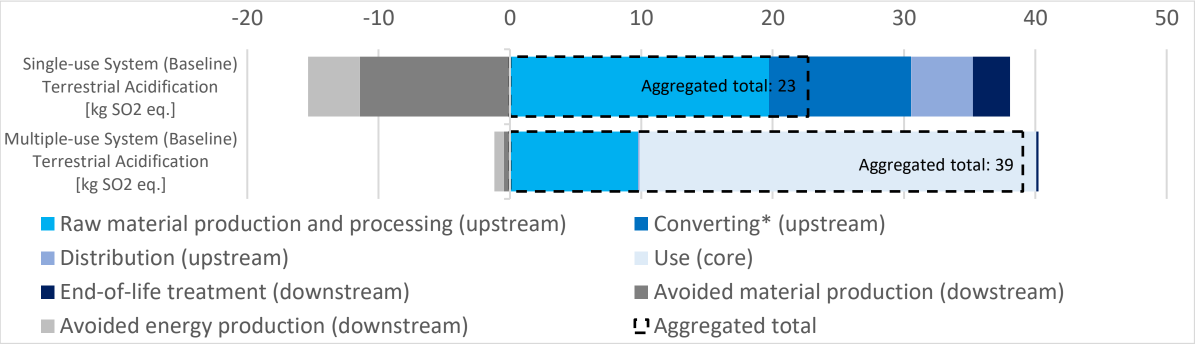

Figure 17: Baseline comparison results for the impact category Terrestrial Acidification in kg SO_2 eq.

<u>Single-use system</u>

The largest contributors in the baseline scenario of the single-use system are paper manufacturing and electricity demand for converting. These contributions are again significantly counteracted by credits from recycling and energy recovery (corresponding to almost 70% of the aggregated total).

<u>Multiple-use system</u>

With regard to the baseline scenario of the multiple-use system, terrestrial acidification is dominated by the electricity demand of the washing process. The use phase is responsible for 77% of the aggregated total impact. 25% of the impact on terrestrial acidification stem from the upstream production of multiple-use items and around 3% credits are generated through their EoL treatment.

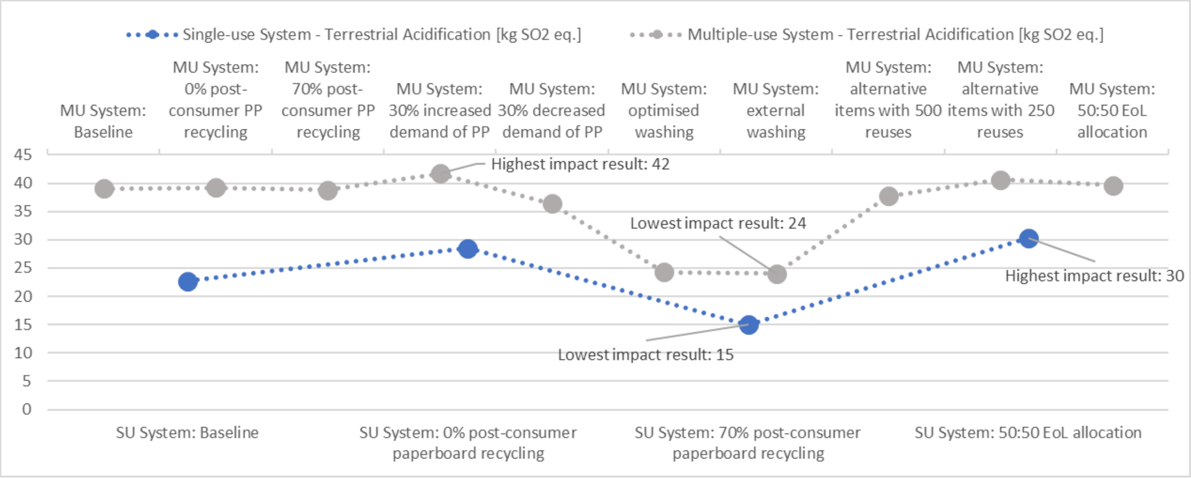

Figure 18: Summary of aggregated results for the impact category Terrestrial Acidification of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the single-use system on average shows **significant** environmental benefits with regard to terrestrial acidification. **Noticeable** environmental benefits for the multiple-use system are solely identified in situations where the effects of post-consumer paper recycling are less prevalent (i.e. different allocation assumption and/or no post-consumer paperboard recycling) and optimised or external washing is fully adopted.

1. INTRODUCTION

1.1 Objective of the study

Ramboll has been appointed by the European Paper Packaging Alliance (hereafter "EPPA" or the Client) as technical consultant for conducting a Life Cycle Assessment (LCA) study.

EPPA is an association representing suppliers and manufacturers of renewable and sustainable paper board and paper board packaging for Food and Foodservice Industry. They include, e.g., Seda International Packaging Group, Huhtamaki, AR Packaging, Smith Anderson, CEE Schisler Packaging Solutions, Stora Enso, Metsä Board, Mayr-Melnhof Karton, WestRock, Iggesund/Holmen, Reno De Medici and Paper Machinery Corporation.

It is Ramboll's understanding that EPPA seeks support for the development of a comparative LCA study between a single use dishes system and equivalent multiple-use dishes in Quick Service Restaurants (hereafter "QSRs") in accordance with ISO standards 14040 and 14044 as a basis for discussion with authority representatives on the current legal developments within the European Union and the United Kingdom regarding circular economy and waste prevention.

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

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. It is evident that previous studies seem to 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.**

1.2 Methodological approach

Given above outlined rationale behind this study the methodological approach comprises a literature screening and a full comparative LCA.

1.2.1 Literature screening

A focused literature screening gives an overview of existing research on relevant product systems (i.e. single-use and multi-use food containers and/or beverage cups to be used in restaurants or cafés). The main purpose of this screening is to provide data and information concerning product systems in the focus of this study and to put results into perspective. Moreover, potential issues in conducting the quantitative assessment by means of LCA (e.g. data gaps, allocation issues) are identified and can be addressed accordingly. To this end, main results and interpretations of the identified literature is made available in Appendix 1. Moreover, here the hypotheses that existing studies take a predominantly product-focused approach is substantiated and put in contrast to this study.

The list of incorporated literature is the result of previous knowledge and a web-search using specific search terms connected to the subject (e.g. LCA, environmental impact, carbon footprint, disposable, reusable, tableware, cup, container, restaurant). In addition, the following criteria or containments are applied:

- Publicly available or made available by the commissioner of this study;

- Year of publication 2010 or later;
- Comparative assertion;
- LCA methodology or life-cycle thinking applied;

A summary of relevant studies and respective results is presented in chapter 2. The incorporated literature raises no claim to completeness.

1.2.2 Life cycle assessment and modelling

Currently, LCA provides the best and most mature framework for assessing the potential environmental impacts of products according to the European Commission (European Commission, 2019). One of the most frequent application of LCA studies is the comparison of specific goods or services (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010). Several results of life cycle based assessment are already being used in relation to certain EU policies (e.g. Ecolabel Regulation, Green Product Procurement, Ecodesign Directive). Given the method’s standardized framework and maturity as well as methodological adaptation to policy needs, the consideration of LCA studies in policymaking is expected to increase (European Commission, 2017). A very prominent example of the use of LCA in EU policies and impact assessment is the justification of possible changes in the waste hierarchy due to environmental concerns (European Commission, 2017).

The general methodology for LCA aims to assess previously 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). The scientifically grounded procedure of life cycle impact assessment (LCIA) includes the following mandatory elements according to ISO 14040/44 (Hauschild, 2017):

- selection of impact categories, indicators and characterization models;
- assignment of LCI results to the selected impact categories (classification); and
- calculation of category indicator results (characterization).

The LCA model for this study is developed with GaBi Professional software using background data primarily from the associated GaBi Professional database (version 2020), Ecoinvent (version 3.6) and available extension databases.

2. LITERATURE SCREENING

The study is to be seen in light of other relevant studies and respective results. Relevant literature identified during the project is analysed regarding the obtained results and differences to the study conducted. Based on these studies, an environmental comparison of single-use and multiple-use products and systems for serving meals/drinks often shows lower environmental impacts for multiple-use products compared to single-use products (Almeida et al., 2018; Bortoluzzi and Ostan, 2015), as long as the number of uses is greater than a value that depends on system boundaries, materials, and assumptions. This value ranges from 50 up to 420: for example, 50 (UBA Report, 2019), 132 (Giraffe Innovation, 2018), and 420 (CIRAIG Report, 2014).

The following potential environmental hotspots are identified in the respective literature:

- Disposable components (e.g., lids) made of fuel-based materials (e.g., plastic lids) in single-use (Hohenthal et al., 2019) and multiple-use systems (UBA Report, 2019) have a great relevance on environmental impacts, and they can influence the overall results;
- In single-use systems, manufacturing contributes the most to the overall results (Antony and Gensch, 2017; UBA, 2019)
- In multiple-use systems, cleaning (washing and rinsing) contributes most to the overall results, mainly due to electricity consumption (Antony and Gensch, 2017; Giraffe Innovation, 2018; Bortoluzzi and Ostan, 2015; Vercalsteren et al.). Important factors are the use of washing machines BAT compliant (best-available-technique, CIRAIG, 2014; UBA, 2019) and green energy supply (UBA, 2019). These two factors are the major contributors to the overall environmental impacts.

Table 44 in the appendix shows the studies that are taken into account by the literature screening and presents their respective major results in terms of environmental impacts of analysed products, hot spots and underlying assumptions and scenarios. The right-hand column lists the main differences of the current study which can give an indication on the applicability of the results for the context of QSRs. Moreover, the respective products covered by those studies are indicated in Table 45 in the appendix. From this overview it becomes evident that no studies have used a combined portfolio and systems approach to take into consideration the entire portfolio comprised of single-use and multiple-use items (i.e. system approach).

3. COMPARATIVE LIFE CYCLE ASSESSMENT

3.1 Goal and scope

3.1.1 Goal of the assessment, intended audience, intended and not intended applications of the assessment

There are two fundamentally different ways of serving meals to consumers for in-store consumption in QSRs: either using single-use (disposable) dishes or multiple-use dishes. Both alternatives can generally be provided by a number of processes using different materials of various origins. In this context, an LCA study according to the ISO 14040/44 standards is carried out. The main goal of the LCA study is to **compare the environmental performance of single-use and multiple-use dishes options for in-store consumption in QSR in Europe.**
For the comparative assessment, two fundamentally distinct systems are taken into consideration:

- current system in 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), accounting for regulatory implications in 2023 (e.g. targets for separate waste collection and end of life (EoL) recycling);
- expected (hypothetical) future system in the near future based on equivalent multiple-use products (also referred to as multiple-use product system) and respective processes and infrastructure for washing operations (in-store or sub-contracted).

In accordance with the ISO 14040/44 standards, the equivalence of the two distinct systems (single-use and multiple-use) is to be 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 in QSRs deserves particular attention. In this regard, the acquisition and establishment of new dishwashing and drying machines for in-store washing is to be assessed as well as separate waste collection at QSRs and potential regulatory demands for recycling.

The comparative LCA study will adhere to an attributional modelling approach, meaning that a specified and static state of a system or product is examined. Thus, average data (representing average environmental burden from a specific activity or production volume) is incorporated in this assessment and results refer to an unambiguously defined current or future system. In contrast to the attributional modelling as done in this assessment, a consequential modelling approach would account for expected changes in broader systems as consequence of change in demand of certain products or processes. Instead of average data, marginal data (= effect per unit of an infinitesimal change in a given variable) would be implemented. However, this modelling approach bears more uncertainties and data availability is expectedly lower. Not least for this reason attributional LCA is the most commonly adopted approach. Moreover, an attributional approach is deemed applicable for the goal of this study as a system as it can be observed (currently or in the future) is described.

This study is intended for different audiences:

- Policymakers who are interested in examining the comparative 'footprints' of different systems;
- (Environmental) authorities and agencies which may be involved in review of the legislation and preparing its own assessment;
- QSRs, who will be involved in advocacy and / or implementation of legislation;

- The European Commission, which has said it will assess the environmental footprints of single-use and multiple- use as part of its Green Deal work plan. New evidence will support this work;
- Member States and MEPs, who should be informed of new evidence as they will be part of legislative negotiations with the European Commission;
- The media and wider public.

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. As a consequence, the impact result may not be used for product development, production process improvement, or any product-related decisions.

3.1.2 Systems perspective and functional unit

In line with the systems perspective adopted in this study the derivation of a valid functional unit as a basis for the comparison of distinct product systems requires an understanding of the general and specific functioning of QSRs.

3.1.2.1 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 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 and do not require table service;
- Hygiene and food safety are to be at the highest level;
- Dishes should be recyclable and security providing: multi-use plastic would therefore be the base-case material responding to both imperative, as ceramic and glass (used for dishes) are not recyclable, and together with metal in QSR can be dangerous in terms of misuses or accidents.
- 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[7];
- Take away may represent at least up to 40% of the total sales;
- Home delivery service has fast grown (double digit) over the last few years representing on average 20% 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;

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[7] However, this study focuses on in-store consumption only.

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).

3.1.2.2 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. Here, it is understood that the current system has evolved around single-use products for serving food and beverage for both in-store consumption and take-away. As a consequence, 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 this regard, the functional unit must comprise both qualitative and quantitative aspects.

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. First, 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. Second, 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.

3.1.2.3 Functional unit

Based on methodological recommendations in LCA studies and the outlined fundamental understanding of the study’s context as well as acknowledging the expected systems change within QSRs in Europe, the following functional unit is derived as reference for all assumptions and calculations:

Accommodating in-store consumption of foodstuff and beverages with single-use or multiple-use dishes (including cups, lids, plates, containers and cutlery) in an *average* QSR for 365 days in Europe in consideration of established facilities and hygiene

standards as well as QSR-specific characteristics (e.g. peak times, throughput of served dishes).

In this context an *average* Quick Service Restaurant is defined by the parameters presented in Table 6.

Table 6: Type of single-use and multiple-use items and assumed average numbers of in-store consumption in an average QSR in Europe (Source: confidential client data)

Type of servings	Single-use system items	Number of single use items/ servings per year	Applicable Multiple-use system items	Assumption for number of reuses per multiple use item	Resulting number of multiple use items per year	Assumption for rewashing rate[8]	Resulting number of washing cycles per multiple use item per year
Hot drinks	Hot drink cup	Confidential data	PP hot cup	100	Confidential data	5%	Confidential data
	Clip-on lid	Confidential data	PP lid for hot cup	100	Confidential data	5%	Confidential data
Cold drinks and shakes	Cold drink cup	Confidential data	PP cold cup	100	Confidential data	5%	Confidential data
Burgers	Clamshell	Confidential data	Acrylic plastic plate	100	Confidential data	5%	Confidential data
	-		PP serving cover for plate	100	Confidential data	5%	Confidential data
	Paper wrap	Confidential data			Confidential data		Confidential data
Fries and snacks	Fry box	Confidential data	PP basket	100	Confidential data	5%	Confidential data
	Paper fry bag	Confidential data			Confidential data		Confidential data
Salads	Salad box	Confidential data	PP salad bowl	100	Confidential data	5%	Confidential data
	-		PP lid for salad bowl	100	Confidential data	5%	Confidential data
Cold desserts	Cold dessert cup	Confidential data	PP dessert cup	100	Confidential data	5%	Confidential data
Cutlery	Wooden cutlery (modelled as 1 piece)	Confidential data	Thick washable PP cutlery set (modelled as 3 pieces)	100	Confidential data	5%	Confidential data

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[8] Rewashing rate is an average value based on Antony and Gensch, 2017; the exact rate will depend on organisational structures in a QSR (e.g. time between serving of dishes and washing; pre-rinsing of dishes)

In determining the associated reference flows (e.g. type and quantity of food or beverage containers, percentage of lids) to accommodate in-store consumption as defined above, several assumptions (e.g. replacement rate of multi-use items, dimensioning of dishwashing and potential drying machines, minimum size of rotating stocks of multi-use items, extra precautionary stocks, etc.) are made and documented in the respective sections of this report. In addition, critical assumptions will be tested by means of sensitivity analysis. These assumptions mainly refer to the multiple-use system and respective number of product items. For the single-use system it is assumed that the number of servings in an average QSR in Europe equals the number of single-use product items.

QSRs are at the core of utilized product items and accompanying processes (e.g. transport, dishwashing) in this assessment. Therefore, it is crucial that the established functioning of a QSR restaurant is maintained despite the fundamental change related to the use of reusable food and beverage containers for in-store consumption. In line with the goal and envisaged systems approach of this assessment and current or hypothetical future operations in QSRs being in the foreground of this assessment, this LCA seeks to differentiate between upstream, core, and downstream processes which are inextricably linked to the functional unit (see Figure 1).

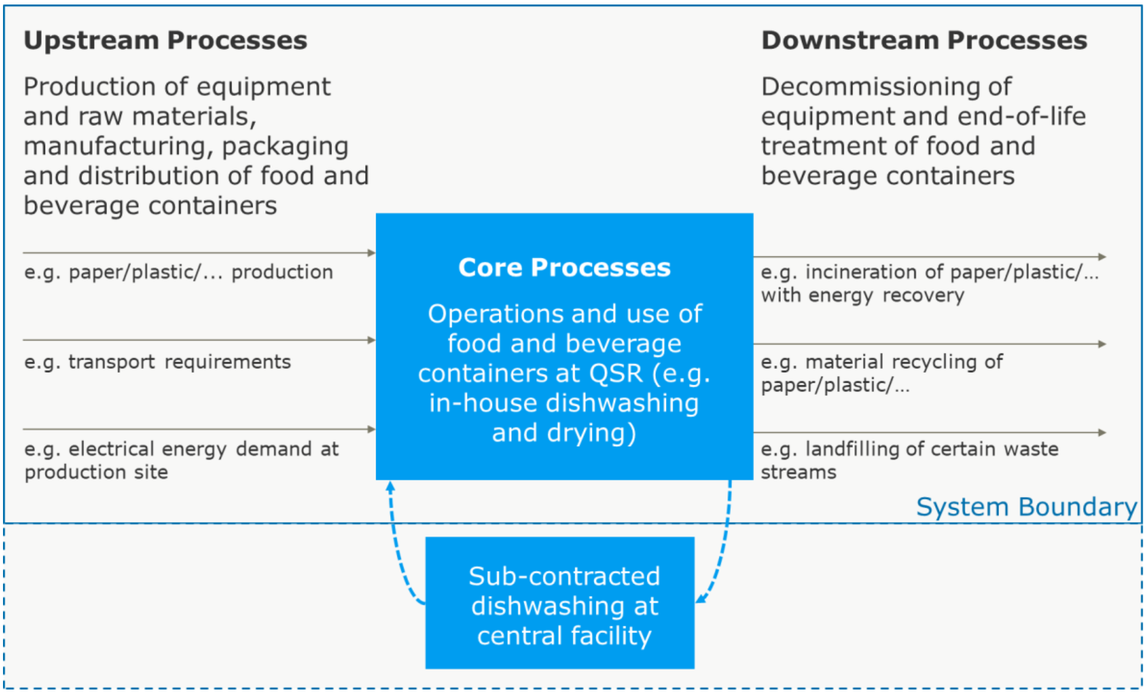

Figure 19: Schematic system boundary and differentiation between upstream, core, and downstream processes from the perspective of a QSR (Source: own depiction)

Due to the fact that the single-use system is well established in QSRs, primary data from manufacturers (e.g. detailed bill of materials and LCI on specific production processes) can be retrieved while for the hypothetical multiple-use scenario only secondary data and publicly available information (e.g. scientific literature, LCA studies, product declarations, etc.) can be identified and implemented. To prevent any misconceptions or misinterpretations, the notion "simplified" is added to respective inventories. This predominantly applies to multiple-use food and beverage dishes. Provided that a comparably high number of reuses of multiple-use items is actually realized under QSR-specific conditions (which may not always be the case), production and end-of-life treatment stages of such items may rather be insignificant in terms of their influence on the overall environmental impacts of a multiple-use system (Umweltbundesamt, 2019). Therefore, approximations of the upstream effects of entailed items are deemed appropriate for the purpose of this study but needs to be borne in mind when interpreting the results. Consequently, the adopted product items shall not be analysed individually but as a representative and equivalent system associated with well-defined upstream, core, and downstream processes to deliver the expected function to the QSR. Thus, comparisons on a product-level or conclusions concerning single items or their combination are not the objective of this study, i.e. environmental hot-spots will not be disclosed on a product-level but solely on a systems-level. Moreover, absolute impacts associated with single product items or the entire systems are to be handled with care as both data availability and the comparative nature of this assessment will mainly allow for disclosure and interpretation of relative impacts, i.e. the potential magnitude of differences between both situations in terms of environmental impact categories. In summary, this assessment is rather disentangled from a product-specific perspective as to give recommendations on a systems-level.

3.1.2.4 Incorporated product items

As indicated in Table 6 in section 3.1.2.3, the LCA study will take into account the life cycles of:

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

Table 7 summarises the relevant specifications of the different product items.

Table 7: Single-use and multiple-use product specifications

Function within QSR system	Single-use (SU) product item	Material of SU item	Dimensions/ volume of SU item	Product weight of SU item	Multiple-use (MU) product item	Material of MU item	Product weight of MU item
Serving of hot drinks	Hot drink cup (PE content < 10 % w/w)	Virgin-fibre bleached board with PE coating on the reverse side	~266 ml (9 oz)	6.7 g	Simplified* hot drink cup	1) PP 2) ceramic**	1) 33 g (8 oz) 2) 280 g (8 oz)
Spillover protection of hot 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	Simplified* lid for hot drink cup	PP	7 g
Serving of cold drinks and shakes	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	~473 ml (16 oz)	9.8 g	Simplified* cold drink cup	1) PP 2) tempered glass**	1) 76 g (16 oz) 2) 240 g (16 oz)
Serving of burgers	Clamshell	Partially recycled cartonboard (only post-industrial white recycled fibres)	94x94x70 mm	15.6 g	Simplified* plate	1) acrylic 2) ceramic**	1) 30 g (20 cm) 2) 550 g (20 cm)
	Paper wrap	Virgin-fibre oil and grease-resistant bleached paper with ecological (soy-based) barrier coating	40x30.5 mm	29.5 g/m²	n.a.	n.a.	n.a.
Protection cover for burgers	n.a.	n.a.	n.a.	n.a.	Simplified* serving cover	PP	50 g
Serving of fries and snacks	Fry bag (box)	Partially recycled cartonboard (only post-industrial white recycled fibres)	90x41x119 mm	7.5 g	Simplified* 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	n.a.	n.a.	n.a.
Serving of salads	Salad box (incl. lid)	Partially recycled brown cartonboard (only post-industrial recycled fibres)	155x135x65	28.9 g	Simplified* salad bowl	PP	92 g

Function within QSR system	Single-use (SU) product item	Material of SU item	Dimensions/ volume of SU item	Product weight of SU item	Multiple-use (MU) product item	Material of MU item	Product weight of MU item
Protection cover for salads	n.a.	n.a.	n.a.	n.a.	Simplified* lid for salad bowl	PP	14 g
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	Simplified* dessert cup	PP	54 g
Provision of cutlery	Cutlery (1 item)	Thin pressed wood (e.g. birch, bamboo)	-	3 g	Simplified* cutlery set (3 items)	1) PP 2) Stainless steel**	1) 7.8 g 2) 104 g

* To prevent misconceptions or misinterpretations, the notion "simplified" is added to respective inventories. This predominantly applies to multiple-use food and beverage dishes. Provided that a comparably high number of reuses of multiple-use items is actually realized under QSR-specific conditions, production and end-of-life treatment stages of such items may rather have subordinate effects of their influence on the overall environmental impacts of the entire multiple-use system.

** Product material is considered by means of sensitivity analysis.

Other food containers/packaging (i.e. shovel for coffee, placemat, drinking straw, additional product items for product labelling) are not included in the LCA study.
In summary, the systems perspective adopted for this assessment can be seen as a distinctive feature compared to rather product-oriented assessments within this field of research.

3.1.3 System boundaries

In general, all life cycle stages as indicated in Figure 19 are included in this study. However, life cycle stages or certain processes that are identical for both systems may be excluded from this comparative assertion.
For the present study, system boundaries are defined for the single-use and the multiple-use dishes system that allow for a comparison of the two systems and their equal function. In this context, the inclusion of the production processes, the use phases as well as the end-of-life scenarios for each option is essential.

Several aspects are beyond the system boundaries of this LCA, i.e. the food and beverage value chains including their preparation at the QSRs, the infrastructure at the production and QSR facilities, food handling, storage and waste, potential differences in the working time for handling used dishes, and space requirements for machinery in the QSRs (see also section 3.1.2).

Based on the investigations of previous studies, the manufacture, maintenance and disposal of dishwashers may not be included in the comparison as this has been shown to have very limited impacts (Antony and Gensch 2017 after Rüdenauer et al. 2011; VTT 2019). However, equal functioning of the multiple-use systems requires washing of the respective items. In case of in-house washing of the items in the QSRs, a high number of dishwashers will need to be installed in QSRs (e.g. almost 8.000 McDonald's[9] and 3.000 Burger King’s restaurants in Europe restaurants in Europe). Although QSRs already have smaller dishwashers in place, larger or more devices are expected to be needed for implementing multiple-use items. In the context of this study the upstream impacts of additional dishwashers are therefore included using a simplified bill of materials of an average dishwasher. In addition, the use phase of the dishwasher is an essential component of the multiple-use system and is therefore necessarily included in the comparison. This includes the water, chemicals, i.e. detergent and rinse agent, and energy used for the washing and drying phase.
Both systems share the general life cycle phases of production of the dishes systems, transport to the QSR, and serving of food using the dishes. In addition, transport and packaging required for both systems are included in the LCA for all life cycle stages (e.g. distribution of dishes to QSR, transport to and from a washing service provider in case of the reusable system). The systems however differ in the material inputs and production processes during their production phase as well as in the treatment after use for food serving; i.e. the single-use system is at its EoL and the multiple-use system enters the washing and reuse phase repeatedly until it arrives at its own EoL phase after a specific number of uses depending on the material. Table 8 lists the life cycle phases included for each system. Several processes only apply to the multiple-use system due to the required washing, potential transport for washing, and at the EoL phase, wastewater treatment.

Table 8: Overview of life cycle stages and processes of the two dishes systems included in the analysis.

Life cycle stage	Single-Use System	Multiple-Use System
Raw material production and processing (upstream)	• cradle-to-gate production of PE-coated paperboard • cradle-to-gate production of uncoated cartonboard	• simplified cradle-to-gate production of multiple-use product items

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[9] https://de.statista.com/statistik/daten/studie/263619/umfrage/anzahl-der-mcdonalds-restaurants-in-europa-nach-laendern/

Life cycle stage	Single-Use System	Multiple-Use System
	• cradle-to-gate production of thin greaseproof paper • cradle-to-gate production of thin pressed wood • intermediate transports from pulp producers to paper manufacturers • treatment of production wastes at paper mills	• 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 at QSR (core)	*n.a.*	• washing and drying of multiple-use items after each use • simplified cradle-to-gate production of detergent and rinse agent • simplified production of additional dishwashers • municipal wastewater treatment
End-of-life treatment (downstream)	• 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 QSRs and production wastes (i.e. trimmings) from converters • transport from QSRs or converters to incineration or recycling plant	• post-consumer PP, acrylic and PE in waste incineration plant • recycling of sorted PP post-consumer waste from QSRs • transport from QSRs to incineration or recycling plant
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 electricity grid mix

Life cycle stage	Single-Use System	Multiple-Use System
	• cradle-to-consumer thermal energy from natural gas	• cradle-to-consumer thermal energy from natural gas
Not included in system boundaries:	• sorting of post-consumer paperboard for recycling (it is assumed that this process is handled at the QSRs and not associated with additional environmental impacts) • upstream transport of production materials/chemicals for cartonboard production (lack of data, see also sections High-brightness cartonboard: and Brown kraft cartonboard:)	• sorting of post-consumer PP for recycling (it is assumed that this process is handled at the QSRs and not associated with additional environmental impacts) • packaging and transport of detergent and rinse agent for washing process • production of racks for transport of multiple-use items for external washing sensitivity analysis (see section 3.3.2.5)

3.1.3.1 Multifunctionality and allocation procedures

Multifunctional processes (i.e. multi-input or multi-output processes) constitute an omnipresent methodological challenge in LCA studies (Hauschild, 2017). This is mainly due to the aspiration of analysing individual product systems based on the main function they provide despite their real-world implications and interrelations with potential other functions or processes (i.e. environmental impacts associated with a certain process cannot be fully ascribed to an isolated product system). In order to deal with such issues, the ISO standard 14044 presents a hierarchy of procedures. These procedures are a prerequisite for comparative assertions between different product systems and allow a hotspot analysis of a single product system. In general, the ISO hierarchy for solving multifunctionality is as follows (Hauschild, 2017):

1. Perform sub-division of the affected process, i.e. cut off subprocesses providing secondary functions;
2. Perform system expansion, i.e. integrate the secondary function into the system boundaries (displacement/avoidance of impacts or crediting for avoided production);
3. Perform allocation using physical causality, representative physical parameter, or another parameter (e.g. economic) (in this order), i.e. partition the environmental flows and associated impacts between the primary and secondary functions and cut off the part related to the secondary functions.

Inherent allocation at process level

Datasets adopted from existing databases (e.g. Ecoinvent, GaBi Professional database) for the modelling of background processes adhere to inherent allocation procedures. The respective datasets coming from databases are transparently documented for the affected processes within both product systems in section 3.2.

Allocation on system level

Allocation on the product system level adheres to the ISO hierarchy outlined above and documented in the respective sections. A prominent allocation issue in relation to the analysed product systems (in particular concerning the single-use system) is the handling of EoL treatment processes (Hohenthal, Leon, *et al.*, 2019). Hence, where (intermediate) products have both recycled content and outputs for recycling or recovery, it is necessary to apply consistent allocation procedures. According to the ISO hierarchy system expansion (i.e. avoided burdens approach) is the preferred approach for solving multifunctionality in certain end-of-life scenarios (e.g. open- or closed-loop recycling, incineration with energy recovery) (Hauschild, 2017). More specifically, material outputs from recycling processes are credited based on the assumed reduced requirement of virgin material production. Similarly, incineration of some materials in the EoL stage produces heat and electricity, which is credited using average energy equivalents (e.g. energy mix from grid) based on the assumption that respective primary energy generation is substituted. Since this approach should be used wherever possible, and system expansion is arguably always possible in recycling cases, the ISO standard advices against all other methods (e.g. cut-off or recycled content approach) in this regard. Yet, two variants of the allocation of credits resulting from energy or material recovery have to be considered in order to fulfil the ISO norm. This will be ensured by a sensitivity analysis.

Moreover, in order to ensure consistent comparability between systems that generate different outputs or different amounts of the same outputs (which is often the case for different recycling processes), system expansion (avoided burden and crediting of the studied system) is considered the only scientifically sound approach.

From a policy perspective, this approach leads to a focus on recycling at the end-of-life and promotes the concept of the circular economy, while the so-called cut-off approach (or: recycled content approach) leads to a focus on increasing the percentage of recycled materials in a new product.

In order to account for the environmental benefits of recycling, only the net amount of material recovered at the end of a product´s life cycle is to be credited (i.e. amount of material recycled minus the amount of recycled content used to make the product). Thus, life cycle inventory (LCI) data accounting for recycling activities must entail potential impacts of using recycled content in the manufacturing process as well as credits for the end-of-life recycling of a certain material. In order to maximise transparency, recycling credits are reported separately. Another important feature of the system expansion approach (or end-of-life recycling approach) is that, regardless of any actual recycled content in products in the real world, all of the material input upstream in the LCA model should bear the load of primary production if the end-of-life crediting is based on avoided primary material production (Frischknecht, 2010). Otherwise there is a risk of accounting for the benefits of recycling twice in the same life cycle.

3.1.3.2 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. recycling rates) and background datasets (e.g. electricity from grid) as inventory data for the manufacturing stage of certain products will be site-specific or representing average production scenarios (e.g. global, EU).

3.1.3.3 Time boundary

This study compares the single-use system currently applied in QSRs in Europe with a potential future multiple-use scenario. Furthermore, potential regulatory implications in the near future (e.g. targets for separate waste collection and end of life recycling) are taken into account for both systems as far as possible.

Data presenting the two systems relies on the most recent and currently available information and its applicability in particular for a potential future scenario is subject to speculation. Hence, the future situation is primarily defined by robust assumptions and expected system characteristics. Representativeness is ensured and the reference years are transparently documented for all primary data and assumptions (see section 3.2). Time-related coverage of secondary data is indicated in the respective databases and the adopted versions.

3.1.4 Cut-off criteria

No general cut-off rule is applied. Instead, material and energy flows are modelled to the most detailed extend possible. Excluded processes, materials or life cycle aspects are indicated in section 3.1.3 and in the respective inventory lists in the appendix. All simplifications of inventories or the exclusion of certain processes are deemed appropriate in the light of the adopted systems approach and are not expected to change the conclusions of this assessment.

3.1.5 Data quality requirements

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

- **Time-related coverage:** Primary datasets and inventories are not older than 2018. 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, 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 the appendix.
- **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.
- **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. Moreover, primary data is benchmarked with literature data (see also section 1.2.1 for a list of relevant LCA studies).
- **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.

3.1.6 Impact categories and assessment method (LCIA)

As required by ISO 14044, LCIA used in comparative assertions intended to be disclosed to the public shall comprise a sufficiently comprehensive set of indicators. It is, however, understood that potentially insufficient inventory data does not allow for a scientifically sound derivation of certain impacts or that certain impact categories seem irrelevant for both assessed systems. For instance, the assessment of toxicity impacts is not without controversy (Antony and Gensch, 2017). This is due to the anticipated uncertainties concerning data availability or data symmetry in background datasets. Hence, the selection of impact categories for further interpretation is guided by both data quality and intelligibility in the public and scientific debate around respective systems.

In accordance with the goal and scope of this assessment, ReCiPe is suggested as an LCIA method in this study. The ReCiPe method was created by RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft. The group of authors include the developers of the CML 2001 and Ecoindicator 99 methodologies. ReCiPe can be seen as a fusion of the two methodologies, taking the midpoint indicators from CML and the endpoint indicators from Ecoindicator. In this study, midpoint indicators are disclosed adhering to a hierarchist (H) cultural perspective. Hierarchist (H) is based on the most common policy principles with regard to time frame and other issues. It uses the medium time frame, e.g. a 100 year time frame for global warming (GWP100). Therefore, ReCiPe 2016 v1.1 Midpoint (H) as implemented in the available software solution (GaBi Professional) is used for this study.

Table 9 gives an overview of <u>all</u> possible midpoint indicators covered by ReCiPe 2016 Midpoint (H).

Table 9: List of potentially relevant impact categories according to ReCiPe 2016 Midpoint (H) (Huijbregts *et al.*, 2016).

Impact category	Indicator	Unit	Abbr.
Climate change	Infra-red radiative forcing increase	kg CO2 to air	GWP
Stratospheric ozone depletion	Stratospheric ozone decrease	kg CFC-11 to air	ODP
Ionizing radiation	Absorbed dose increase	kBq CO-60 to air	IRP
Fine particulate matter formation	PM2.5 population intake increase	kg PM2.5 to air	PMFP
Photochemical oxidant formation: ecosystem quality	Tropospheric ozone increase (AOT40)	kg NOx to air	EOFP
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase (M6M)	kg NOx to air	HOFP

Impact category	Indicator	Unit	Abbr.
Terrestrial acidification	Proton increase in natural soils	kg SO2 to air	TAP
Freshwater eutrophication	Phosphorus increase in fresh water	kg P to fresh water	FEP
Human toxicity: cancer	Risk increase of cancer disease incidence	kg 1,4-DCB to urban air	HTPc
Human toxicity: non-cancer	Risk increase of non-cancer disease incidence	kg 1,4-DCB to urban air	HTPnc
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	kg 1,4-DCB to industrial soil	TETP
Freshwater ecotoxicity	Hazard-weighted increase in fresh water	kg 1,4-DCB to fresh water	FETP
Marine ecotoxicity	Hazard-weighted increase in marine water	kg 1,4-DCB to marine water	METP
Land use	Occupation and time-integrated transformation	m2 x yr annual crop land	LOP
Freshwater consumption	Increase of water consumed	m3 water consumed	WCP
Metal depletion	Ore grade decrease	kg Cu	SOP
Fossil depletion	Upper heating value	kg oil	FFP

In this study the following impact categories from above list are selected for the environmental comparison:

- Climate change;
- Stratospheric ozone depletion;
- Ionizing radiation;
- Fine particulate matter formation;
- Terrestrial acidification;
- Freshwater eutrophication;
- Freshwater consumption;
- Metal depletion;
- Fossil depletion.

The remaining impact categories from the selected ReCiPe LCIA (ecotoxicity, human toxicity, photochemical oxidant formation, and land use) are excluded due to the following reasons:

- The comparative assessment and underlying data predominantly focus on environmental impacts, thus midpoint impact categories solely attributable to damage to human health are excluded;
- Primary LCA data does not disclose certain impact categories (e.g. land use impacts due to forest operations) due to insufficient data availability and inherent methodological issues within available LCIA methods (e.g. applicability for the forest industry);
- The assessment of toxicity impacts is not without controversy (see above) and would add additional uncertainty.

Indicators from alternative or potentially complementary LCIA methods (e.g. CML, LANCA, TRACI, EF) are not assessed in this LCA study. Apart from the observed lack of consensus on certain methods and the ongoing development of respective methods, this due to above mentioned reasons and the circumstance that data acquisition, data validation and subsequent LCA modelling are done in alignment with the requirements (e.g. reference flows, data, etc.) for the adopted ReCiPe method. This approach is deemed appropriate given the implementation of numerous primary data and information and the broad scope of this assessment. Moreover, the approach ensures credibility of disclosed indicators.

3.1.7 Assumptions and limitations on a 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 3.2. 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 in the near future as both primary data and background data (e.g. electricity from grid) from databases are retrospective. Therefore, the future 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.

Further assumptions and limitations of this LCA study are as follows:

- Take-away or food delivery scenarios are excluded from this assessment;
- 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;
- The infrastructure of production and restaurant facilities as well as auxiliary processes (e.g. heating of plants, offices and restaurants) is excluded;
- 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 dishes 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;
- As both systems are intended for in-store consumption, lids may be excluded (except for hot drinks) as long as they aren’t an integral part of the respective food or beverage container (Hohenthal, Kujanpää, *et al.*, 2019);
- Trays are assumed to be used in both scenarios and therefore can be excluded from this comparative assessment;

- Packaging for auxiliary materials such as detergents and chemicals for the dishwashing process is excluded from the assessment;
- Potential plastic leakage into the environment (e.g. freshwater ecosystems) cannot adequately be addressed by the underlying methodological possibilities of LCA (Federal Environment Agency Germany, 2019a);
- No distinctive assumptions are made relating to collection and sorting quotes as those are covered by the hypothetically assumed recycling rates. In addition, LCIs for respective recycling processes inherently account for the yield of the technical process;
- 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 future scenario. However, due to the lack of equal primary information on environmental commitments of plastic producers (e.g. PP or acrylic plastics) 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.

3.1.8 Normalization and weighting

According to ISO 14040, normalization is an optional part of the life cycle impact assessment procedure (see section 3.1.6). Given the comparative nature of this assessment, additional normalization of results is not deemed necessary.

3.2 Life cycle inventory analysis

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 and specific datasets for all product systems as well as necessary processes are presented as input-output tables in the Appendix 3 - Life cycle inventory.

3.2.1 Product systems and process flowcharts

The LCI covers single-use and multiple-use items fulfilling similar functions to serve food products in QSRs. 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 (see further details on the functional unit below). For the hypothetical multiple-use scenario, items produced from plastic (PP, acrylic), ceramic, glass or steel are used as alternative options to fulfil similar functions compared to their established single-use equivalents. Data for the multiple-use scenario is obtained from secondary sources (literature; GaBi professional and Ecoinvent database). Table 7 in section 3.1.2.4 lists an overview of the items used in the single-use and multiple-use system, with different multiple-use options, if available (e.g. PP hot cup or ceramic hot cup). The complete LCI for both scenarios listing input/output values and modelling assumptions is disclosed) Appendix 3 - Life cycle inventory (under consideration of confidentiality issues) for the different components listed in Table 7 in section 3.1.2.4.

3.2.2 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. 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 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), assumptions, and certain reference flows or values. The respective classification of incorporated inventory data is marked in the Appendix 3 - Life cycle inventory.

3.2.2.1 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.

3.2.2.2 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 are 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.

3.2.2.3 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.

3.2.2.4 Single-use system

The single-use 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 7 in section 3.1.2.4.

Raw material production and processing (upstream)

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 (e.g. Sweden, Finland, Austria). The respective origin of the paper products and thus the geographical coverage of the distinct pulp and paper inputs to the subsequent converting processes are disclosed in Appendix 3 - Life cycle inventory (Upstream - Raw material production/processing).

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 10. Further details on the implemented LCA information and data are disclosed in Appendix 3 - Life cycle inventory (Upstream - Raw material production/processing).

Table 10: 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)	Primary data	Confidential	Finland	1 t dry chemical pulp	2019
PE-coated paperboard (different variants and specifications)	Primary data	Confidential	Finland	1 t board	2020

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 11. Further details on the implemented inventory data and modelling choices are disclosed in Appendix 3 - Life cycle inventory Upstream - Raw material production/processing.

Table 11: Primary data for paper making implemented by means of inventory data and own modeling

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Thin greaseproof paper with soy-based coating	Primary data	Confidential	Austria	1 t paper	2020
High-brightness cartonboard	Primary data	Confidential	Austria	1 t cartonboard	2019
Brown kraft cartonboard	Primary data	Confidential	Slovenia	1 t cartonboard	2019

For this assessment it is assumed that all single-use products are entirely made of virgin paper. On a more general note, however, it would be advised to account for recycled fibre age for the recycled content as well as for the number of subsequent uses of recycled fibres (Hohenthal, Leon, *et al.*, 2019). However, the chosen LCA modelling approach allows to circumvent these difficult assumptions. Given the assumption that all single-use products upstream of the system are assumed to be made of solely virgin paper, the fibre age for the recycled content is irrelevant. In this regard it is important to remember that actually a significant share of some paper products listed in Table 11 comes from post-industrial paper waste. Consequently, this assumption reflects a conservative approach and avoids the risk of double counting of the credits associated with energy or material recovery at the EoL stage. In line with this approach, EoL credits are assigned based on the assumption that an equivalent virgin paper product is displaced in the market by the recovered material. Thus, a potential loss of quality is in inherently accounted for in this assumption (see further details in section End-of-life treatment (downstream)).

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

- Upstream processes refer to the respective geographical context of the paper mill or manufacturer; thus, representing Finland, Austria, and Slovenia. 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);
- Paper reject or paper residues at paper mills are accounted for in the upstream process models and/or are not attributable to the paper grade used in the single-use system;
- Other generated wastes (e.g. unspecified non-hazardous/hazardous waste for further processing, metal scrap, sewage sludge, waste heat) are largely accounted for in upstream processes;
- Although some paper producers reportedly source 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;
- Intermediate transport from paper producers to converters is modeled according to primary data provided by converters.

Converting (upstream)

The production stage of single-use product items (i.e. converting stage) 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. The respective single-use product items required to fulfil the functional unit are listed in Table 12. Further details on the implemented inventory data and modelling choices are disclosed in Appendix 3 - Life cycle inventory (Upstream – Converting).

Table 12: Primary data for the converting stage implemented by means of inventory data and own modeling

Provider process name	Classification	Source	Geographical coverage	Reference value	Reference year
Hot drink cup	Primary data	Huhtamaki	Finland	1 t dry weight product	2018
Cold drink cup	Primary data	Seda	Germany	1000000 pcs	2020
Clamshell	Primary data	Seda	Germany	1000000 pcs	2020
Fry bag	Primary data	Seda	Germany	1000000 pcs	2020
Salad box	Primary data	Seda	Germany	1000000 pcs	2020
Clip on Lid	Primary data	Seda	Germany	1000000 pcs	2020
Ice Cream Cup	Primary data	Seda	Germany	1000000 pcs	2020
Paper wrap	Primary data	CEE Schisler	France	1000 pcs	2019
Paper fry bag	Primary data	CEE Schisler	France	1000 pcs	2019
Wooden cutlery	Secondary data	Paspaldzhiev *et al.* (2018)	Europe	1 pc	2017

For the baseline scenario the following additional assumptions are made at this stage (i.e. converting or production of single-use product items):

- 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;
- All production paper wastes during converting (i.e. post-industrial waste) are materially recycled as indicated in primary information obtained from converters; For the recycling of post-industrial paper wastes the same recycling process as for the post-consumer wastes is assumed (see further details in the section on End-of-life treatment (downstream)); no further transport demands are accounted for at this stage for waste collection as this is deemed insignificant from an environmental perspective and ensures comparability to the multiple-use system;
- 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;
- Type and amount of packaging materials for wooden cutlery is based on the assumption that on average three pieces of cutlery (e.g. fork, knife, spoon) are packed together in one paper packaging.

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 Table 13.

Table 13: Secondary data for transport from manufacturer to QSR

Provider process	Data classification	Source	Geographical coverage
Articulated lorry transport incl. fuel, Euro 0-6 mix, 40 t total weight, 27 t max payload	Secondary data	GaBi	EU-28

Use stage (core)

In the context of this comparative assessment, the use stage of the single-use system is not relevant from an environmental perspective.

End-of-life treatment (downstream)

The end-of-life stage is an environmentally important life-cycle stage when considering single-use products.

Due to a lack of reliable and detailed material flow information on the current and future downstream pathways of disposed single-use product items, assumptions are made concerning the end-of-life treatment in the future scenario (i.e. baseline scenario). In this regard, it is understood that both the renewable raw material sources and the general feasibility for material recycling of coated and uncoated paper products are distinctive features of single-use products when comparing them to multiple-use products that are either made of non-renewable raw materials (e.g. PP) and/or cannot be materially recycled (e.g. ceramic) into high-quality products. In order to facilitate a valid comparison with the material recycling of multiple-use products made of PP for which available recycling processes (e.g. data in GaBi or Ecoinvent databases) are considered state-of-the-art, primary data on the potential recycling process for coated paperboards is crucial. Furthermore, a suitable point of substitution is to be defined; i.e. the intermediate virgin product that is actually displaced by the recycled materials. Moreover, it is safe to say that uncoated paper products are easily recyclable by means of established recycling processes while PE-coated paper products are recyclable but complicate the recycling in current practice (Lee, Yoon and Ryu, 2017; Ma, 2018). The polymeric coating is a few microns thick. As paper is a hygroscopic material, the presence of limited quantities of polymers is necessary for paper fibre food containers to provide barriers against liquid or grease and therefore preserve the integrity of the food and its safety. From a technical viewpoint, the main function of polymers is essentially to make the paper container water-proof for a longer period in order to provide it with adequate levels of protection, safety and hygiene. From a purely technical point of view PE-coated paper products can be materially recycled (Suskevice and Grönman, 2019). Appropriate recycling facilities in EU are available, while separate collection requires additional efforts. While separate collection of PE-coated and other paper wastes can be accommodated by QSRs as long as in-store consumption is concerned, recycling mills operate a number of different technologies. PE coated paper is recycled at large quantities in Europe, at several mills. Standard paper recycling mills can handle lower volumes of one side coated paper, and special paper recycling mills can handle large amounts and also 2 side coated paper (CEPI, 2019).

In order to investigate the future scenario (also referred to as the baseline for this assessment), it is important to acknowledge that several paper mills have made adjustments to the recycling process over the last few years and other paper mills are expected to do so as well in the near future. Hence, it is fair to assume, that a certain share of paper in PE-coated paper wastes may be treated and recycled appropriately in this future scenario which is adopted as a baseline for this comparison (see section 3.1.1). To what extent financial incentives or the lack of them may influences future recycling of PE-coated paper products cannot be assessed in this study. Moreover, any potential environmental impacts associated with the installation of additional infrastructure and adjustments to the paper mills are neglected.

In conclusion, it is postulated that significant paper waste material fractions are materially recycled in the future scenario (i.e. baseline scenario). In this context it is assumed that the recycled paper materials are not suitable for food contact applications, thus the recycling does not occur in a closed loop. Instead, recycled paper fibres from food or beverage containers are used in different products (e.g. magazine paper, secondary packaging or corrugated board packaging), hence recycling usually occurs in an established open loop characterized by lower material quality requirements. As a result, secondary and primary materials are often mixed for the production of certain paper products (e.g. cardboard) (European Environment Agency, 2006). As to apply the introduced system expansion approach (see section Allocation on system level) to the modelling of end-of-life recycling in this open-loop situation, the recycling is assumed to create functionally equivalent materials (Nordelöf *et al.*, 2019). Thus, it can be approximated as occurring in a closed loop. In addition, it is assumed that the recovered paper materials do not displace recycled materials from other product systems (i.e. not affecting the secondary material market).

In order to represent an appropriate recycling scenario as well as to account for environmental credits of recycling, primary gate-to-gate inventory data of a dedicated recycling process for plastic (PE)-coated as well as uncoated paperboard products is implemented (Table 14). Further details on the implemented inventory data and modelling choices are disclosed in Appendix 3 - Life cycle inventory (

Downstream – End-of-life treatment).

Table 14: Primary data for coated/uncoated paper recycling implemented by means of inventory data and own modelling

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	1,000 kg	2019

In order to account for environmental credits from material recycling, inventory data of the manufacturing of intermediate paper products until the point of substitution through respective material outputs of the recycling process are implemented as indicated in Table 15.

Table 15: Secondary data for avoided pulp production

Provider process	Data classification	Source	Geographical coverage
Market for sulfate pulp, bleached	Secondary data	Ecoinvent 3.6	Europe (RER)
Market for sulfate pulp, unbleached	Secondary data	Ecoinvent 3.6	Europe (RER)
Sulfite pulp production, bleached*	Secondary data	Ecoinvent 3.6	Europe (RER)
Thermo-mechanical pulp (TMP) production*	Secondary data	Ecoinvent 3.6	Europe (RER)
Chemo-thermomechanical pulp (CTMP) production*	Secondary data	Ecoinvent 3.6	Europe (RER)

* implemented data is adjusted to reflect energy efficiency gains in the industry

Some Ecoinvent datasets (as indicated in Table 15) seem to overestimate impacts throughout all relevant impact categories which would lead to significantly overestimated environmental credits assigned to the single-use system from material recycling. Thus, the background data is adjusted according to energy efficiency gains reported by the industry. To this end, energy and electricity efficiency gains as reported in CEPI statistics[10] from the year 2000 to 2018 are applied to the datasets. More specifically, the following process parameters are adjusted by respective efficiency gains (see Table 16).

Table 16: Assumed efficiency gains between 2000 and 2018 for certain avoided pulp products

Process parameter or flow	Assumed efficiency gain between 2000 and 2018 based on industry statistics[10]
Electricity, medium voltage	34 %
Heat, district or industrial, natural gas	6 %
Heat, district or industrial, other than natural gas	34 %

Next to inventory data on the recycling process, distinct waste incineration processes are implemented (see Table 17).

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[10] https://www.cepi.org/wp-content/uploads/2020/07/Final-Key-Statistics-2019.pdf

Table 17: Secondary data for waste incineration processes

Provider process	Data classification	Source	Geographical coverage
Paper and board (water 0%) in waste incineration plant	Secondary data	GaBi	EU-28
Polyethylene (PE) in waste incineration plant	Secondary data	GaBi	EU-28
Wood (natural) in municipal waste incineration plant	Secondary data	GaBi	EU-28

In order to account for environmental benefits associated with the recovered energy during incineration processes, electricity as well as thermal energy are implemented as avoided burdens (see Table 18).

Table 18: Secondary data for avoided provision of energy due to energy recovery from waste incineration

Provider process	Data classification	Source	Geographical coverage
Electricity grid mix	Secondary data	GaBi	EU-28
Thermal energy from natural gas	Secondary data	GaBi	EU-28

All transport processes during EoL treatment are implemented with the same dataset as indicated in Table 13.

For the baseline scenario the following additional assumptions are made at this stage (i.e. EoL treatment of single-use product items):

- Product waste is collected and sorted at QSRs and transported over a distance of 100 km to a waste incineration plant or recycling facility;
- 30% of paper waste material fractions are materially recycled by means of state-of-the-art recycling processes (see Table 14). Environmental credits associated with the avoided production of virgin pulps are entirely attributed to the system. To this end, it is assumed that 53% from the obtained recycled pulps substitute chemical pulp (i.e. sulphate and sulphite pulps) and the remaining 47% substitute mechanical pulp (i.e. TMP and CTMP). This assumption is based on primary industry information as it is probable that recycled pulp is replacing more mechanical pulp than chemical pulp than the average market shares (chemical pulp 75% and mechanical pulp 25%[11]) would suggest. The assumed split between chemical and mechanical pulp to be replaced is further based on the circumstance that the technical properties of recycled fibres are closer to mechanical pulps and in many products that eventually use recycled pulps, the used virgin pulp is mechanical pulp. When factoring in further industry statistics[12], the resulting shares of avoided pulp products per ton of recovered pulp are as follows:
    - 49 %: Sulphate pulp, bleached;
    - 2 %: Sulphate pulp, unbleached;
    - 2 %: Sulphite pulp production, bleached;
    - 24 %: Thermo-mechanical pulp (TMP);
    - 24 %: Chemo-thermomechanical pulp (CTMP);

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[11] https://www.cepi.org/wp-content/uploads/2020/07/Final-Key-Statistics-2019.pdf

[12] According to industry data (https://www.cepi.org/wp-content/uploads/2020/07/Final-Key-Statistics-2019.pdf) the sulphite pulp share makes up about 4% of the total chemical pulp production in 2019.

- Remaining 70% of paper waste material fractions as well as all PE from coating associated with certain single-use products within the system are entirely incinerated with energy recovery. Environmental credits associated with the avoided provision of average electricity from grid and thermal energy from natural gas in the EU-28 are entirely attributed to the system;
- 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;
- Corrugated board wastes from packaging of single-use products to the QSRs are modelled according to background data adhering to a cut-off approach and thus the eventual recycling of such wastes is already taken into account;
- PE waste from dispatch packaging occurring at QSRs is assumed to be incinerated with energy recovery. Environmental credits associated with the avoided provision of average electricity from grid and thermal energy from natural gas in the EU-28 are entirely attributed to the system;
- Paper waste from dispatch packaging (only relevant for wooden cutlery sets) occurring at QSRs is assumed to be materially recycled.

3.2.2.5 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 7 in section 3.1.2.4.

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, simplified 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);
- The FU is calculated by means of average servings per day (as described in section 3.1.2);

Table 19 gives and overview of input materials, respective items produced from these materials and data used for modelling. A detailed overview of the individual items and their weights can be obtained from Table 7. Further details on the implemented inventory data and modelling choices are disclosed in Appendix 3 - Life cycle inventory (Upstream – Raw materials).

Table 19: Material composition and secondary data of the multiple-use system (baseline scenario)

Material	Items	Provider process	Data classification	Source	Geographical coverage
PP	Hot cup (including lid), cold cup, serving cover for plate, basket for serving fries, salad bowl (including lid), dessert cup, thick washable cutlery set	Polypropylene injection moulding part (PP); technology mix	Secondary data	GaBi (PlasticsEurope)	Europe (RER)
Acrylic	Plastic plate	Polymethyl-methacrylate granulate (PMMA); Plastic injection moulding	Secondary data	GaBi	Germany; Global
Corrugated paperboard for packaging	Packaging of all items for transport	corrugated board box production	Secondary data	Ecoinvent 3.6	Europe (RER)
Polyethylene film for packaging	Packaging of all items for transport	Polyethylene film (PE-LD)	Secondary data	Ecoinvent 3.6	Europe (RER)

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.

Distribution of final products (upstream processes)
Transport from producers to QSRs is modelled by considering production in Europe and transport of 800 km by means of 40 ton-lorry. The process listed in Table 13 (section 3.2.2.4) is used to implement transport in the LCA model.

Use stage and reuse (core process)
This stage is modelled by including washing and drying of multiple-use items after use in QSRs. The following key assumptions are made for the baseline scenario of the multiple-use system:

- Washing, rinsing and drying processes are performed in-house (in QSRs); inputs to these processes are based on literature values for water, energy, detergent and rinse agent demand (per item basis);
- Average reuse rate of 100 reuses[13] is considered. Reuse rates also include potential replacement reasons such as damages, stains, theft or loss. The latter reasons are presumably high in QSRs as higher volumes of product items are involved than in regular restaurants;
- An average scenario for dishwashers is used to reflect different grades of devices' efficiencies (see further details below and in Table 20);
- State-of-the-art detergent and rinse agent 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 5% is considered (as described in 3.1.2.3) – this assumption is made to avoid persistent residues that might remain after washing (Antony and Gensch, 2017); however, the exact rate will depend on organisational structures in a QSR (e.g. time between serving of dishes and washing; pre-rinsing of dishes by hand);
- Production of simplified dishwashers is considered (generic assumption of two additional devices to be installed inside a QSR to perform in-house washing; ten-year lifetime of the dishwasher): list of materials is based on bill-of-materials (cut-off approach for processes with relative weight <1%) reported in Porras (2019).

The following paragraphs provide further details on the assumptions related to the washing process listed above.

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. 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. These dishwashers differ in terms of washing capacity, cycle time, dimensions, drying function, energy consumption, water use, and detergent and rinse agent use. 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). On the one hand, space in some QSRs are reported to be limited and drying shall be performed inside the device, and therefore undercounter dishwashers present suitable options[14]. In this case, more than one device (e.g. three undercounter dishwashers) may be needed. If space allows and faster washing cycles are required, hood-type dishwashers are assumed to be used and only one (although larger) device may be required.

Both types of dishwashers show different ranges of efficiencies in terms of energy, water and chemicals demand. For the baseline scenario it is assumed that already installed devices in QSRs will be maintained until their end of life and will be supplemented by new devices. To reflect the different options of dishwashers in QSRs and the different levels of efficiencies, an average washing scenario is assumed for the baseline comparison. Given the board geographical scope of this assessment (EU average) this assumption is further justified. This average washing scenario consists of two options of undercounter dishwashers (conservative and optimised performance) and two options of hood-type dishwashers (conservative and optimised performance), resulting in four options with 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

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[13] This assumption is based on average reuse rate for plastic cup products retrieved from literature: > 75 (Hope Solutions, 2018), > 100 (Oya Festival, 2019), 100 (Green Goblet, 2020), > 130 (CupClub, 2018), 30 (Almeida, Le Pellec and Bengtsson, 2018).

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.

These four options along with their LCI data and the resulting overall average used for the baseline comparison are summarised in Table 20. Inputs for the washing and drying processes are energy demand (kWh/item), water demand (litres/item), detergent and rinse agent demand (g/item). Detailed descriptions about these demands are provided in the paragraphs below the table.

Table 20: Technical specifications of dishwashers for the inhouse washing scenario (LCI data).

	Undercounter dishwasher		**Hood-type dishwasher**		**Average washing process**
	Conservative	Optimised	Conservative	Optimised	
Reference year	2011	2020	2011	2017	
Energy demand* [kWh/item]	0.043	0.027	0.024	0.014	0.027
Water demand [l/item]	0.80	0.23	0.16	0.08	0.318
Combined detergents and rinse demand [g/item]**	0.80	0.20	0.50	0.17	0.417
Source	Based on (Rüdenauer *et al.*, 2011); (CIRAIG, 2014)	Based on Miele[15]; (CIRAIG, 2014; Paspaldzhiev *et al.*, 2018)	Based on (Rüdenauer *et al.*, 2011); (Paspaldzhiev *et al.*, 2018)	Based on (Antony and Gensch, 2017)	

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

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

Energy demand

Drying of dishes after dishwashing 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. The two undercounter dishwasher options presented in Table 20 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. 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

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[15] Source: Miele Website (accessed 26.10.2020), commercial dishwashers: https://www.miele.co.uk/professional/product-selection-commercial-dishwashers-429.htm

energy demand for washing and drying[16]. Therefore, energy demands reported in literature for the two hood-type devices are assumed to reflect 70% and are increased by 30% to model in-house dishwashing of plastic-based multiple-use items. Such a separate drying process would require the installation of an additional drying module[17].

Water demand

Water demand for washing and rinsing processes is retrieved from literature for undercounter and hood-type dishwashers, as listed in Table 20.

Detergent and rinse agent demand

For washing and rinsing processes, detergent and rinse agent demands are retrieved from literature as far as available on a per item basis. As reliable data for the chemical composition and demands is scarce, best-case (optimised undercounter) and worst-case assumptions (conservative hood-type) are based on Paspaldzhiev *et al.* (2018). Chemical composition is based on (Rüdenauer *et al.*, 2011) and was combined with expert judgement to reflect regulatory and efficiency developments since 2011[18]. Resulting compositions for detergent and rinse agent used to model the washing process of multiple-use items are listed in Appendix 3 - Life cycle inventory, Use phase.

The use stage of the multiple-use items also comprises the treatment of wastewater from washing in a municipal wastewater treatment plant. An overview of the processes used for the use stage is provided in Table 21.

Table 21: Secondary data for use phase in the multiple-use system

Process/item	Provider process	Data classification	Source	Geographical coverage
Electricity	Electricity grid mix	Secondary data	GaBi	EU-28
Water	Tap water from groundwater	Secondary data	GaBi	EU-28
Detergent	Several; see Use phase (Appendix 3) for details	Secondary data	GaBi; Ecoinvent 3.6	Europe, Germany
Rinse agent	Several; see Use phase (Appendix 3) for details	Secondary data	GaBi; Ecoinvent 3.6	Europe, Germany
Wastewater treatment	Municipal waste water treatment (mix)	Secondary data	GaBi	EU-28

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[16] 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.

[17] Generic additional material demands for additional dishwashers and/or dryers are included using a bill of materials of a simplified dishwasher (see key assumptions above and Appendix 3 - Life cycle inventory, Use phase)

[18] 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.

Process/item	Provider process	Data classification	Source	Geographical coverage
Simplified dishwasher	Several; see Use phase (Appendix 3) for details	Secondary data	GaBi; Ecoinvent 3.6	Global, Europe, Germany

<u>End-of-Life Treatment (downstream processes)</u>

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

- Items are separately collected and disposed of in dedicated containers in QSRs (without implications for environmental impacts);
- Items are expected to be transported by waste collection company from QSR to waste treatment facility (100 km transport distance via lorry is assumed);
- End-of-life treatment: multiple-use products are made of non-renewable raw materials (e.g. PP) and currently, generic plastic packaging shows EU average recycling figures lower than paper packaging[19]. However, mixed plastic packaging waste from end consumers is not directly comparable to PP waste generated from QSRs in a multiple-use future scenario and thus recycling rates for PP products resulting from such a system cannot be estimated. In order to facilitate a symmetric comparison with the single-use system 30% of the PP is assumed to be recycled in the baseline scenario (material recycling of pure plastic fractions with the aim of substituting primary material), and 70% of PP as well as acrylic are incinerated with energy recovery (electricity and thermal energy provision in the EU); sensitivity analyses are performed with 0% recycling (100% incineration) and 70% recycling (30% incineration), respectively;
- Packaging waste (upstream for transport from manufacturing to QSR) is sent to incineration with energy recovery.

The respective life-cycle inventories are disclosed in Appendix 3 - Life cycle inventory and in Table 22 and Table 23.

Table 22: Secondary data for EoL processes in the multiple-use system

Provider process	Data classification	Source	Geographical coverage
Polypropylene (PP) in waste incineration plant	Secondary data	GaBi	EU-28
Plastic granulate secondary (low metal contamination)	Secondary data	GaBi	EU-28
Polyethylene (PE) in waste incineration plant	Secondary data	GaBi	EU-28
Plastic packaging in municipal waste incineration plant	Secondary data	GaBi	EU-28

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 (see Table 23).

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[19] https://ec.europa.eu/eurostat/databrowser/view/ten00063/default/table?lang=en

Table 23: Secondary data for avoided provision of material and energy due to recycling and energy recovery from waste incineration

Provider process	Data classification	Source	Geographical coverage
Polypropylene, PP, granulate	Secondary data	GaBi, PlasticsEurope	EU-28
Electricity grid mix	Secondary data	GaBi	EU-28
Thermal energy from natural gas	Secondary data	GaBi	EU-28

All transport processes during EoL treatment are implemented with the dataset indicated in Table 13.

3.3 Impact assessment results

Based on the baseline modelling of the single-use items and the multiple-use equivalents, impact results are provided in the figures and discussions below. Absolute figures per life cycle stage are disclosed in Appendix 4 - Impact assessment results – Baseline comparison. In this section main contributors to the final results as well as relative differences between the systems are explained per impact category. For this LCA, the relevant comparative assertion is shown as "aggregated total" values in the respective figures (see dashed bars and absolute numbers in figures), thus accounting for all positive and negative impact contributions within a system.

3.3.1 Baseline comparison results

3.3.1.1 Climate Change

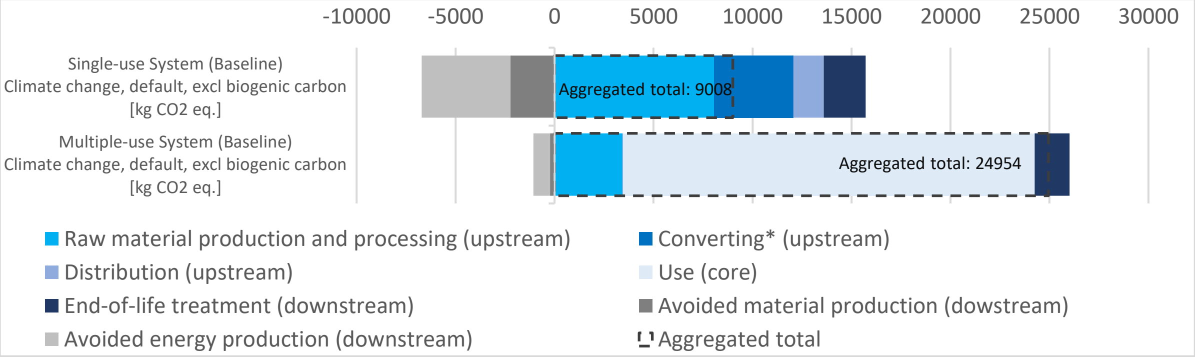

Figure 20: Baseline comparison results for the impact category Climate Change (excl. biogenic carbon) in kg CO_2 eq.

Single-use system

The potential climate change impacts of the single-use system are largely driven by paper manufacturing (about 90% of the aggregated total and half of the positive impact contributions, i.e. from raw material stage until EoL treatment). Next to paper manufacturing, the electricity demand for converting plays an important role in this category (assumed as EU-28 average grid mix). While paper manufacturing adds significant climate impacts, it is important to bear in mind that the total climate change impact is also significantly affected by the assigned climate change credits through material recycling and incineration with energy recovery (i.e. calculated negative impacts due to assumed avoidance of primary production of pulp or energy). Avoided climate change impacts through recycling and energy recovery correspond to about 75% of the aggregated total. The resulting climate change credits are, in turn, mainly associated with the avoided energy production, i.e. avoided production of electricity and thermal energy from natural gas in Europe.

Multiple-use system

The single main contributor to climate change impact in the multiple-use baseline scenario is the electricity demand of the washing process. Overall, the use phase accounts for 83% of the total aggregated impact. Another 14% are generated from the upstream production of multiple-use products and 7% from the EoL treatment of the item, although again a credit of 4% is associated with EoL treatment (credits for material and energy).

3.3.1.2 Fine Particulate Matter Formation

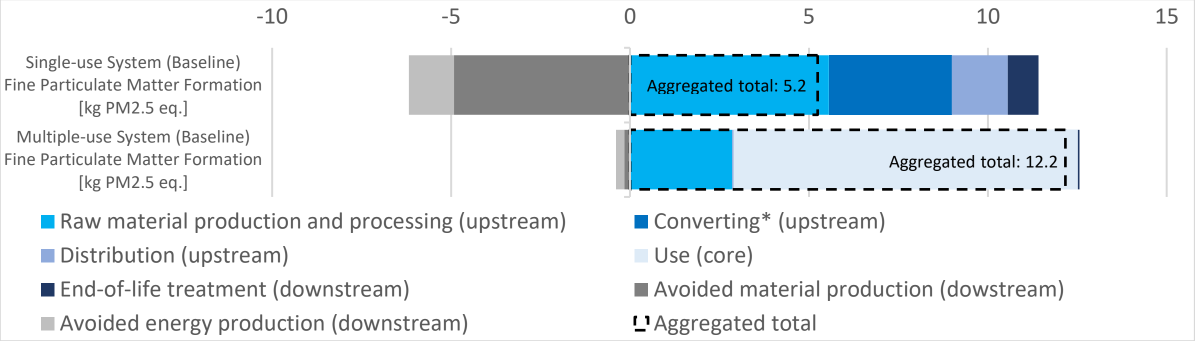

Figure 21: Baseline comparison results for the impact category Fine Particulate Matter Formation in kg PM2.5 eq.

<u>Single-use system</u>

Next to significant contributions from the paper manufacturing stage (both paper-based products as well as cardboard for packaging), converting (more than 60% of the aggregated total) and transport emissions during final distribution of single-use product items to QSR locations (about 30% of the aggregated total) are the main contributors to the total impacts associated with the baseline scenario of the single-use system. The resulting aggregated total impact is, again, significantly affected by the credits associated with material recycling and energy recovery. Overall, the incorporated credits are as high as the aggregated impacts of the single-use system in this category.

<u>Multiple-use system</u>

Similar as for the climate change impact category, 79% of the aggregated total for fine particulate matter are associated with the washing process, dominated by its electricity demand (i.e. EU-28 average grid mix). Upstream multiple-use items cradle-to-gate production accounts for 23% of the aggregated total impact.

3.3.1.3 Fossil Depletion

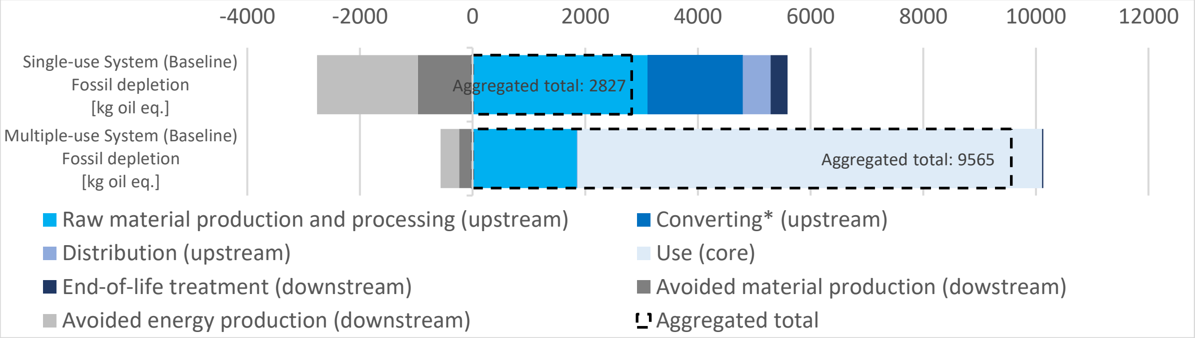

Figure 22: Baseline comparison results for the impact category Fossil depletion in kg oil eq.

<u>Single-use system</u>

The largest contributors to the baseline scenario of the single-use system are paper manufacturing and electricity demand for converting which is based on the EU-28 average grid mix. However, these contributions are again significantly counteracted by credits from material recycling and energy recovery, together corresponding to about 50% of the total positive impact contributions (see contributions from upstream, core, and EoL treatment).

Multiple-use system

With regard to the baseline scenario of the multiple-use system, fossil depletion is dominated by the electricity demand (i.e. EU-28 average grid mix) for washing and the washing phase accounts for 86% of the aggregated total impact. Upstream multiple-use items production is responsible for 19% of the aggregated total impact to fossil depletion.

3.3.1.4 Freshwater Consumption

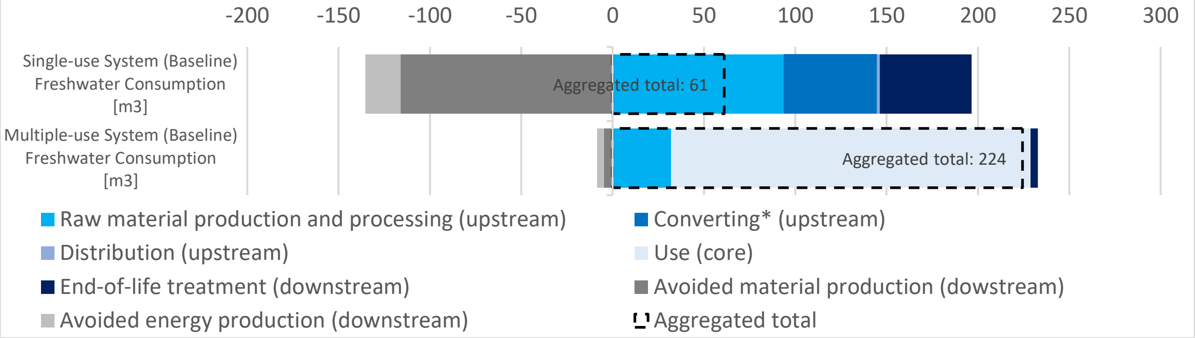

Figure 23: Baseline comparison results for the impact category Freshwater Consumption in m^3

Single-use system

Paper manufacturing and electricity demand for converting and the paper incineration process (see contribution from End-of-life treatment) are significant contributors in the baseline scenario of the single-use system. Despite the relatively high impact from the actual incineration process. Despite the relatively high impact from the actual incineration process, freshwater consumption credits associated with energy recovery and recycling more than outweighs these impacts (in particular credits from avoided primary production of bleached sulphate pulp; see also uncertainty analysis in section 3.4.2.3).

Multiple-use system

The main contributor to freshwater consumption in the baseline scenario of the multiple-use system is the water demand of the washing process. However, the net effect is rather small as a most of the water is only used temporarily and made available again through a wastewater treatment process. Other significant contributions to freshwater consumption arise again from electricity demand of the washing process and upstream items production as well as from chemicals production for the washing process.

3.3.1.5 Freshwater Eutrophication

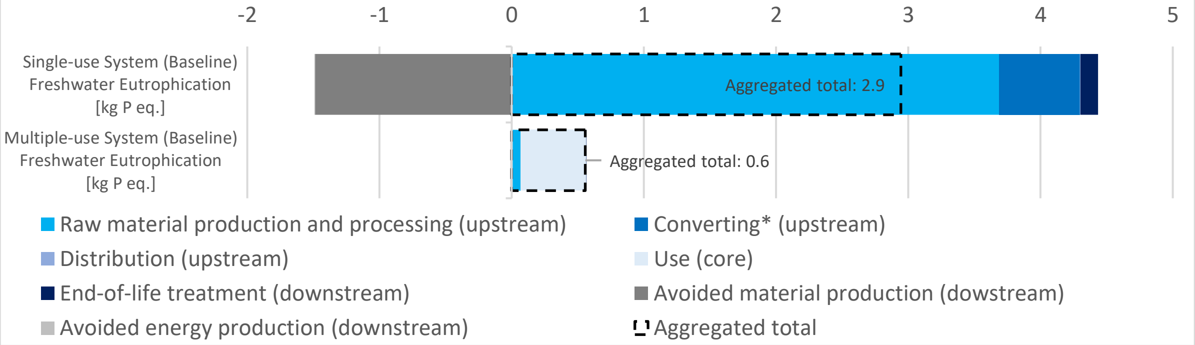

Figure 24: Baseline comparison results for the impact category Freshwater Eutrophication in kg P eq.

Single-use system

The resulting impact of the baseline scenario of the single-use system is predominantly influenced by paper manufacturing. Credits from avoided primary production of pulp contributes significant credits (i.e. negative impacts) to this impact category.

Multiple-use system

The single main contributor to freshwater eutrophication in the baseline scenario of the multiple-use system is wastewater treatment as a result of the washing process (see use phase). Combined with the contributions from the electricity demand of the washing process and the production of chemicals for the detergent, 89% of the aggregated total impact are generated by the use phase of the multiple-use system. The upstream production of items is another significant contributor with a share of 12% of the total aggregated impact.

3.3.1.6 Ionizing Radiation

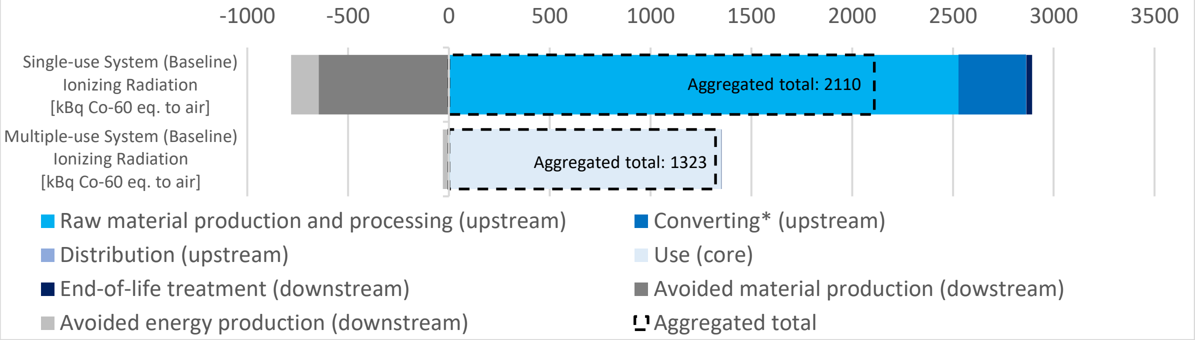

Figure 25: Baseline comparison results for the impact category Ionizing Radiation in kBq Co-60 eq. to air

Single-use system

The resulting impact in the baseline scenario of the single-use system is almost entirely affected by both the paper manufacturing and subsequent credits from material recycling. The latter corresponds to almost 40% of the aggregated total.

Multiple-use system

In the baseline scenario of the multiple-use system, ionizing radiation is dominated by the electricity demand (i.e. EU-28 average grid mix) of the washing process in the use phase, which accounts for almost 102% of the aggregated total impact. Around 2% of these impacts are offset due to the credits from EoL treatment.

3.3.1.7 Metal depletion

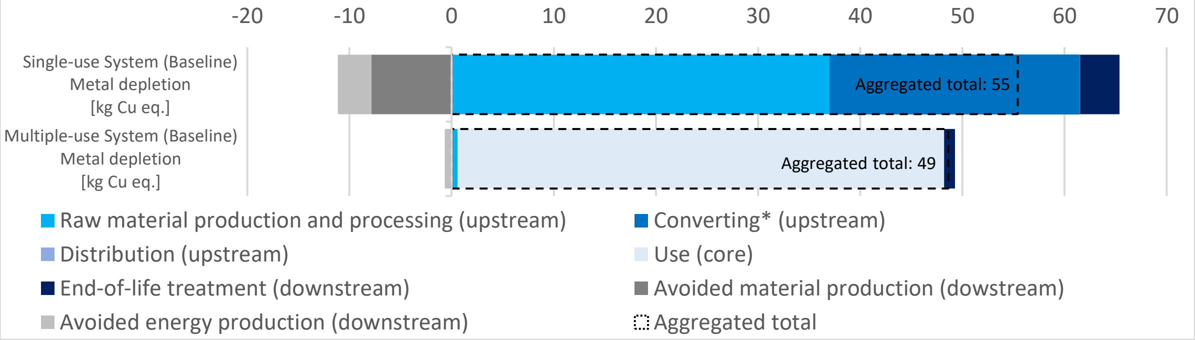

Figure 26: Baseline comparison results for the impact category Metal Depletion in kg Cu eq.

Single-use system

The main contributors in the baseline scenario of the single-use system are chemicals/fillers and varnishes/paints during paper manufacturing and converting. Noteworthy credits are resulting from energy recovery and material recycling (corresponding to about 20% of the aggregated total).

Multiple-use system

The main contributor to metal depletion in the baseline scenario of the multiple-use system is the electricity demand of the washing process, followed by the water demand for washing and the production of chemicals and additional dishwashers. The combined impacts of the processes in the use phase account for 98% of the total impact. Smaller contributions come from the upstream items production and the EoL treatment of these items.

3.3.1.8 Stratospheric Ozone Depletion

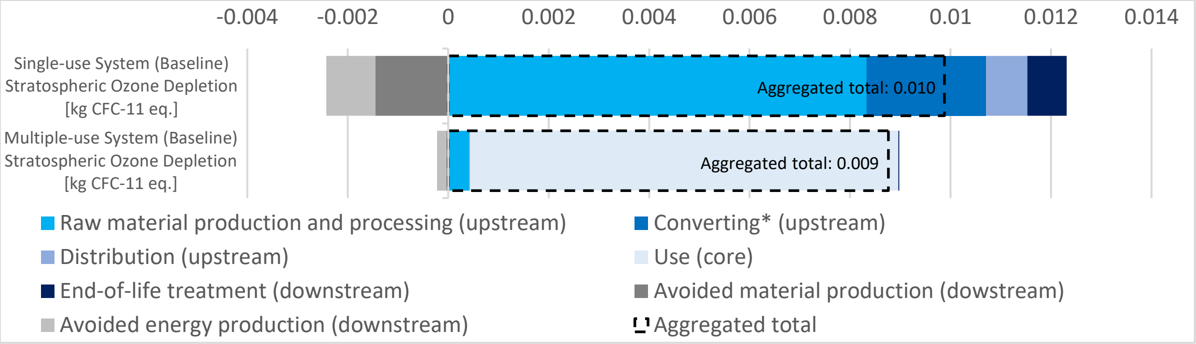

Figure 27: Baseline comparison results for the impact category Stratospheric Ozone Depletion in kg CFC-11 eq.

Single-use system

Looking at the baseline scenario of the single-use system, this impact category is almost entirely influenced by certain paper manufacturing processes. Credits from recycling and energy recovery are less significant in this category compared to other impact categories.

Multiple-use system

With regard to the baseline scenario of the multiple-use system, the stratospheric ozone depletion is again dominated by the electricity demand of the washing process, followed by municipal wastewater treatment and the production of chemicals for washing. Thus, the use phase generates 97% of the total aggregated impact.

3.3.1.9 Terrestrial Acidification

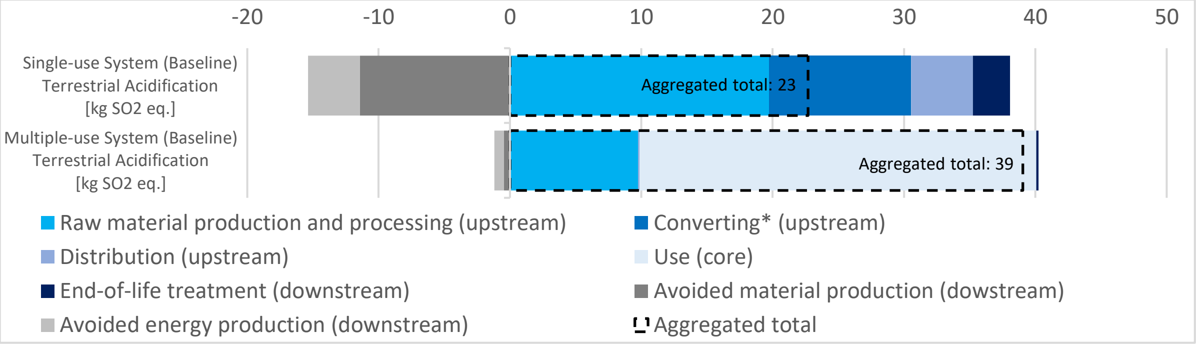

Figure 28: Baseline comparison results for the impact category Terrestrial Acidification in kg SO_2 eq.

Single-use system

The largest contributors in the baseline scenario of the single-use system are paper manufacturing and electricity demand for converting. These contributions are again significantly counteracted by credits from recycling and energy recovery (corresponding to almost 70% of the aggregated total).

Multiple-use system

With regard to the baseline scenario of the multiple-use system, terrestrial acidification is dominated by the electricity demand of the washing process. The use phase is responsible for 77% of the aggregated total impact. 25% of the impact on terrestrial acidification stem from the upstream production of multiple-use items and around 3% credits are generated through their EoL treatment.

3.3.1.10 Summary of baseline comparison

Table 24: Summary of aggregated total impacts of the baseline scenarios

ReCiPe 2016 (H) Indicator	Single-use system - Baseline Scenario	Multiple-use system - Baseline Scenario
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	9008	24954
Fine Particulate Matter Formation [kg PM2.5 eq.]	5.2	12.2
Fossil depletion [kg oil eq.]	2827	9565
Freshwater Consumption [m3]	61	224
Freshwater Eutrophication [kg P eq.]	2.9	0.6
Ionizing Radiation [kBq Co-60 eq. to air]	2110	1323
Metal depletion [kg Cu eq.]	55	49
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.010	0.009
Terrestrial Acidification [kg SO2 eq.]	23	39

3.3.2 Sensitivity analyses

For the sensitivity analysis and respective scenarios only one parameter or assumption is changed per system in order to maintain transparency and ensure traceability of results. It is, however, understood that more than one parameter or assumption can change simultaneously (e.g. different recycling ratio in combination with external washing scenario). This circumstance is acknowledged when interpreting the results in section 3.4.1. As the baseline scenarios are selected with scrutiny and expected to best represent the actual current and near future situation, all sensitivity scenarios are considered less likely to materialise in practice with regard to an EU average context. Yet, these scenarios are important to evaluate critical assumptions and their potential effect on the baseline comparison. For this purpose, detailed results are presented per sensitivity scenario and compared to the baseline scenarios. The suggested sensitivity scenarios are based on both the contribution analysis of the baseline comparison and the identified variability with regard to critical parameters. Table 25 gives an overview of all sensitivity analyses performed for this study. Evidently, the hypothetical multiple-use system is inherently associated with more uncertainties as the established single-use system. This is reflected in the more numbers of sensitivity analyses for the multiple-use system. In other words, the established single-use system – with its variations – serves as a fixed point for this comparative assessment.

Table 25: Overview of performed sensitivity analyses

Affected system	Variation in relation to baseline scenario	Section
Single-use system	Different recycling rates of post-consumer paperboard (0%; 70%)	3.3.2.1
Multiple-use system	Different recycling rates of post-consumer PP items (0%; 70%)	3.3.2.2
Multiple-use system	Varied demand for multiple-use items (30% higher; 30% lower)	3.3.2.3
Multiple-use system	Optimised washing scenario	3.3.2.4
Multiple-use system	External washing with band transport dishwasher	3.3.2.5
Multiple-use system	Alternative multiple-use items (dishes made from ceramic, glass, steel and PP)	3.3.2.6
Both systems	Different EoL allocation approach for avoided energy and material production (50:50)	3.3.2.7

3.3.2.1 Different recycling rates of post-consumer paperboard

As elaborated in section 3.2.2.4, the actual recycling rate of post-consumer paperboard waste is to some extent uncertain. This is mainly due to the fact that no product-specific recycling rates (i.e. recycling rates explicitly referring to the product items considered in this study) can be derived from the available recycling statistics for paper and cardboard waste. While the overarching recycling rate for paper and cardboard packaging waste in the EU is traditionally high at around 85%[20], it remains unclear to what extent this rate is transferrable to the product items included in the single-use system as defined for this study. Therefore, considering the in-store restaurant study focus, an assumption of 30% recycling of post-consumer paperboard waste is implemented for the baseline comparison. Despite this rather low recycling rate, the environmental effects associated with the material recycling are significant (see section 3.3.1 and Appendix 4 - Impact assessment results – Baseline comparison). The positive effects from recycling are associated with both the avoided material and energy production referring to an average EU market situation for pulp production and energy provision, respectively (see section 3.2.2.4 and 3.3.1). Given the magnitude of the positive environmental contributions through recycling in combination with the inherent uncertainty in the assumed recycling rate, the following different recycling rates are tested:

- **0% of post-consumer paper waste material fractions are materially recycled** by means of state-of-the-art recycling processes; as a consequence, 100% of paper waste material fractions associated with certain single-use products within the system are incinerated with energy recovery (see Table 26)
- **70% of post-consumer paper waste material fractions are materially recycled** by means of state-of-the-art recycling processes; as a consequence, 30% of paper waste material fractions associated with certain single-use products within the system are incinerated with energy recovery (see Table 27)

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[20] https://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00063&language=en

The tested recycling rates only affect the post-consumer paperboard waste stream (i.e. paper waste fractions from used single-use product items). All other recycling rates remain as assumed for the baseline comparison (i.e. 100% incineration of PE, 100% material recycling of post-industrial paper waste at the converting stage).

Table 26: Impact assessment results for sensitivity scenario (0% of post-consumer paper waste material fractions are materially recycled)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 0% of post-consumer paper waste material fractions are materially recycled								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total SU sensitivity scenario 0% recycling		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	8065	4002	1537	-	1763	-845	-6039	**8483**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	5.6	3.4	1.6	-	0.8	-1.9	-1.7	**7.8**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	3109	1691	491	-	207	-368	-2416	**2713**	**2827**	**9565**
Freshwater Consumption [m3]	93	51	1	-	53	-44	-26	**129**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	3.7	0.6	0.005	-	0.1	-0.6	-0.01	**3.8**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	2529	335	1	-	15	-245	-184	**2450**	**2110**	**1323**
Metal depletion [kg Cu eq.]	37	25	1	-	5	-3	-4	**60**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.008	0.002	0.001	-	0.0004	-0.001	-0.001	**0.010**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	20	11	5	-	3	-4	-5	**28**	**23**	**39**

Table 27: Impact assessment results for sensitivity scenario (70% of post-consumer paper waste material fractions are materially recycled)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 70% of post-consumer paper waste material fractions are materially recycled								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total SU sensitivity scenario 70% recycling		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	8065	4002	1537	-	2584	-4078	-2403	**9707**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	5.6	3.4	1.6	-	0.9	-9.0	-0.7	**1.8**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	3109	1691	491	-	425	-1776	-962	**2979**	**2827**	**9565**
Freshwater Consumption [m3]	93	51	1	-	47	-212	-10	**-30**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	3.7	0.6	0.005	-	0.2	-2.7	0.00	**1.8**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	2529	335	1	-	47	-1181	-73	**1656**	**2110**	**1323**
Metal depletion [kg Cu eq.]	37	25	1	-	2	-14	-2	**49**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.008	0.002	0.001	-	0.001	-0.003	-0.001	**0.010**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	20	11	5	-	3	-21	-2	**15**	**23**	**39**

Evidently, upstream processes and associated impacts remain unchanged in both altered recycling scenarios. Interestingly, potential climate change and fossil depletion impacts decrease when assuming a higher percentage of post-consumer paper being incinerated instead of materially recycled. These relative changes are associated with the assumption that all recovered energy replaces average European electricity production and heat production with natural gas (the sensitivity of this assumptions is evaluated in section 3.3.2.7). Given the substantial environmental impacts associated with the EU-28 average grid mix and average thermal energy from natural gas, both of which are largely based on fossil fuels, the assumed displacement of both average processes yields significant environmental credits (i.e. negative impacts as depicted e.g. in Figure 20). Despite slight (calculatory) increases of aggregated total impacts for climate change and fossil depletion due to the higher rate of post-consumer paper recycling in the single-use system (i.e. less environmental credits from incineration with energy recovery), the results remain significantly lower than in the baseline scenario of the multiple-use system.

All other impact categories (except for stratospheric ozone depletion) show significantly decreased environmental impacts when a higher recycling rate for post-consumer paper waste is assumed. The potential freshwater consumption impacts are even negative, meaning that environmental offsets would theoretically be created by the system. This is a rather mathematical potential which is tied to the underlying LCI data. In this study, upstream paper production is modelled according to precise and water-efficient state-of-the-art production processes (e.g. often using river water). Avoided pulp production is based on average EU data from Ecoinvent (partly adjusted, as described in section 3.2.2.4 - End-of-life treatment (downstream)) which is associated with relatively high freshwater consumption impacts.

For metal depletion, increased material recycling in the single-use system yields comparable results with the baseline scenario of the multiple-use system. Stratospheric ozone depletion is mainly unaffected and remains comparable to the multiple-use baseline system.

In summary, the sensitivity analyses presented above demonstrate that the relative differences between the single-use and the multiple-use system (as interpreted in section 3.3.1) remain stable, disregarding the assumed recycling rate for post-consumer paper waste material fractions.

3.3.2.2 Different recycling rates of post-consumer polypropylene items

This sensitivity analysis reflects the same assumptions as described above for the single-use system to ensure data symmetry between the two systems:

- **0% of post-consumer PP waste material fractions are materially recycled** by means of a generic recycling processes; as a consequence, 100% of PP waste material associated with multiple-use products within the system are incinerated with energy recovery (see Table 28)
- **70% of post-consumer PP waste material fractions are materially recycled** by means of a generic recycling processes; as a consequence, 30% of PP waste material associated with multiple-use products within the system are incinerated with energy recovery (see Table 29)

Table 28: Impact assessment results for sensitivity scenario (0% of post-consumer PP waste material fractions are materially recycled)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 0% of post-consumer PP waste material fractions are materially recycled								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario 0% recycling		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	3422	-	35	20802	2227	0	-1121	**25366**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	2.9	-	0.04	9.6	0.03	0	-0.3	**12**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1855	-	11	8242	10	0	-448	**9670**	**2827**	**9565**
Freshwater Consumption [m3]	32	-	0.03	197	5	0	-5	**229**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.07	-	0.0001	0.5	0.00005	0	-0.001	**0.56**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	6.98	-	0.01	1343.61	0.42	0	-34.42	**1317**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.62	-	0.03	47.58	0.91	0	-0.83	**48**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0004	-	0.0002	0.009	0.00001	0	-0.0002	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	9.8	-	0.1	30.2	0.2	0	-1.0	**39**	**23**	**39**

Table 29: Impact assessment results for sensitivity scenario (70% of post-consumer PP waste material fractions are materially recycled)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 70% of post-consumer PP waste material fractions are materially recycled								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario 70% recycling		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	3422	-	35	20802	1127	-532	-451	**24403**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	2.9	-	0.04	9.6	0.1	-0.4	-0.1	**12**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1855	-	11	8242	47	-552	-181	**9424**	**2827**	**9565**
Freshwater Consumption [m3]	32	-	0.03	197	3	-11	-2	**218**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.07	-	0.0001	0.50	0.001	-0.02	-0.0006	**0.55**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	6.98	-	0.01	1343.61	4.08	-9.02	-13.84	**1332**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.62	-	0.03	47.58	1.30	-0.15	-0.33	**49**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0004	-	0.00002	0.009	0.00004	-0.00009	-0.0001	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	9.8	-	0.1	30.2	0.2	-1.1	-0.4	**39**	**23**	**39**

In contrast to the single-use system, the recycling process and potential credits of multiple-use PP products is not decisive for the overall environmental performance of the system. Major differences between the baseline and the two sensitivity scenarios are observed for the climate change impact category, where the result increases about 2% in case of no recycling (100% incineration) and decreases about 2% in case of 70% recycling. As described in section 3.3.1 for the baseline scenario, this can be explained by the fact that the environmental hotspot of the multiple-use system is the use phase with washing of items. In relative terms, EoL phase for multiple-use items is less decisive for the performance of the multiple-use system. Compared to the single-use baseline, different recycling rates for PP do not affect the results.

3.3.2.3 Varied demand for multiple-use items

The baseline for the multiple-use system assumes that plastic items are used 100 times before they enter the EoL phase. This assumption is based on industry information[21] and literature data that ranges from 50 to 500 or 564 reuses (CIRAIG, 2014; Paspaldzhiev *et al.*, 2018).
This sensitivity scenario analyses the environmental effects of:

- **30% increased demand for multiple-use items and**
- **30% decreased demand for multiple-use items.**

These varying demands can be induced by different factors, namely:

- Increased or decreased reuse rates of items. 30% increased demand is equivalent to a reuse rate of approximately 77. A 30% decreased demand is equivalent to approximately 143 reuses.
- Promotional article: single-use products in QSRs currently feature seasonal or campaign-related designs. Similarly, special editions of multiple-use items can be assumed that would entail an increased demand for raw materials and items manufacturing.
- Factor to allow for equal functioning of single-use and multiple-use systems: As described in section 3.2.2.5, two daily peaks dominate the serving of meals in QSRs. Due to the workload for staff during these peak times it is possible that washing of multiple-use items occurs mainly after these peak times and therefore more items need to be circulating and – initially – an additional factor needs to be included in the functional unit. The initial surplus of multiple-use items will in turn be used longer as items are reused (and washed) less frequently. No experience exists as to whether the initial additional demand balances out over time with longer periods of use and additional demand to ensure equal functioning of both systems is therefore tested.

Results for the increased demand are shown in Table 30 and results for the decreased demand are shown in Table 31.

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[21] PROFIMIET GmbH, personal communication

Table 30: Impact assessment results for sensitivity scenario (30% increased demand for multiple-use items)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 30% increased demand for multiple-use items								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario +30% demand		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	4449	-	46	20801	2282	-297	-1084	**26198**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	3.7	-	0.05	9.6	0.1	-0.2	-0.3	**13**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	2412	-	15	8242	34	-308	-434	**9961**	**2827**	**9565**
Freshwater Consumption [m3]	42	-	0.04	197	5	-6	-5	**233**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.09	-	0.0001	0.50	0.0006	-0.01	-0.001	**0.57**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	9.08	-	0.02	1343.60	2.58	-5.03	-33.28	**1317**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.81	-	0.04	47.56	1.40	-0.08	-0.80	**49**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.001	-	0.00002	0.009	0.00003	-0.00005	-0.0002	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	12.7	-	0.1	30.2	0.2	-0.6	-1.0	**42**	**23**	**39**

Table 31: Impact assessment results for sensitivity scenario (30% decreased demand for multiple-use items)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: 30% decreased demand for multiple-use items								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario -30% demand		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	2396	-	25	20801	1229	-160	-584	**23707**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	2	-	0.03	9.6	0.03	-0.1	-0.2	**11**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1299	-	8	8242	18	-166	-234	**9168**	**2827**	**9565**
Freshwater Consumption [m3]	22	-	0.02	197	3	-3	-3	**216**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.05	-	0.00008	0.50	0.0003	-0.01-	0.001	**0.54**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	4.89	-	0.01	1343	1.39	-2.71	-17.92	**1329**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.4	-	0.02	48	0.75	-0.04	-0.43	**48**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0003	-	0.00001	0.01	0.00001	-0.00003	-0.0001	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	6.8	-	0.1	30.2	0.1	-0.3	-0.5	**36**	**23**	**39**

The upstream production of multiple-use items has relevant impacts on the overall environmental performance, although they are by far not as significant as the impacts associated with the use phase (upstream production accounts for approximately 1 to 25% of the overall impact, depending on the impact category, as described in section 3.3.1). Thus, an increased or decreased demand for multiple-use PP and acrylic items does have some impact on the overall performance of the system, in particular on impact categories terrestrial acidification, fine particulate matter formation, fossil depletion, and climate change. Other impact categories, e.g. metal depletion and stratospheric ozone depletion are not affected by a varied demand for multiple-use items. Comapred to the single-use baseline, increased or decreased demands for multiple-use items do not change the overall result.

3.3.2.4 Optimised washing scenario

Using multiple-use items to serve meals in QSRs is mostly a hypothetical future scenario. For instance, it should be considered that QSRs will not upgrade their existing washing facilities to new machines until the old machines reach their end of life, unless this will be strictly needed to cover peak days/hours in terms of number of servings. In addition, the potential transition to the new system will not be running at the same rate throughout all countries and for all QSRs and will mostly be affected by local market conditions such as space constraints, incentives and other possible external factors. However most probably the Best Available Technology will not be applied by 2023 and the existing technology will be used.

Little precise data and experience exists in particular on key parameters such as the washing process and the baseline scenario is subject to several assumptions in this regard. As described in section 3.2.2.5, the baseline scenario takes into account existing dishwashers in QSRs. Results in section 3.3.1 show that environmental impacts are dominated by the use phase, i.e. the washing process and associated provision of energy, water and chemicals as well as the treatment of wastewater. In order to understand the impact of altered demands for these inputs, this scenario investigates a future and hypothetical optimised washing process using an efficient, state-of-the-art hood-type dishwasher. Table 32 shows the relative differences of the energy, water and chemicals demands for the optimised washing process. Absolute values can be obtained from Table 20 in section 3.2.2.5. Further development of dishwashers may lead to additional increases in efficiency compared to the 2017 data used here; however, this cannot be reflected due to a lack of data.

Table 32: Relative differences of environmentally relevant inputs to optimised dishwashing scenario in comparison to the baseline.

	Optimised hood-type dishwasher (sensitivity analysis)	Average washing process (baseline)
Energy demand [kWh/item]	52%	100%
Water demand [l/item]	25%	100%
Combined detergents and rinse demand [g/item]	40%	100%

Results of this scenario are listed in Table 33.

Table 33: Impact assessment results for sensitivity scenario (optimised washing scenario)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: optimised washing scenario								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario optimised washing		
Climate change, default, excl. biogenic carbon [kg CO2 eq.]	3422	-	35	10626	1756	-228	-834	**14777**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	2.9	-	0.04	5.0	0.04	-0.2	-0.2	**8**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1855	-	11	4238	26	-237	-334	**5560**	**2827**	**9565**
Freshwater Consumption [m3]	32	-	0.03	100	4	-5	-4	**128**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.07	-	0.0001	0.16	0.0005	-0.01	-0.001	**0.22**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	6.98	-	0.01	723	1.99	-3.87	-25.60	**703**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.6	-	0.03	22.7	1.08	-0.06	-0.62	**24**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0004	-	0.00002	0.004	0.00002	-0.00004	-0.0002	**0.004**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	9.8	-	0.1	15.5	0.2	-0.5	-0.7	**24**	**23**	**39**

The use phase (i.e. washing of items using electricity, water and chemicals as well as the associated production of these chemicals and the necessary wastewater treatment) is the environmental hotspot of the multiple-use system. In a future scenario with the use of efficient (hood-type) dishwashers, results of this sensitivity analysis reveal significant reduction potentials of the impacts across all impact categories. Table 34 lists the relative impact reductions for the optimised washing scenario compared to the baseline. The reduced impacts in the use phase also lead to a relative increase of the importance of the upstream production of multiple-use items that ranges between 1 and 40% in the optimised washing scenario, depending on the respective impact category. For Terrestrial Acidification, the multiple-use system becomes comparable to single-use system. For all other impact categories relative advantages of multiple use system become even more important (in comparison to the baseline scenario of the multiple-use system). However, the sensitivity analysis scenario presented above demonstrates that even under the uncertain assumption that a full transition to an optimized washing scenario occurs, the baseline scenario of the single-use-system still shows potential advantages in the following impact categories: Climate Change, Fine Particulate Matter Formation, Fossil depletion, Freshwater Consumption. For the same impact categories as well as Terrestrial Acidification, the environmental benefits of the single-use system decrease when compared to the optimised washing scenario. For the remaining impact categories the environmental benefits of the multiple-use system are increased due to optimised washing.

Table 34: Relative differences of impacts per impact category between the optimised washing scenario and the multiple-use baseline.

Impact category	Relative difference of optimised washing scenario to multiple-use baseline
Climate change, default, excl biogenic carbon [kg CO2 eq.]	41%
Fine Particulate Matter Formation [kg PM2.5 eq.]	34%
Fossil depletion [kg oil eq.]	42%
Freshwater Consumption [m3]	43%
Freshwater Eutrophication [kg P eq.]	63%
Ionizing Radiation [kBq Co-60 eq. to air]	47%
Metal depletion [kg Cu eq.]	51%
Stratospheric Ozone Depletion [kg CFC-11 eq.]	56%
Terrestrial Acidification [kg SO2 eq.]	38%

3.3.2.5 External washing with band transport dishwasher

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[22], and it is assumed to represent best-available-technique (BAT). Information is provided by Profimiet[23] and data is reported for PP cup washing in the year 2020, including a dedicated drying module to achieve highest hygiene standards.

Table 38 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);

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[22] This type of dishwasher can handle over 8000 plates per hour.

[23] PROFIMIET GmbH, personal communication

- 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[24];

All other assumptions of the baseline scenario (e.g. reuse rates of multiple-use items) remain unchanged. However, in practice it remains to be seen whether additional multiple-use items are needed to allow for washing and transport times (compare section 3.3.2.3, increased demand for multiple-use items) or if the additional amount is balanced out over time with reduced frequencies of reuse.

Table 35: Relative differences of environmentally relevant inputs to the external dishwashing scenario in comparison to the baseline.

	External washing using a band-transport dishwasher	Average washing process (baseline)
Energy demand [kWh/item]	33% [0,009]	100%
Water demand [l/item]	20% [0,062]	100%
Combined detergents and rinse demand [g/item]	18% [0,07 g detergent and 0,005 g rinse agent]	100%

Results for the external washing sensitivity scenario are listed in Table 36.

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[24] 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

Table 36: Impact assessment results for sensitivity scenario (external washing with band transport dishwasher)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: external washing with band transport dishwasher								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario external washing		
Climate change, default, excl biogenic carbon [kg CO2 eq.]	3422	-	35	8609	1756	-228	-834	**12760**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	2.9	-	0.04	4.9	0.04	-0.2	-0.2	**7**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1855	-	11	3299	26	-237	-334	**4622**	**2827**	**9565**
Freshwater Consumption [m3]	32	-	0.03	65	4	-5	-4	**93**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.07	-	0.0001	0.11	0.0005	-0.01	-0.001	**0.17**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	6.98	-	0.01	432.84	1.99	-3.87	-25.60	**412**	**2110**	**1323**
Metal depletion [kg Cu eq.]	0.62	-	0.03	13.61	1.08	-0.06	-0.62	**15**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0004	-	0.00002	0.003	0.00002	-0.00004	-0.0002	**0.004**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	9.8	-	0.1	15.2	0.2	-0.5	-0.7	**24**	**23**	**39**

External washing is performed with highly efficient dishwashers and the resulting impacts of the sensitivity analysis are in a similar range as those of the optimised washing scenario because of additional environmental impacts associated with the transport of multiple-use items between the QSR and the service provider performing the washing process. This sensitivity analysis scenario demonstrates again that the baseline scenario of the single-use-system still shows potential advantages in the following impact categories: Climate Change, Fine Particulate Matter Formation, Fossil depletion, Freshwater Consumption, and Terrestrial Acidification. For the remaining impact categories the environmental benefits of the multiple-use system are increased due to optimised washing.

Table 37 lists the relative impact reductions for the external washing scenario compared to the baseline. As for the optimised washing scenario, the reduced impacts in the use phase also lead to a relative increase of the importance of the upstream production of multiple-use items. For this sensitivity analysis, these impacts range between 2 and 41%, depending on the respective impact category.

Table 37: Relative differences of impacts per impact category between the external washing scenario and the multiple-use baseline.

Impact category	Relative difference of external washing scenario to multiple-use baseline
Climate change, default, excl biogenic carbon [kg CO2 eq.]	49%
Fine Particulate Matter Formation [kg PM2.5 eq.]	43%
Fossil depletion [kg oil eq.]	52%
Freshwater Consumption [m3]	58%
Freshwater Eutrophication [kg P eq.]	72%
Ionizing Radiation [kBq Co-60 eq. to air]	69%
Metal depletion [kg Cu eq.]	69%
Stratospheric Ozone Depletion [kg CFC-11 eq.]	56%
Terrestrial Acidification [kg SO2 eq.]	38%

3.3.2.6 Alternative multiple-use items

Multiple-use items based on plastics (PP and acrylic plastic) are used for the baseline comparison due to their suitability for a QSR context. A combination of PP multiple-use items with items made of ceramic, tempered glass or stainless steel presents another option that is investigated in this sensitivity scenario in terms of the environmental implications of alternative multiple-use items. Table 38 provides an overview of which items are assumed to be produced from materials other than PP. All items not listed in the table (e.g. the dessert cup) are unchanged in this scenario (i.e. remain PP). Respective product weights are listed in Table 7 in section 3.1.2.4.

Two different reuse rates are assumed for the alternative multiple-use items made from ceramic and glass. This due to the fact that although these items in theory withstand many reuse cycles, break, loss, staining or theft may have an impact on the overall average reuse rate. As steel is not likely to break, the reuse rate is fixed at 1000. PP reuse rate remains at 100 as in the baseline analysis. The following reuse rates are tested:

- **500 reuses for ceramic and glass**[25]**;**
- **250 reuses for ceramic and glass**[26]**.**

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[25] As e.g. in (CIRAIG, 2014)

[26] Assumed lower reuse rate due to replacement because of damage, coloring/staining, loss or theft

Table 38: Alternative materials in multiple-use system for the sensitivity analysis.

Item	Baseline scenario	Sensitivity analysis
Hot drink cup	PP cup and lid	ceramic hot cup (no lid)
Cold drink cup	PP	tempered glass
Plate	acrylic	ceramic
Cutlery	PP	stainless steel

Assumptions regarding the EoL treatment of the PP items remain unchanged. Steel EoL treatment is neglected as input materials in the background processes already include secondary steel.

Ceramic and glass items are assumed to be landfilled after they reach their EoL. Processes used to reflect production and EoL treatment of ceramic, glass and steel are listed in Table 39.

What cannot be reflected in an LCA and in this sensitivity analysis in particular are questions regarding security and feasibility of ceramic, glass and steel items in a QSR context. Potentials for increased damage/break of such items is reflected by the reduced reuse rates of fragile items.

Table 39: Secondary data for alternative multiple-use items

Provider process	Data classification	Source	Geographical coverage
Market for sanitary ceramics[27]	Secondary data	Ecoinvent 3.6	Global
Market for sodium silicate, solid	Secondary data	Ecoinvent 3.6	Europe
Glass/inert waste on landfill	Secondary data	GaBi	EU-28
Stainless steel white hot rolled coil (304)	Secondary data	GaBi	EU-28
Final manufacturing (stainless steel product)	Secondary data	GaBi	Global

Results for the two sensitivity scenarios are listed in Table 40 and Table 41 for 500 and 250 reuses, respectively.

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[27] According to expert judgement from in-house sector experts and based on available information of the production processes and energy demands for sanitary and tableware ceramics, sanitary ceramics can be taken as an approximation to calculate environmental impacts of tableware ceramic items.

Table 40: Impact assessment results for sensitivity scenario (combination of ceramic, glass, steel and PP multiple-use items with ceramic and glass reuse rate of 500)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: combination of ceramic, glass, steel and PP multiple-use items with ceramic and glass reuse rate of 500								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario alternative items 500 reuses		
Climate change, default, excl biogenic carbon [kg CO2 eq.]	2678	-	47	20801	813	-126	-371	**23842**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	7.2	-	0.05	9.6	0.04	-0.1	-0.1	**17**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1235	-	15	8242	17	-131	-149	**9230**	**2827**	**9565**
Freshwater Consumption [m3]	23	-	0.04	197	2	-3	-2	**217**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.32	-	0.0001	0.50	0.0003	-0.004	-0.0005	**0.81**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	53.76	-	0.02	1343.60	1.07	-2.14	-11.41	**1385**	**2110**	**1323**
Metal depletion [kg Cu eq.]	16.92	-	0.04	47.56	2.18	-0.04	-0.28	**66**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.0005	-	0.00003	0.009	0.00001	-0.00002	-0.0001	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	7.8	-	0.1	30.2	0.1	-0.3	-0.3	**38**	**23**	**39**

Table 41: Impact assessment results for sensitivity scenario (combination of ceramic, glass, steel and PP multiple-use items with ceramic and glass reuse rate of 250)

ReCiPe 2016 (H) Indicator	Sensitivity Scenario: combination of ceramic, glass, steel and PP multiple-use items with ceramic and glass reuse rate of 250								Total SU Baseline	Total MU Baseline
	Raw material production and processing (upstream)	Converting (upstream)	Distribution (upstream)	Use (core)	End-of-life treatment (downstream)	Avoided material production (downstream)	Avoided energy production (downstream)	Aggregated total MU sensitivity scenario alternative items 250 reuses		
Climate change, default, excl biogenic carbon [kg CO2 eq.]	3746	-	78	20801	827	-126	-371	**24954**	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	12.9	-	0.1	9.6	0.1	-0.1	-0.1	**22**	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	1611	-	25	8242	21	-131	-149	**9620**	**2827**	**9565**
Freshwater Consumption [m3]	30	-	0.07	197	2	-3	-2	**224**	**61**	**224**
Freshwater Eutrophication [kg P eq.]	0.59	-	0.0002	0.50	0.0003	-0.004	-0.0005	**1.08**	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	105.74	-	0.03	1343.60	1.10	-2.14	-11.42	**1437**	**2110**	**1323**
Metal depletion [kg Cu eq.]	30.51	-	0.06	47.56	4.23	-0.04	-0.28	**82**	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.001	-	0.00004	0.009	0.00002	-0.00002	-0.00008	**0.009**	**0.010**	**0.009**
Terrestrial Acidification [kg SO2 eq.]	10.6	-	0.2	30.2	0.2	-0.3	-0.3	**41**	**23**	**39**

Compared to the baseline, environmental impacts in certain impact categories can be slightly reduced or remain equal due to a combination of plastic, ceramic, glass and steel items while the impact on other impact categories increases significantly. For some impact categories, this also depends on whether 500 or 250 reuses are considered for the ceramic and glass items.

More specifically, the following impact categories are positively affected by the use of alternative multiple-use items in combination with PP or are not affected (relative deviations from baseline maximum +/-5%):

- Climate change (positive impact for 500 reuses, no impact for 250 reuses)
- Freshwater consumption (positive impact for 500 reuses, no impact for 250 reuses)
- Stratospheric ozone depletion (no impact for both scenarios)

The following impact categories are negatively affected by the alternative items in combination with PP (relative deviations from baseline up to +80%):

- Fine particulate matter formation
- Freshwater eutrophication
- Ionizing radiation
- Metal depletion

Depending on the number of reuses, increased or decreased impacts are observed for the following impact categories (deviations from baseline maximum +/-5%):

- Fossil depletion
- Terrestrial acidification

Compared to the single-use baseline, increased or decreased demands for multiple-use items do not change the overall result.

3.3.2.7 Different EoL allocation approach for avoided energy and material production (50:50)

For the baseline comparison assumed environmental credits associated with avoided energy and material production are entirely assigned to the respective systems. The underlying reasoning for this allocation approach is described in section 3.1.3.1. Moreover, this allocation approach is in line with the guidance given in relevant ISO standards and is common practice in comparative LCAs. For both systems this is done equally but due to the significantly different material throughputs in both systems, the effects of this assumption are more prevalent in the single-use system. This allocation approach is not merely an interchangeable methodological approach as it is fundamentally based on the premise that generated recycled materials and recovered energy displace equivalent products or energy carriers in the market. There is, however, inevitable uncertainty with regards to both the actual future displacement rate (i.e. to what extent does the generated output actually replace virgin production) and the appropriateness of affected systems or products (i.e. whether the generated electricity and thermal energy does replace average EU energy provision which is associated with relatively high environmental burdens). For example, the assumed mix of substituted pulp products (see section 3.2.2.4, End-of-life treatment (downstream)) could be different or displaced energy would rather occur in countries or industrial contexts characterised by environmentally friendly energy mixes (e.g. assigned credits from avoided energy provision would be significantly lower in e.g. Scandinavian countries or France for many impact categories). Evidently, the assumptions concerning avoided burdens at the EoL stage are speculative. Due to a lack of more data to support the underlying assumptions inherent in the adopted allocation approach for the baseline comparison, a different allocation approach is tested (i.e. reflecting a hypothetical system in which environmental credits are less dominant). The variation of environmental credits can be of various reasons as explained above. However,

this study cannot elaborate and substantiate all potential reasons and therefore a simplified approach is adopted by cutting-off some of the assumed environmental credits.
Given the observed significance of environmental credits (in particular in the single-use system due to the large material flow of paperboard products), a different allocation approach is tested for both systems. However, a full cut-off approach (i.e. not accounting for any environmental credits from recycling or incineration) is deemed not appropriate for the goal and scope of this comparative assessment as the effect of recycling and energy recovery are inherent features of respective life cycles. Moreover, upstream production is assumed to be from virgin sources only, which represents a conservative approach as e.g. some paper grades contain significant shares of recycled content from post-industrial sources. It is, moreover, recognised that e.g. environmental credits due to avoided pulp production are significant if increased recycling rates or incineration with energy recovery are assumed. Given the unavoidable uncertainty concerning the extent to what recovered pulp actually replaces virgin pulp and the inherent uncertainty in the underlying datasets for primary pulp products (see also section 3.2.2.4 - End-of-life treatment (downstream)) a 50:50 allocation approach is applied to both systems (i.e. instead of assigning the full credits, only 50% of the calculated credits are attributed to either of the system). Besides above explained reasons for this alternative assumption, a different variant for the allocation of credits has to be considered according to the requirements for comparative assertions defined in ISO 14040/14044 standards. This is in particular important if the hypothetical effect of environmental credits affects the compared systems in different ways (see negative contributions for impact categories presented in section 3.3.1), as is a natural characteristic of comparisons between single-use and multiple-use product systems (Antony and Gensch, 2017; Federal Environment Agency Germany, 2019b).

Table 42: Impact assessment results for sensitivity scenarios referring to both systems (50:50 EoL allocation approach)

ReCiPe 2016 (H) Indicator	Aggregated total SU Sensitivity Scenario 50:50 EoL allocation	Aggregated total MU Sensitivity Scenario 50:50 EoL allocation	Total SU Baseline	Total MU Baseline
Climate change, default, excl biogenic carbon [kg CO2 eq.]	12363	25484	**9008**	**24954**
Fine Particulate Matter Formation [kg PM2.5 eq.]	8.3	12.4	**5.2**	**12.2**
Fossil depletion [kg oil eq.]	4209	9850	**2827**	**9565**
Freshwater Consumption [m3]	129	229	**61**	**224**
Freshwater Eutrophication [kg P eq.]	3.7	0.6	**2.9**	**0.6**
Ionizing Radiation [kBq Co-60 eq. to air]	2501	1338	**2110**	**1323**
Metal depletion [kg Cu eq.]	61	49	**55**	**49**
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.011	0.009	**0.010**	**0.009**

ReCiPe 2016 (H) Indicator	Aggregated total SU Sensitivity Scenario 50:50 EoL allocation	Aggregated total MU Sensitivity Scenario 50:50 EoL allocation	Total SU Baseline	Total MU Baseline
Terrestrial Acidification [kg SO2 eq.]	30	40	**23**	**39**

While the different allocation approach affects the single-use system more due to the larger material fractions involved, the relative significance remains stable throughout all impact categories when compared to the baseline scenario of the multiple-use system.

3.4 Interpretation

The interpretation of results adheres to the goal and scope of this assessment. Therefore, the discussions acknowledge the systems focus and do not allow for detailed interpretations on a product or process level. Moreover, emphasis is given to the relative significance of aggregated impact results between the two distinct systems. Differences between different scenarios within a certain system are not further elaborated on, as these aspects are discussed in section 3.3.2. In particular, comparative assertions are presented, taking into account the sensitivity and uncertainty of the results.

3.4.1 Results interpretation

Overall, resulting impacts associated with the baseline scenario of the single-use system are predominantly driven by the paper manufacturing process and subsequent converting. Within the converting stage, the impacts are mainly associated with the electricity demand (i.e. EU-28 average grid mix). Yet, the aggregated results are significantly influenced by recycling and energy recovery credits. This is because of the fact that primary production of paper or generation of thermal energy and electricity in Europe is on average environmentally significant. When perceiving the single-use system as a potential provider of high-quality fibre material for recycling purposes it is deemed appropriate to allocate full environmental credits to the system. In addition, only virgin fibre material is used for upstream production in the system, thus allowing for high-quality recycling when collected and separated appropriately.

With regard to the baseline scenario of the multiple-use system, resulting impacts are predominantly driven by the washing process, in particular its electricity demand (i.e. EU-28 average grid mix), which is the single most important contributor to all impact categories, except freshwater consumption and eutrophication. In addition, the production of PP products also shows significant impacts in five out of nine impact categories. For some impact categories water and chemicals demand for the washing process as well as wastewater treatment are relevant contributors.

The following sections provide an overview of all aggregated results throughout the scenarios within both systems. The results are presented per impact category. Based on these overviews, the robustness and potential variation of the baseline comparison between the single-use and multiple-use system is interpreted. Final statements per impact category also make reference to averages relating to all included scenarios. Moreover, the comparative assertion and conclusions follow a consistent terminology as presented in Table 43. The term "consistent" is used whenever there are no exceptions from the stated comparative assertion throughout all considered scenarios.

Table 43: Terminology for results interpretation

Relative difference in % based on the indicated single-use system as reference value (e.g. baseline scenario)	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

3.4.1.1 Climate Change

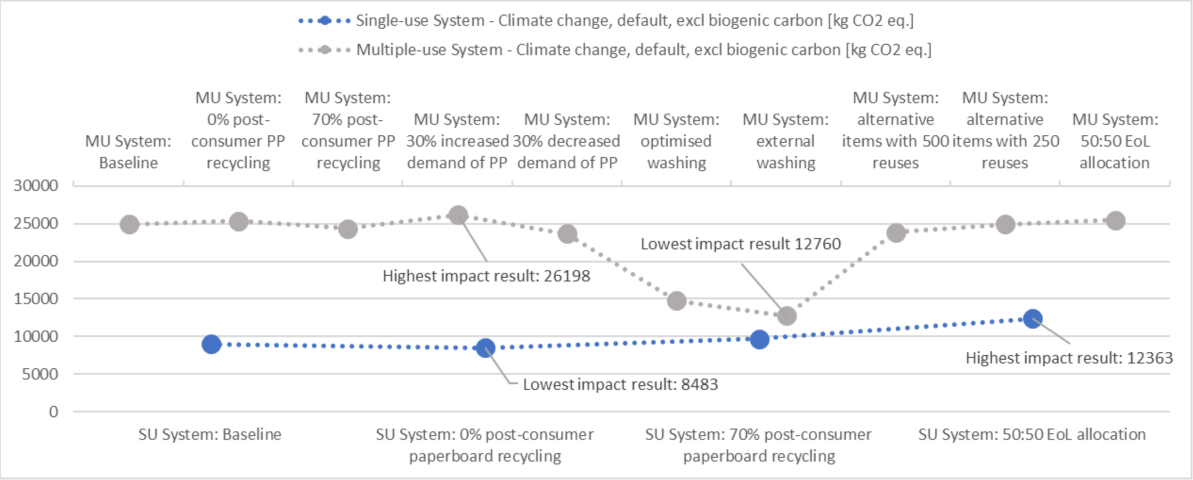

Figure 29: Summary of aggregated results for the impact category Climate Change of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

As can be seen in Figure 29, the aggregated climate change impacts associated with the single-use system remain in a relatively narrow range and consistently show environmental benefits for the single-use system, disregarding the critical assumptions tested by means of sensitivity analyses. In contrast, the results of the multiple-use system exhibit a larger variation with regard to potential climate change impacts. In particular, the optimised and external washing scenarios are associated with substantially lower climate change impacts compared to the baseline scenario of the multiple-use system. However, even the lowest climate change impact reported for the multiple-use system with external washing (as well as accounting for the effects due to the different EoL assumption) is still slightly higher than the highest impact of the single-use system which would result from a different EoL allocation assumption (i.e. less environmental credits for recycling and energy recovery would be assigned to the single-use system).

In summary, the single-use system predominantly and on average shows **very significant** climate change benefits, apart from a scenario where very efficient dishwashing processes are implemented either through solely using efficient hood-type dishwashers or in an external dishwashing scenario. Only in these cases do the relative differences in climate change impacts become smaller (i.e. ranging from **very significant benefits** for the single-use system to **minor benefits** for the single-use system).

3.4.1.2 Fine Particulate Matter Formation

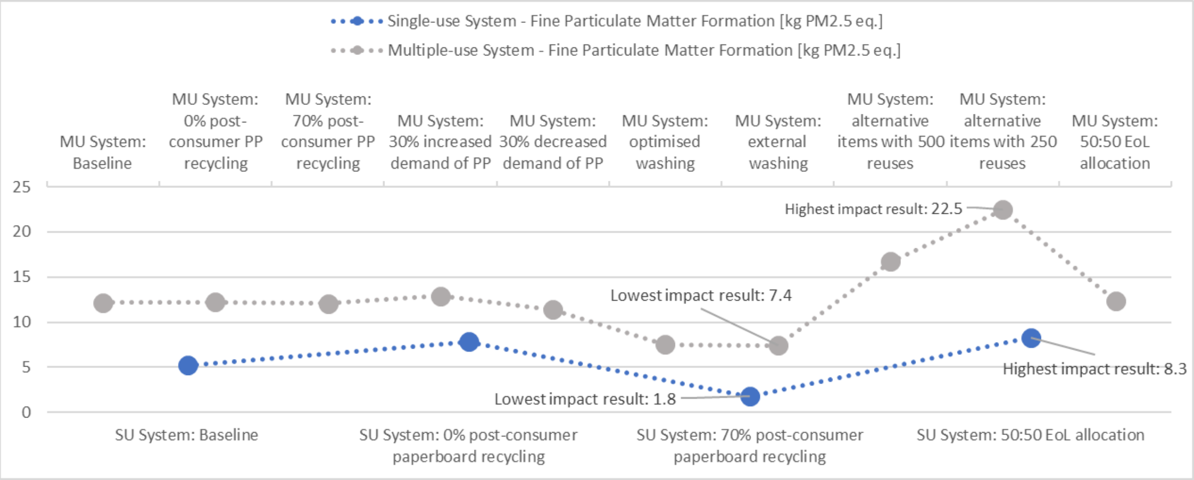

Figure 30: Summary of aggregated results for the impact category Fine Particulate Matter Formation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In general, reported differences between the single-use and multiple-use system within the impact category of fine particular matter formation suggest benefits for the single-use system. However, the relative benefits of the single-use system are less obvious than the reported benefits for climate change impacts. In this category, the impacts reported on the higher end of the single-use system (i.e. 0% post-consumer paperboard recycling and/or different allocation assumption for EoL credits) would exceed the lowest reported impacts for optimised or external washing scenarios (as well as accounting for the effects due to the different EoL assumption) of the multiple-use system and result in minor benefits for the multiple-use system.
In summary, the majority of the considered scenarios confirm the tendency of the baseline comparison, i.e. on average the single-use system shows **very significant** environmental benefits for fine particulate matter formation. **Minor** benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits.

3.4.1.3 Fossil Depletion

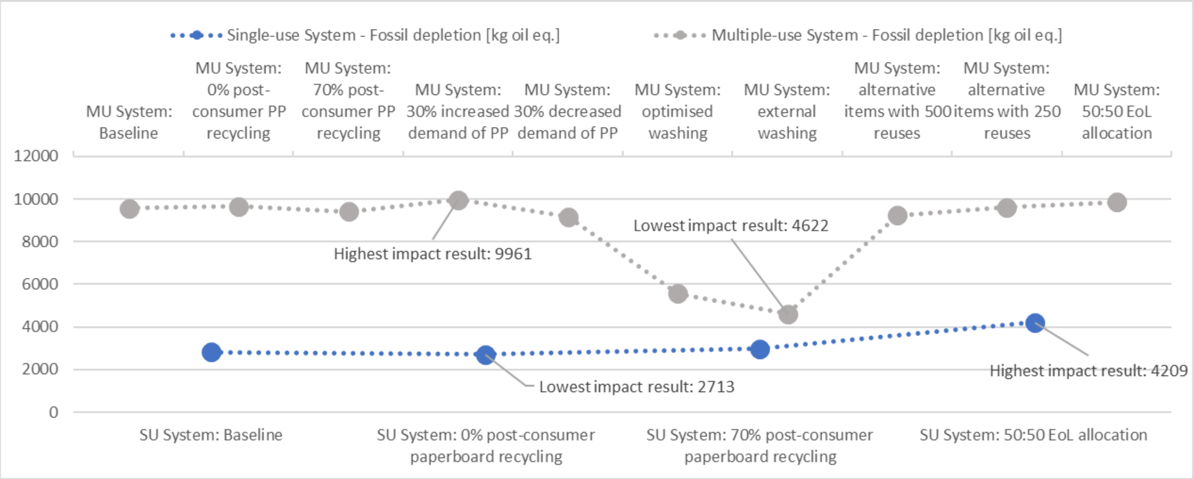

Figure 31: Summary of aggregated results for the impact category Fossil Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

The variation of the results within the impact category fossil depletion is mainly due to the influence of electricity demand in the multiple-use system which is very reliant on fossil fuels (i.e. EU-28 average grid mix) but consistently shows environmental benefits for the single-use system. In summary, reported results mainly and on average suggest **very significant** benefits for the single-use system with regard to fossil depletion. Only when assuming an efficient external washing scenario in combination with a different assumption concerning the EoL stages of both systems, the relative difference between the two systems becomes smaller (i.e. ranging from **very significant** benefits for the single-use system to **noticeable** benefits for the single-use system).

3.4.1.4 Freshwater Consumption

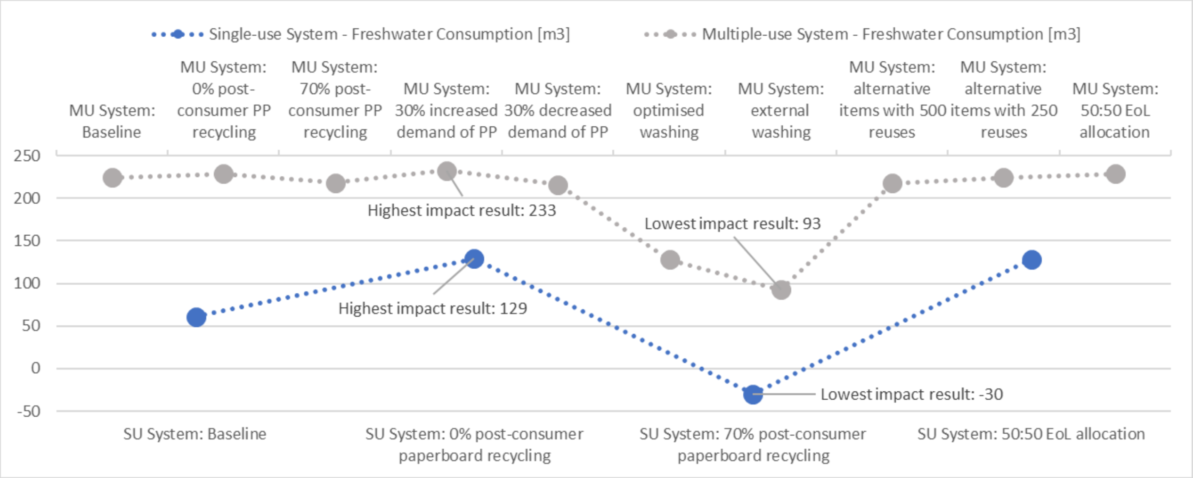

Figure 32: Summary of aggregated results for the impact category Freshwater Consumption of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

With regard to the impact category freshwater consumption, both systems show significant variations in terms of aggregated impact results. While most scenarios demonstrate very significant environmental benefits for the single-use system, there are a few assumptions which change the comparative assertion. Similar to other impact categories, the scenarios postulating optimized or external washing in the multiple-use system potentially lead to environmental benefits for the multiple-use system if either no post-consumer paperboard recycling takes place or if environmental credits from recycling are assumed to be lower as in the case of the different allocation approach (see also section 3.3.2.7).

In summary, the comparison between the single-use and the multiple-use system is dependent on underlying assumptions. However, there is a tendency that on average the single-use system shows **very significant** environmental benefits in terms of freshwater consumption. **Moderate** environmental benefits for the multiple-use system are solely identified in hypothetical situations where the effects of post-consumer paper recycling are less prevalent and optimised or external washing is fully adopted. In general, it is important to bear in mind inherent uncertainties relating to the adopted impact assessment method and, in particular, the freshwater consumption indicator (see section 3.4.2.1).

3.4.1.5 Freshwater Eutrophication

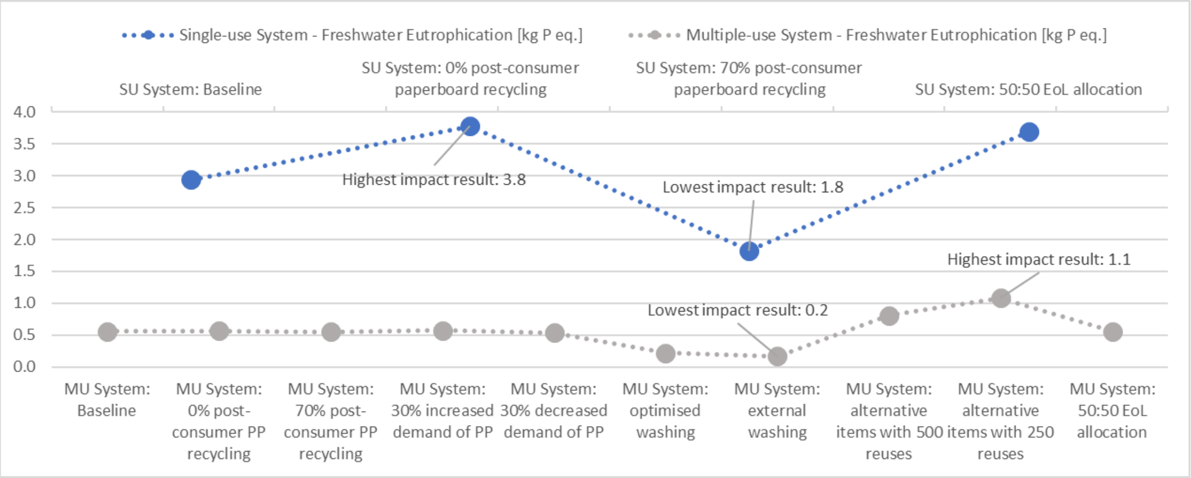

Figure 33: Summary of aggregated results for the impact category Freshwater Eutrophication of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

Compared to the variation within the single-use system, there is rather little variation within the multiple-use system with regard to freshwater eutrophication. Despite the variation of impacts within the single-use system, there is a clear tendency that the multiple-use system consistently exhibits lower environmental impacts in terms of freshwater eutrophication. Even the lowest reported aggregated impact result in case of a scenario with 70% post-consumer paperboard recycling is very significantly higher than the highest reported impact for the multiple-use system. In summary, reported results exclusively suggest **very significant** benefits for the multiple-use system with regard to freshwater eutrophication.

3.4.1.6 Ionizing Radiation

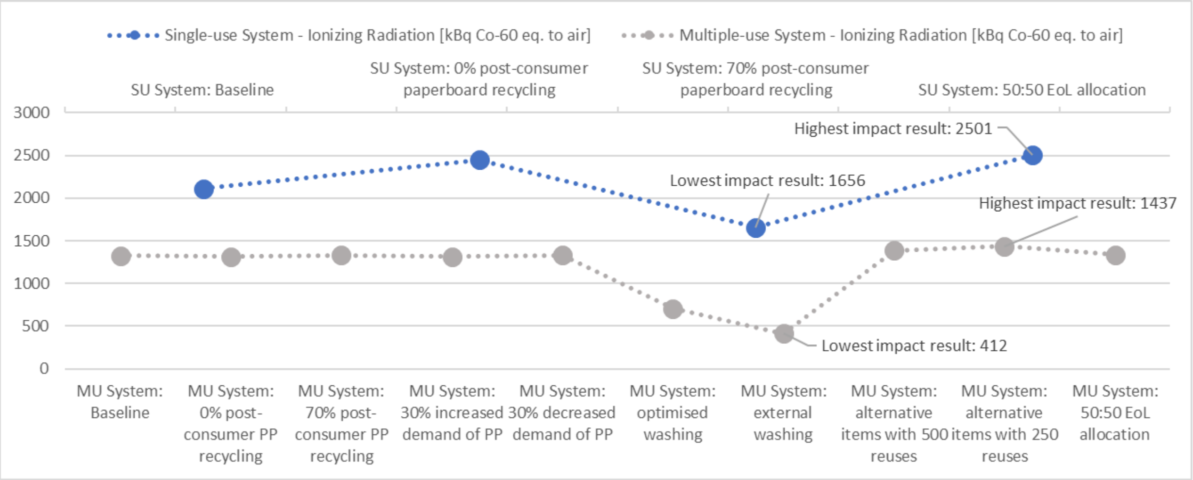

Figure 34: Summary of aggregated results for the impact category Ionizing Radiation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

The comparative assertion with regard to ionizing radiation shows consistent benefits for the multiple-use system. This indication is based on the predominantly significant differences throughout all considered scenarios. When assuming a 70% recycling rate for post-consumer paperboard in the single-use system, the difference is smaller.
In summary, there are on average **significant** environmental benefits for the multiple-use system with regard to ionizing radiation. Only **noticeable** environmental benefits for the multiple-

use system are identified when increased post-consumer paper recycling and full crediting at the EoL stage is assumed.

3.4.1.7 Metal depletion

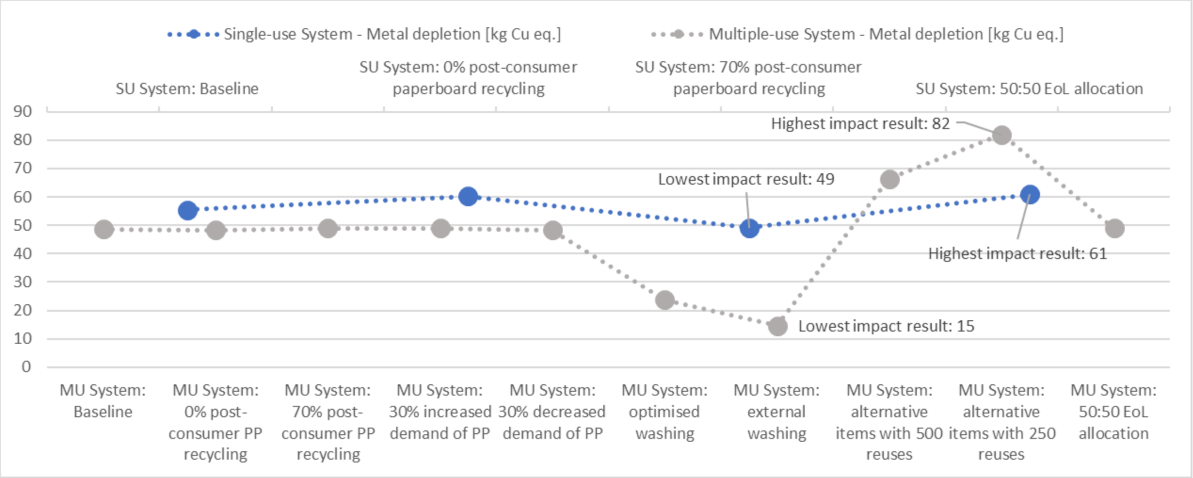

Figure 35: Summary of aggregated results for the impact category Metal Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

The comparative assertion within the impact category metal depletion is relatively dependent on the underlying assumptions. While there is a tendency that the multiple-use system shows environmental benefits for a majority of the scenarios considered, the single-use system may shows environmental benefits in terms of metal depletion when assuming that some of the multiple-use product items are made of ceramic, glass, and steel instead of plastics (see also section 3.3.2.6).

In summary, the multiple-use system shows on average **noticeable** environmental benefits with regard to metal depletion. However, **minor** up to **very significant** environmental benefits are shown for the single-use system when compared to a multiple-use system comprising alternative product items partially made of ceramic, glass, and steel.

3.4.1.8 Stratospheric Ozone Depletion

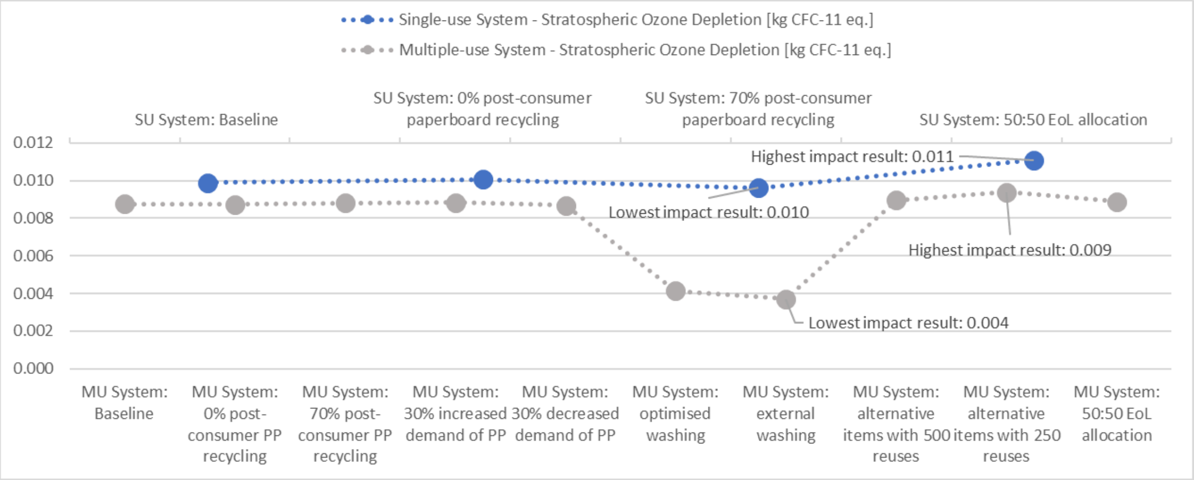

Figure 36: Summary of aggregated results for the impact category Stratospheric Ozone Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In general, the reported aggregated results for the impact category stratospheric ozone depletion do not show significant differences between the single-use and the multiple-use system but there are consistent environmental benefits for the multiple-use system. When assuming optimised or external washing in the multiple-use system, the relative difference further increases to the advantage of the multiple-use system.
In summary, the multiple-use system on average shows **moderate** environmental benefits in terms of stratospheric ozone depletion. **Very significant** environmental benefits for the multiple-use system are identified for the hypothetical scenarios entailing optimised or external washing processes.

3.4.1.9 Terrestrial Acidification

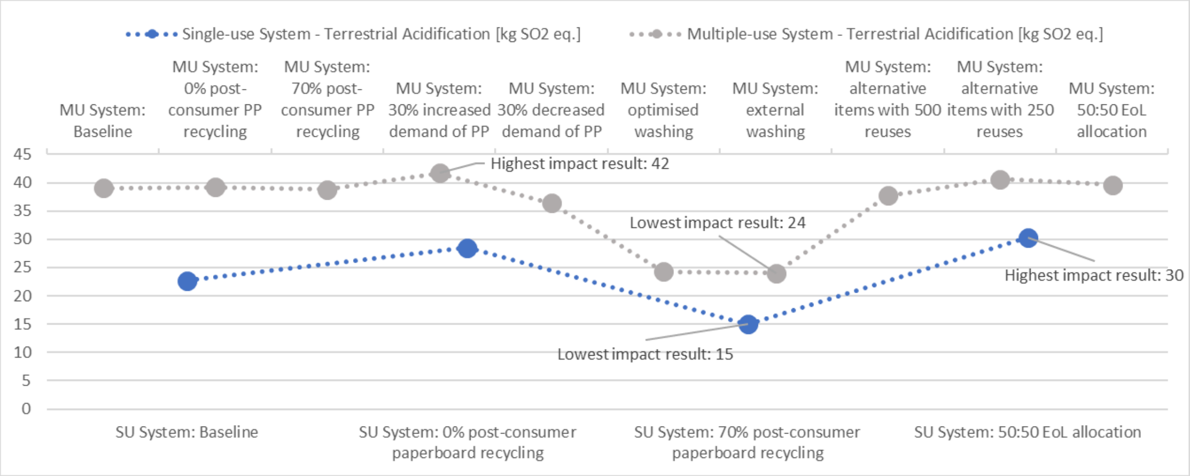

Figure 37: Summary of aggregated results for the impact category Terrestrial Acidification of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

The comparative assertion for the impact category terrestrial acidification is relatively dependent on the underlying assumptions. However, most of the scenarios show environmental benefits for the single-use scenario with regard to terrestrial acidification. Again, only optimised or external washing scenarios in the multiple-use system can lead to substantially decreased impacts.
In summary, the single-use system on average shows **significant** environmental benefits with regard to terrestrial acidification. **Noticeable** environmental benefits for the multiple-use system are solely identified in situations where the effects of post-consumer paper recycling are less prevalent (i.e. different allocation assumption and/or no post-consumer paperboard recycling) and optimised or external washing is fully adopted.

3.4.2 Uncertainty analysis

In this section discovered uncertainties due to data gaps and or inconsistencies in the underlying databases are disclosed and qualitatively discussed.

3.4.2.1 Uncertainty concerning the impact category "freshwater consumption"

In general, three aspects could be considered for water use indicator in LCA: water extraction, water consumption, and water degradation. Water extraction is the withdrawal of water from surface water bodies or the abstraction of groundwater from aquifer. It is the total amount of water withdrawn, irrespective of return flows to the water bodies or water use efficiencies. Water consumption, on the other hand is the amount of water that the watershed of origin is losing" (Huijbregts *et al.*, 2016). Water degradation implies "a quality change in water used and released back to the same watershed" (Pfister, Koehler and Hellweg, 2009). The freshwater consumption indicator in the adopted ReCiPe LCIA method (2016) is defined as "water consumption (increase of water consumed)" and expressed in cubic meter.
Currently, a general accepted method for accounting environmental impacts in LCA of biotic resource depletion like freshwater is nevertheless missing (Hauschild *et al.*, 2013; Sonderegger *et al.*, 2017), and different approaches may lead to interpretation issues (Hoekstra, 2016; Pfister *et al.*, 2017). Several parameters and variables have indeed a great influence on the choice either of a midpoint either of an endpoint indicator, as reported by the literature review of Kounina *et al.* (2013). The author of the study identified twelve different inventory methods and eight midpoint impact assessment methods that differ in terms of scope, environmental relevance (stock, fund or flow resource; consumptive use, degradative use), scientific robustness (data uncertainty), reproducibility, transparency, applicability, and potential acceptance of stakeholders.

Due to this methodological variability and to uncertainties related to the implication related to the freshwater impact indicator, some studies have excluded it from the analysis (e.g., Vercalsteren, Spirinckx and Geerken, 2010; Woods and Bakshi, 2014).

The ReCiPe method (2016) is used to obtain the most recent methodology approach that consider water consumption; GaBi and Ecoinvent 3.6 LCI databases are used to obtain most recent inventory information. However, the results cannot be directly compared to other studies without considering differences in terms of methodology, assumptions, system burdens (and many other factors, out of the scope for this report).

Besides uncertainty on methodology has been debated (Quinteiro *et al.*, 2018), further uncertainties are related to information retrieved from non-primary data sources: water use in the multiple-use system (core process) was gathered from different sources (literature, datasheets), whose uncertainties are related, for example, to time (different years of studies, different dishwashers' manufacturing years), geographical basis (studies based in Europe or in the United States), and water demand measuring method (experimental methods, statistical data, average consumption from behavioural studies, see assumptions, e.g., Rüdenauer *et al.*, 2011). The evaluation of recycling credits in the freshwater consumption impact category presented in section 3.3.1.4 may therefore raise concerns. And this indirectly confirms the observations of other authors over the past decades, who report issues on LCA studies that avoided considering water indicator to highlight environmental credits due to pulp recycling (see, e.g., Grieg-Gran, 1995; Itsubo *et al.*, 2020).

3.4.2.2 Uncertainty concerning the impact of chemicals on the impact category "metal depletion"

Different chemicals are used to produce the detergent and rinse agent for the washing process of multiple-use items (see section 3.2.2.5 and Appendix 3 - Life cycle inventory, Use phase). GaBi and Ecoinvent 3.6 LCI databases were used to obtain most recent inventory information for these chemicals. If a certain chemical is available in both databases, the most recent dataset is used for modelling. However, impacts of both processes were analysed in advance and revealed large differences between the impacts in particular on the impact category metal depletion. This raises concerns about the certainty of these background processes and resulting impacts associated with the production of chemicals have to be taken with caution. Nevertheless, overall results in this impact category are considered stable as chemical production is only the third largest contributor (approximately 17% in the multiple-use baseline) to the impacts on metal depletion.

3.4.2.3 Uncertainty concerning the environmental credits associated with the avoided material production in the single-use system

As can be seen in the presentation of impact assessment results for the baseline comparison, environmental credits associated with the assumed avoided production of materials or energy plays a significant role in the aggregated results of the single-use system. Given the circumstance that primary data is incorporated for upstream processes referring to state-of-the art processes while only secondary data is incorporated for the respective pulp products at the point of substitution, there is a remaining uncertainty concerning the consistence of data. This inconsistency potentially causes an overestimation of the environmental benefits of post-consumer paperboard recycling. However, the sensitivity scenario assuming no post-consumer paperboard recycling (see section 3.3.2.1) demonstrates that comparative assertions mostly remain valid. The described uncertainty is further addressed by the application of a different allocation method (see section 3.3.2.7) which also demonstrates that relative differences suggested by the baseline comparison are quite robust.

3.4.2.4 Uncertainty concerning the impact category "ionizing radiation"

Although it is not the objective of this study to disclose and compare individual paper products (i.e. upstream processes feeding into the single-use system), significant differences in ionizing radiation potentials of certain paper products were identified when comparing them on a per-kg-of-product basis. For some of the paper grades which have been modelled according to primary data on specific process inputs and outputs, the obtained results for ionizing radiation appear to be underestimated which may inhibits the robustness of the total results of the single-use system. While some of the deviation can be explained by the underlying upstream effects associated with electricity provision (i.e. a higher share of nuclear power), the resulting difference cannot be solely explained by this difference. It is therefore assumed that the remaining difference is associated with the lack of data concerning some of the chemical inputs. Given the manifold upstream processes involved in the single-use system, the exclusion of some chemicals (corresponding to a maximum of 0.4% weight-% of the respective unit process) is deemed justified. In any case, this remaining uncertainty would lead to increased ionizing radiation impacts of the single-use system which already shows higher impacts than the multiple-use system. Therefore, this uncertainty is not expected to alter the relative assertion of the comparison within this impact category.

4. CONCLUSIONS AND RECOMMENDATIONS

The chapters above provide background information and results for a comparative LCA of single-use and multiple-use dishes options for in-store consumption in QSRs in Europe (see description of goal and scope of the study in section 3.1). 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 3.1.2 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 nine environmental impact categories (see section 3.1.6). 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 (see section 3.1.6). 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 3.2.2) as well as to acknowledge environmentally decisive life-cycle stages and processes within both systems. Therefore, the study is based on extensive data gathering in particular for the single-use system, for which primary data from paper producers and converters is incorporated to reflect the current practice of upstream manufacturing steps of single-use product items as well as their EoL treatment. For the multiple-use system, upstream and downstream processes are covered using background information available in LCI databases and extensive research is performed regarding the use phase of multiple-use items, in particular the different washing options. In conclusion, particular attention is given to environmentally decisive parameters, assumptions and processes when identifying and selecting appropriate data sources.

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 washing of items (see results in section 3.3.1). To test decisive assumptions in the systems, several sensitivity scenarios are analysed (see section 3.3.2). Uncertainties of the method and the results are discussed in section 3.4.2.

Under consideration of identified uncertainties and sensitivities of impact results, the following conclusions can be drawn from the comparative assessment:

- For Climate Change, the single-use system shows very significant benefits considering the comparison of the baseline scenarios. When including the different sensitivity scenarios, only in cases where very efficient dishwashing processes are implemented either through solely using efficient hood-type dishwashers or in an external dishwashing scenario do the environmental benefits for the single-use system become smaller and range from very significant to minor. Therefore, the environmental benefits for the single-use system in terms of climate change impacts are consistent throughout all considered scenarios.
- For Fine Particulate Matter Formation, the single-use system shows very significant environmental benefits in the baseline comparison. Minor benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or

a different allocation assumption for EoL credits. Therefore, the comparison between the single-use and the multiple-use system is dependent on underlying assumptions.

- For Fossil Depletion, there are very significant benefits for the single-use system in the baseline comparison. Minor environmental benefits for the single-use system may occur in cases where very efficient dishwashing processes are implemented either through solely using efficient hood-type dishwashers or in an external dishwashing scenario. Therefore, the environmental benefits for the single-use system in terms of fossil depletion impacts are consistent throughout all considered scenarios.
- For Freshwater Consumption, there are very significant environmental benefits for the single-use system considering the baseline comparison. Moderate environmental benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits.
- For Freshwater Eutrophication, there are exclusively very significant benefits for the multiple-use system in the baseline and the different scenarios. Therefore, the environmental benefits for the multiple-use system in terms of freshwater eutrophication impacts are consistent throughout all considered scenarios.
- For Ionizing Radiation, there are significant environmental benefits for the multiple-use system in the baseline comparison. Only noticeable environmental benefits for the multiple-use system are identified when increased post-consumer paper recycling and full crediting at the EoL stage is assumed. Therefore, the environmental benefits for the multiple-use system in terms of ionizing radiation impacts are consistent throughout all considered scenarios.
- For Metal Depletion, there are noticeable environmental benefits for the multiple-use system in the baseline comparison. However, minor up to very significant environmental benefits are shown for the single-use system when compared to a multiple-use system comprising alternative product items made of ceramic, glass, and steel. Therefore, the comparison between the single-use and the multiple-use system for the potential metal depletion impact is dependent on underlying assumptions.
- For Stratospheric Ozone Depletion, there are noticeable environmental benefits for the multiple-use system in the baseline comparison. Very significant environmental benefits for the multiple-use system are identified for the hypothetical scenarios entailing optimised or external washing processes. Therefore, the environmental benefits for the multiple-use system in terms of stratospheric ozone depletion impacts are consistent throughout all considered scenarios.
- For Terrestrial Acidification, there are very significant environmental benefits for the single-use system in the baseline comparison. Noticeable environmental benefits for the multiple-use system are only identified when optimised or external washing scenarios are compared to single-use system scenarios representing 0% post-consumer paperboard recycling and/or a different allocation assumption for EoL credits. Therefore, the comparison between the single-use and the multiple-use system for the potential terrestrial acidification impact is dependent on underlying assumptions.

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 chapter 2 for results of the literature screening). This difference can largely be 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 extend, 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 selected industry and expert inputs where possible. This is due to the fact that the multiple-use system presents a hypothetical future scenario for which no primary data exists (i.e. specific functioning of QSRs is mainly based on assumptions) and, as regards the upstream production of multiple-use items, no primary data is available in the context of this LCA study.

The geographical location of production and use is potentially crucial and in particular the energy mix at the location of production and use has significant influence on the associated environmental impacts. Consequently, the geographical context is also a decisive factor for the results of this study. 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). In particular for the multiple-use system where major impacts are generated by this process, the selection of another geographical scope could significantly change the results and comparative assertion.

In the light of potential introduction of multiple-use systems it needs to be borne in mind that this also constitutes a paradigm shift of the environmental monitoring and management. While the single-use system is characterised by rather centralised large, industrialised operators with continuous environmental improvement systems in place, the environmental implications of a hypothetical multiple-use system may be characterised by decentralised and less organised actors. This shift may cause a lack of both environmental management systems and data availability and reliability to steer further environmental strategies.

The results of the study also point to further need for research and investigation of relevant parameters and processes, amongst others related to certain impact categories in LCA methods as well as further need for research on the assumptions and parameters relating to the hypothetical multiple-use system.

5. CRITICAL REVIEW

TÜV NORD CERT Umweltgutachter GmbH

Hanover, 2020-12-16
TNC Umweltgutachter-H

Critical Review of Life Cycle Assessment

for the

European Paper Packaging Alliance (EPPA)

SINGLE-USE AND MULTI-USE DISHES SYSTEMS IN QUICK SERVICE RESTAURANTS

Region: EU

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1 General

1.1 Object and Terms of Reference

EPPA (2593 BM 'S-GRAVENHAGE, Netherlands) commissioned Ramboll to draw up a comparative Life Cycle Assessment "**Single-use and multi-use dishes systems in quick service restaurants”.**

EPPA, commissioned also TÜV NORD CERT Umweltgutachter GmbH to carry out a critical review of the Life Cycle Assessment as an independent body in accordance with DIN ISO 14040 and DIN ISO14044.

The review was carried out for TÜV NORD Cert Umweltgutachter GmbH (DE-V-0263) by Dr.-Ing. Winfried Hirtz, Environmental Assessor licensed under the Environmental Audit Act, registered number DE-V-0151.

Under the terms of reference, the objective of the critical review was to verify the reliability, transparency, relevance and representative nature of the methods used for Life Cycle Assessment with respect to

- Objective and scope of assessment
- Life Cycle Inventory
- Life Cycle Impact Assessment and
- Evaluation of assessment

1.2 Procedure

Taking into account the general quality criteria (chiefly transparency, reproducibility, quality of the computer programs and data used, and information on the sources of data), the procedure used for the critical review was as follows:

- Review of the objective and scope of the assessment, especially the function and functional equivalence of system boundaries and cut-off criteria (space, time, technology), allocation procedures together with the allocation and distribution rules adopted, and the selection of significant parameters and materials.

- Review of the Life Cycle Inventory drawn up, especially with regard to the input/output analyses (major process chains), the input and output data used and the reliability of such data, the systematic nature, completeness and plausibility of the input/output analysis, the sensitivity analyses and the assessment of errors, where necessary, the plausibility and reliability of computer programs, and the consideration of upstream process chains, by-products and secondary post-use effects

- Review of the Life Cycle Impact Assessment, concentrating on the selection of impact categories (with respect to subject areas and problems) and the concentration of data with reference to impact categories

- Review of the evaluation and the comparative statements made on the basis of the evaluation

System representations, data files and other representative documents were inspected and compared on a random sample basis and some data collection and calculation procedures were reproduced on the computer, in some cases with targeted variation. For example, were viewed all baseline assumptions*,* the utilisation phase and the end of life. The assessment of the technologies (especially washing and recycling/EoL) under consideration here were performed based on model calculations. Protocols of the model calculations were viewed and inspected. In general, duplication of effort was avoided during the critical review. Relevant literature concerning life cycle assessment techniques was taken into consideration.

2 Result of Critical Review

2.1 Objective of Assessment

The objectives of the Life Cycle Assessment are defined clearly and unambiguously; external and internal target groups for the assessment are also stated. The presentation adopted for the Environmental Commendation provides sufficient appropriate information to make the intended environmentally holistic approach clear and comprehensible.

2.2 Scope of Assessment

The Life Cycle Assessment considers the single-use and multi-use dishes systems in quick service restaurants. Excluded from the study is the take away system. Promotional units are checked by sensitivity analysis and the amount of units. The baseline of this study is very clear. The Life cycle assessment study refers also to a technology proven for single-use and for multi-use. The technologies refer to the washing systems of the used dishes and also to incineration and recycling at the end-of-life (both referred to existing technologies). Beside of existing technologies there are several variants, the most relevant were considered and directly compared with the baseline system or are checked by sensitivity analyses.

For the comparison of the two different systems in quick service restaurants (QSRs), three scenarios were taken into consideration:

- current system based on single-use and disposable products
- expected (hypothetical) future system in 2023 based on equivalent multiple-use products and respective processes and infrastructure for **in-store** washing operations;
- expected (hypothetical) future system in 2023 based on equivalent multiple-use products and respective processes and infrastructure for **out-store** washing operations.

Despite differences, the chosen systems are equivalent regarding there function. This supposition was intensively investigated as a prerequisite for the study. The scope and system boundaries of the assessment are clearly and unambiguously defined in relation to the entire system with respect to space (EU), time (2023) and technology (processes and necessary infrastructure for 2023). The future systems exist yet today, but are not adapted to QSRs. The boundaries are defined over the whole life cycle. They are compatible with the selected function unit. The assembly has been checked.

Environmental impact is presented and assessed in the categories Climate change (CO_2), depletion of fossils and metals (eq. oil and copper), freshwater consumption (m^3), freshwater eutrophication (P), Ionising radiation (Bq CO-60), terrestrial acidification (SO_2), stratospheric ozone depletion (CFC-11), all expressed as equivalent. The choice considers the differences between the systems and allows a well-grounded result.

Within the scope of the assessment, all relevant materials, processes and infrastructure were logged, analysed and finally grouped together for the subsequent Life Cycle Inventory.
The graphs, diagrams and tables in the assessment confirm the systematic nature and completeness of the procedure selected.

The effects and factors considered negligible for the definition of the Life Cycle Assessment system are explained.

In summary it can be stated that all relevant factors have been identified and taken into consideration within the area investigated in accordance with the state of the art of Life Cycle Assessments.

2.3 Life Cycle Inventory

The input/output analyses for the processes mentioned above were carried out and the Life cycle Inventory for the Life Cycle Assessment was documented using a computer system. The calculations themselves were performed using Commercial and own Databases resp. actual data from the industry.

2.3.1 Data sources

The main processes in the individual areas were modelled realistically. The data sources are based on generally accepted files or are primary data from the industry, e.g. paper producer or washing machines, they are comprehensible and representative as regards this Life Cycle Assessment. The data basis is extremely comprehensive. The data can be understood and traced. There is a difference between primary and secondary data sources. This could have an effect on data symmetry that is relevant for some of the hypothetical multi-use variants. Therefore the importance of sensitivity analyses is high (see 2.3.5). The assumptions for the variants for the near future are realistic and refer to existing technologies. This is the case especially for washing systems.

2.3.2 Plausibility and completeness review

The computer system reflects the system boundaries systematically and is consistent with the assessment area defined. Boundaries were drawn at points where no (significant) impact on the results of the individual areas or the overall assessment is expected (see also the sensitivity analyses conducted). The data are of high quality and are highly symmetrical under consideration of available primary and secondary data (see also chapter 2.3.1). The data used were drawn from databases. The available information regards the individual components and parts lists (set menu) which are used. This information was verified by means of information requested from QSR operators including the material composition.

The correctness and plausibility of the calculations and the results were verified by reviewing selected parameters. In this way, the links between the various areas and the hierarchy of data used for the assessment calculations were verified with respect to the process plans (also checked), the inclusion of partial assessments (where more detailed information are available) and the data basis.

In order to ensure that the data used could be traced back to the original data sources, both the calculations and the documentation were investigated and found to be very clear and transparent.

All significant parameters are available and representative and have been systematically derived and duly assessed. All type approvals have been checked. The assessments and the underlying data collection and calculation procedures are transparent and traceable.

2.3.3 Allocations

Allocations arise in connection with basic data; they are included in a database and it was possible to represent them appropriately. They are represented in the computer system completely, clearly and plausibly.

To the extent that allocations are imported to the process plan from databases, the data basis is adequate. Allocations from the databases have already been taken into consideration in the process plan.

Further allocations were performed e.g. for the part incineration and for the recycling of sorted paperboard and coated paper.

2.3.4 Error assessments/Uncertainty

Separate error assessments were not drawn up. In view of the numeric stability and proven quality of the data used, there is no need to include the separate error assessments (see also 2.3.5). The prediction of future handling for the reuse is not submitted to error assessments but considered in sensitivity analyses.

2.3.5 Sensitivity Analysis

Numerous sensitivity analyses are carried out. Seven are referred in the study.
In order to verify the possible predictions, calculations regarding sensitivities and the associated parametering were performed at the client's premises. There were no indications that further sensitivity calculations were needed at the moment.

2.4. Life Cycle Impact Assessment

The Life Cycle Impact Assessment was based on the results of the Life Cycle Inventory and is an integral part of the process plans.
In order to carry out a Life Cycle Impact Assessment on the basis of data and information derived from the Life Cycle Inventory, it is necessary to compress the data for defined impact categories.
Taking into consideration the objectives of the assessment, the functional unit selected and the (standard) technologies used in the assessment area, the impact categories were well defined.

The impact categories were selected in accordance with the objectives and scope of the Life Cycle Assessment.

These quantifiable impact categories represent the system assessed and the technologies used in terms of key local, regional and global categories.

The calculations were checked. The factors stored in the computer program are internationally recognized. With reference to the objectives of the assessment, other impact categories are of secondary importance.

Data compression within these categories has been carried out on the basis of generally accepted equivalence factors in a way which is clear, reliable and easy to follow.

2.5 Evaluation

The evaluation section of the Life Cycle Assessment includes specific conclusions and recommendations.

The evaluation of the results of the Life Cycle Inventory and Life Cycle Impact Assessment which was submitted is based consistently and appropriately on the objectives defined for the Life Cycle Assessment.
Further statements and recommendations are strictly separated from the Life Cycle Assessment itself.

2.6 General conclusion

This study is valid for the systems described. The results may change when the assumptions change. Other studies refer more to products. Therefore a comparison with existing studies is not always correct. The use of primary data shows the actual state-of-the art of the industry. Secondary data are mostly relevant for the multi-use alternatives and cannot always show the same actuality. But is has to be considered that the multiple-use systems present a hypothetical future scenario for which no primary data are available. Also all secondary data are as actual as possible and are updated regularly. It is recommended to include always the results of the sensitivity analyses when checking the environmental assessment of possible alternatives.

3 Summary of the critical review

The critical review of the Life Cycle Assessment "Single-use and multi-use dishes systems in quick service restaurants" conducted by the undersigned in accordance with the requirements of international standards DIN EN ISO 14040:2009 and DIN EN ISO 14044:2018 may be summarised as follows:

- The methods used for drawing up the Life Cycle Assessment are in accordance with the requirements of DIN EN ISO 14040:2009 / DIN EN ISO 14044:2018. The methods are scientifically well-founded and are in accordance with the state of the art of Life Cycle Assessments.

- The data used are adequate, appropriate and well-founded with reference to the objective of the assessment.
- The evaluations take into consideration the objective of the assessment and the limitations which were identified.
- The Life Cycle Assessment is consistent and transparent.

A certificate of validity has been issued concerning the critical review which was conducted. The report of the critical review will become part of the detailed version of the Life Cycle Assessment.

No remarks are finally found.

Dr. Winfried Hirtz
Environmental Verifier
DE-V-0151