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COMPARATIVE LIFE-CYCLE ASSESSMENT (LCA)

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

RAMBOLL Bright ideas. Sustainable change.

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

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Disclaimer

Due to an extensive GaBi database update, the results for the EU reference model have changed. Therefore, this report includes updated results for the EU baseline scenario and additional sensitivity scenarios that were outside of the scope of the peer-reviewed LCA study. These results are clearly marked and disclosed at the end of this report.

The database update includes, among other things:

- Global energy mix and production data updates;
- Update of the treatment plant models/parameters;
- Updated global supply chains / mixes;
- Further expanded regionalization of land use and water consumption elementary flows
- Energy update: All energy-related datasets, such as electricity, thermal energy, fuels and the like, have been upgraded in line with the latest available, consistent international energy trade and technology data.

Updates of LCA databases, including both, larger annual as well as smaller updates throughout the year, are a means to ensure correctness, accuracy and timeliness of the datasets included. Such updates may include specific updates of dataset regarding the quantities or types of their inputs and outputs as well as updates regarding the characterisation factors used to translate these inputs and outputs into the impact categories of an assessment method (e.g. ReCiPe). The 2021 update of GaBi included major updates on chemicals as well as the metal depletion category of ReCiPe[1]. This update therefore affects in particular the impacts created by chemicals in the metal depletion impact category and let to substantial changes of the impact of chemicals used in detergent and rinse agent for the washing process of multiple-use items. However, the major change is due to one chemical (potassium hydroxide), which accounts for more than one third of the detergent quantity.
Although obtained through unchanged methodology and calculation process, this updated executive summary and disclosed results were not part of the original study and are not subject to a third-party review.

[1] https://sphera.com/wp-content/uploads/2020/04/Details-and-Reasons-for-Changes.pdf

EXECUTIVE SUMMARY

Ramboll has been appointed by the European Paper Packaging Alliance (EPPA[2]) 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)

Ramboll conducted a Comparative Life Cycle Assessment study for the European Paper Packaging Alliance regarding *single-use and multi-use dishes systems in quick service restaurants*. The study was issued in December 2020 after the completion of a Critical Review conducted by TUV (Critical review report is dated 16/12/2020).

However, during 2021 update of GaBi databases (used for the above-mentioned study) ware issued and EPPA asked Ramboll to update the results of the study accordingly.

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).

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

The 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;
- **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%)[3] lower than paper packaging (about 85%[4]). 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.

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

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

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.]	8912	24645
Fine Particulate Matter Formation [kg PM2.5 eq.]	5.2	11.5
Fossil depletion [kg oil eq.]	2813	9605
Freshwater Consumption [m3]	60	202
Freshwater Eutrophication [kg P eq.]	2.9	0.6
Ionizing Radiation [kBq Co-60 eq. to air]	2110	1302
Metal depletion [kg Cu eq.]	55	180
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0.010	0.009
Terrestrial Acidification [kg SO2 eq.]	22	37

These results for the baseline scenario are[5]:

- 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 124% 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 241% 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 235% 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).

[5] 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 **Ionizing Radiation**, there are significant environmental benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 38% lower than in the single-use baseline scenario).
- For **Metal Depletion**, there are very significant environmental benefits for the single-use system (i.e. impacts of multiple-use baseline scenario are 226% higher than in the single-use baseline scenario).
- For **Stratospheric Ozone Depletion**, there are noticeable environmental benefits for the multiple-use system (i.e. impacts of multiple-use baseline scenario are 13% 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 65% 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. <u>Single-use system</u>: Different recycling rates of post-consumer paperboard (0%; 70%);
2. <u>Multiple-use system</u>: Different recycling rates of post-consumer PP items (0%; 70%);
3. <u>Multiple-use system</u>: Varied demand for multiple-use items (30% higher; 30% lower);
4. <u>Multiple-use system</u>: Optimised washing scenario;
5. <u>Multiple-use system</u>: External washing with band transport dishwasher;
6. <u>Multiple-use system</u>: 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. <u>Both systems</u>: 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[5]:

- 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 very significant environmental benefits for the single-use system in the baseline comparison. However, moderate environmental benefits for the multiple-use system are identified when external washing is assumed. 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.

<u>External review</u>
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).

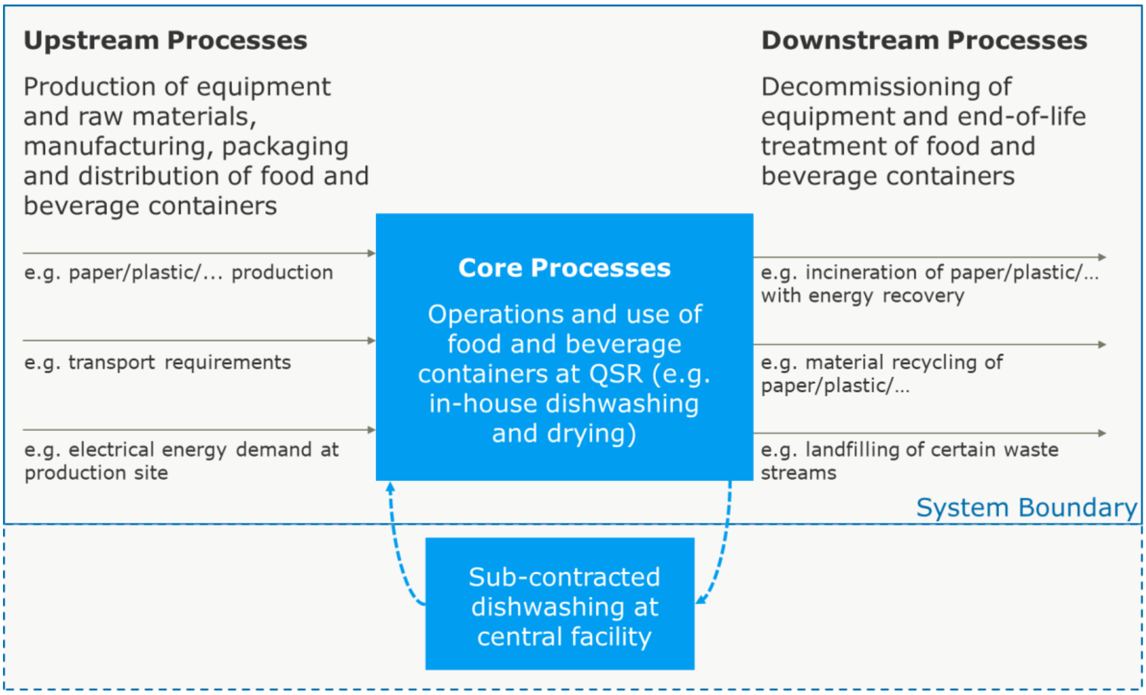

Figure 1: Schematic system boundary and differentiation between upstream, core, and downstream processes from the perspective of a QSR (Source: own depiction)

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[6]. 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[7]; (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.

[6] 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.

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

a) Climate Change

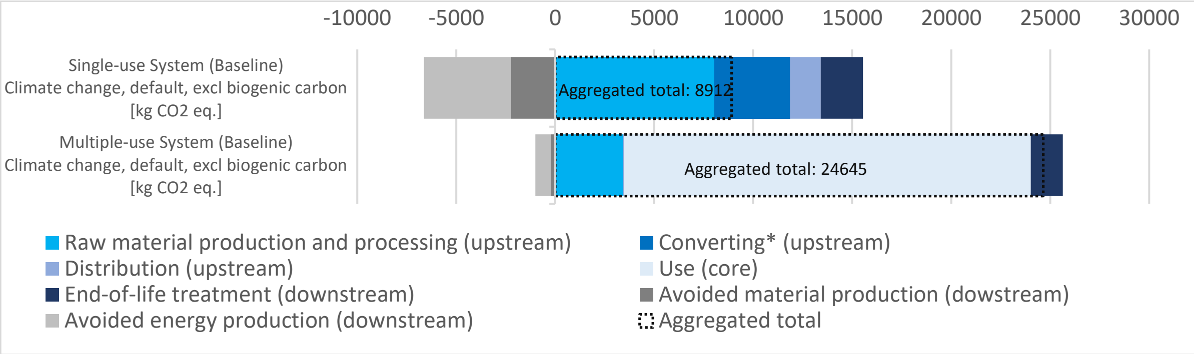

Figure 2: Baseline comparison results for the impact category Climate Change (excl. biogenic carbon) in kg CO_2 eq.

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).

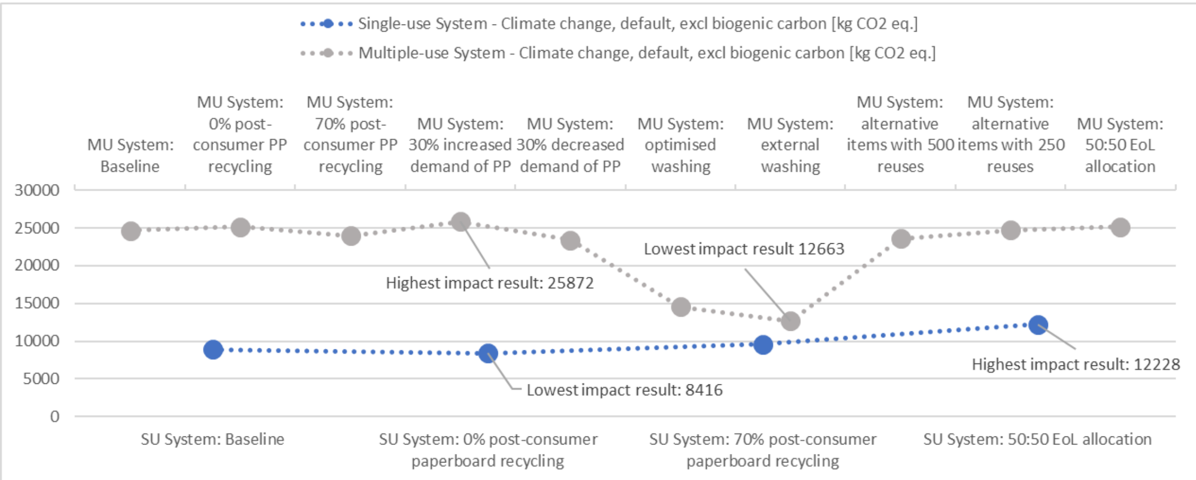

Figure 3: Summary of aggregated results for the impact category Climate Change of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

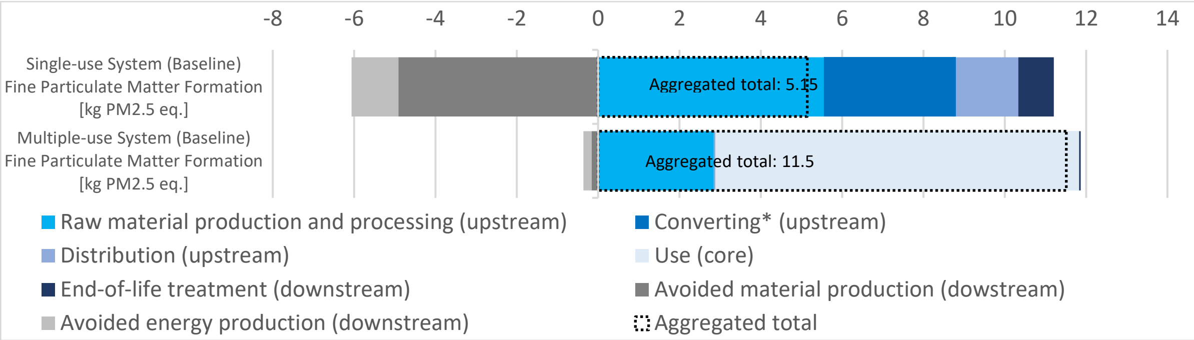

Figure 4: Baseline comparison results for the impact category Fine Particulate Matter Formation in kg PM2.5 eq.

<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>
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.

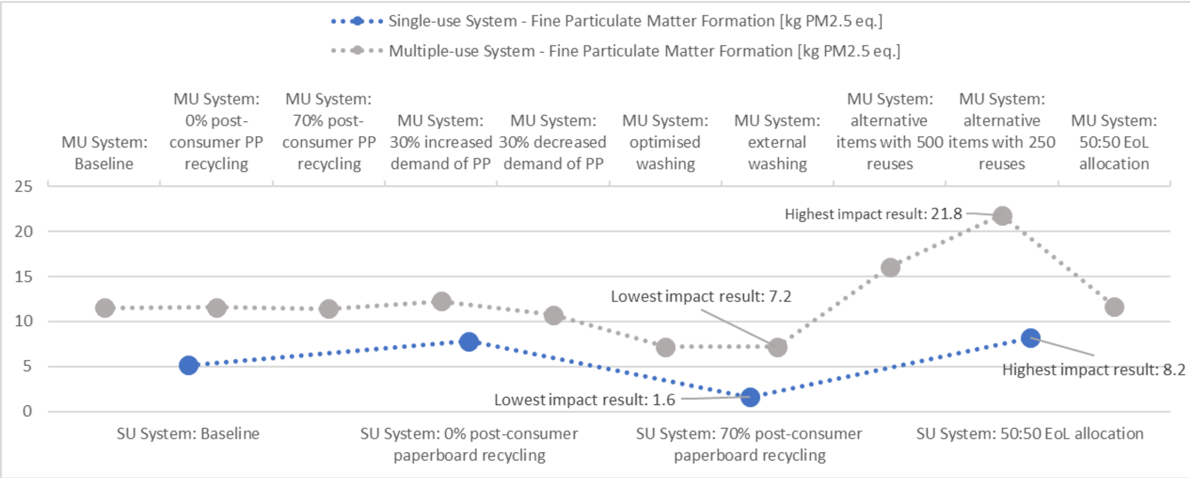

Figure 5: Summary of aggregated results for the impact category Fine Particulate Matter Formation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

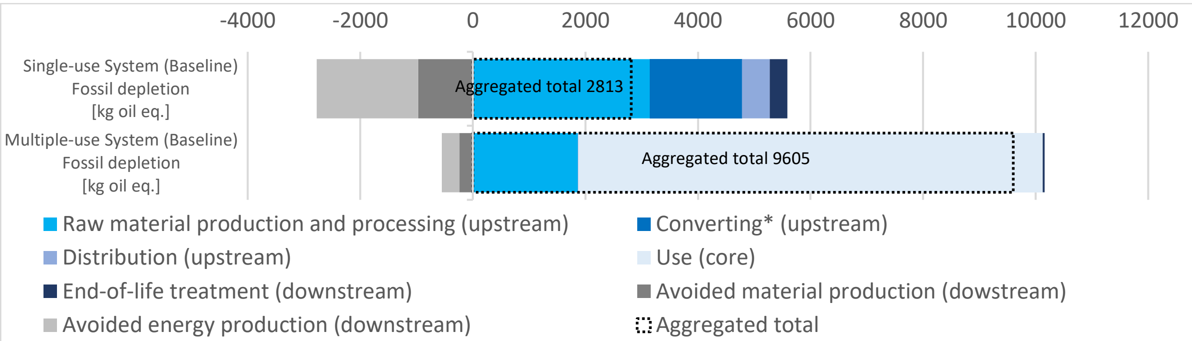

Figure 6: Baseline comparison results for the impact category Fossil depletion in kg oil eq.

<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).

<u>Multiple-use system</u>

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.

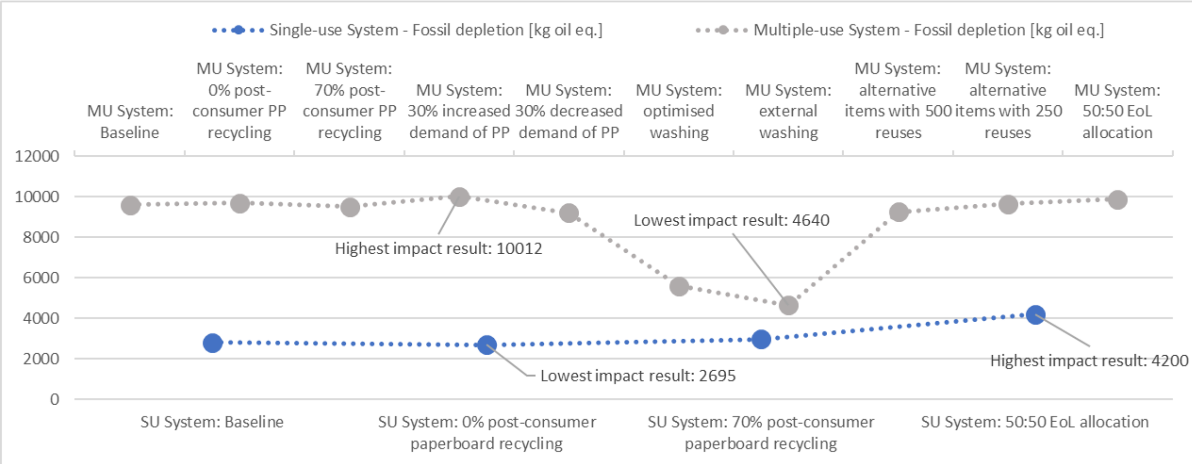

Figure 7: Summary of aggregated results for the impact category Fossil Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

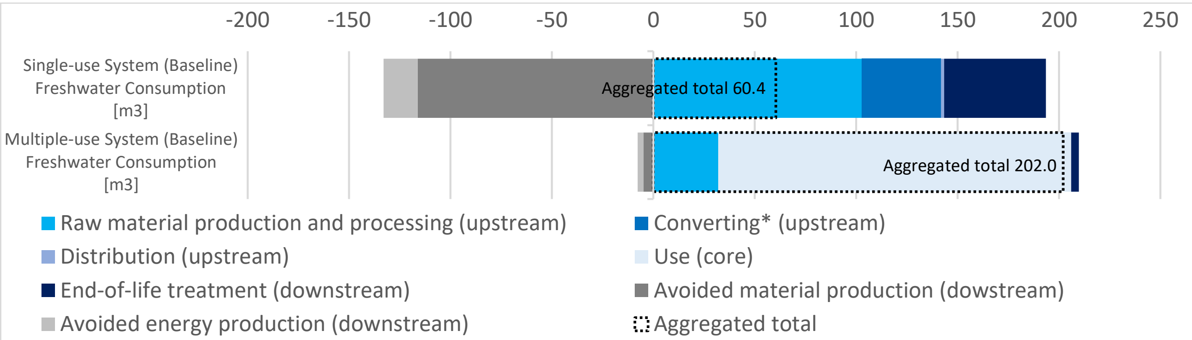

Figure 8: Baseline comparison results for the impact category Freshwater Consumption in m³

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.

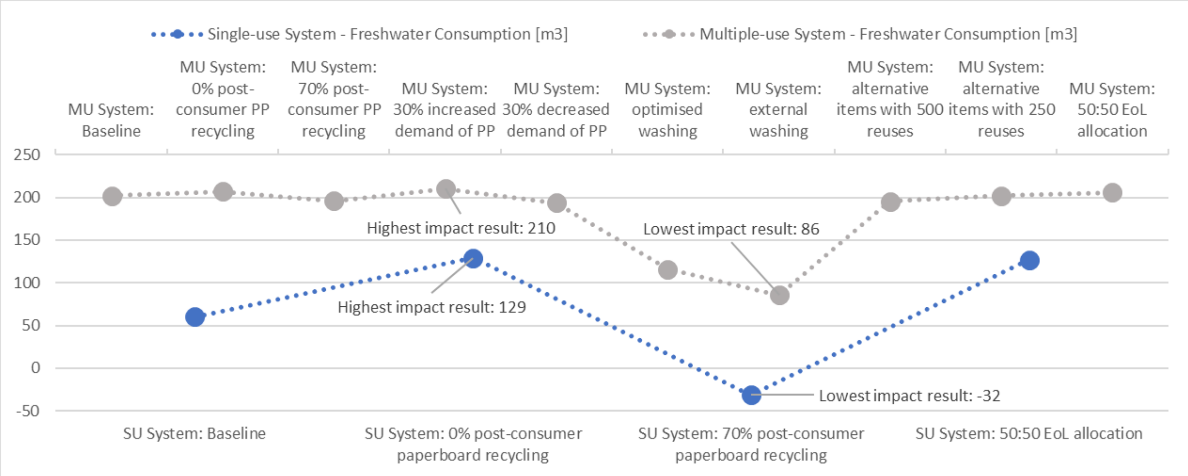

Figure 9: Summary of aggregated results for the impact category Freshwater Consumption of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

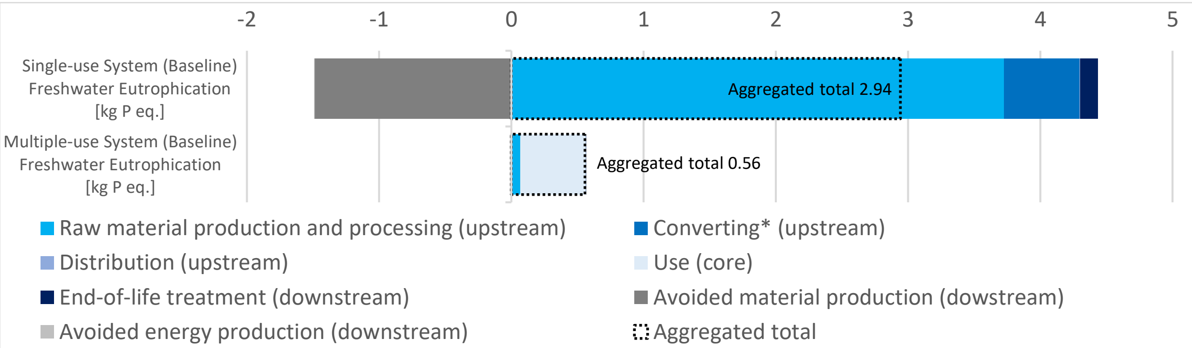

Figure 10: Baseline comparison results for the impact category Freshwater Eutrophication in kg P eq.

<u>Single-use system</u>

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.

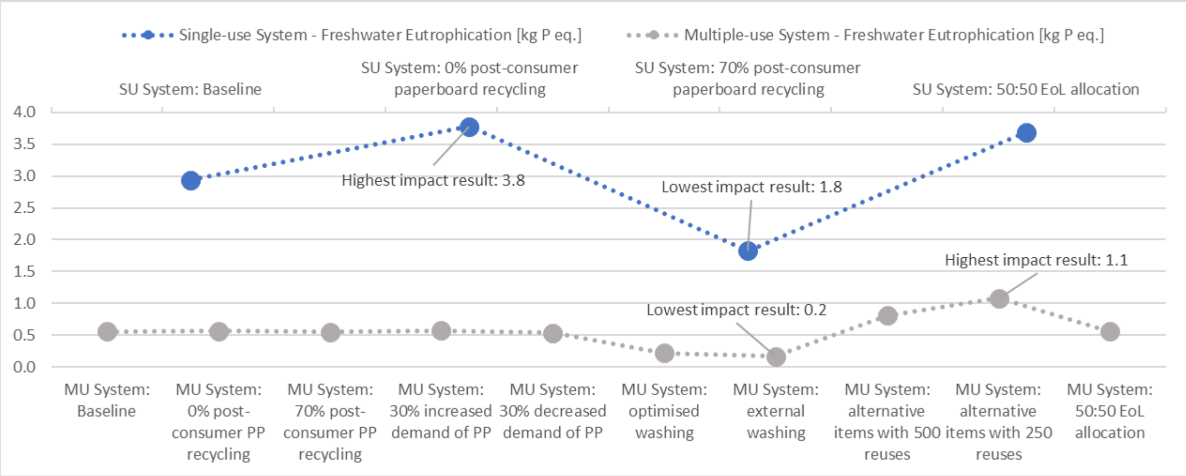

Figure 11: Summary of aggregated results for the impact category Freshwater Eutrophication of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

f) Ionizing Radiation

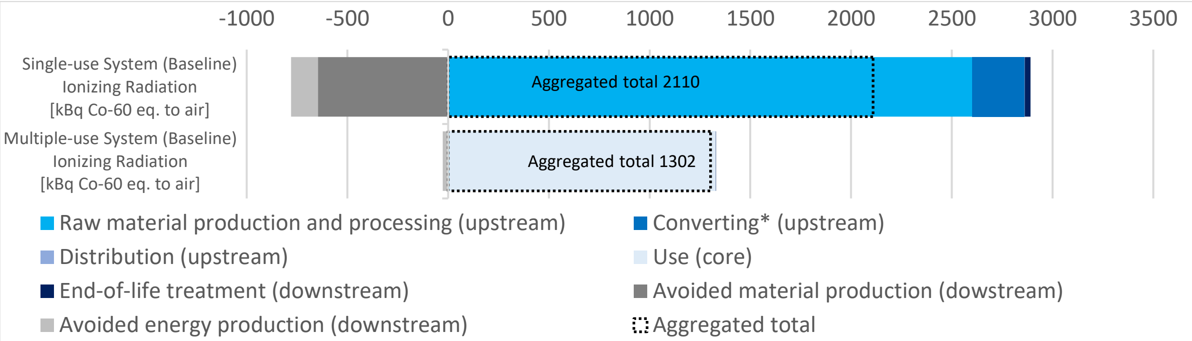

Figure 12: Baseline comparison results for the impact category Ionizing Radiation in kBq Co-60 eq. to air

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.

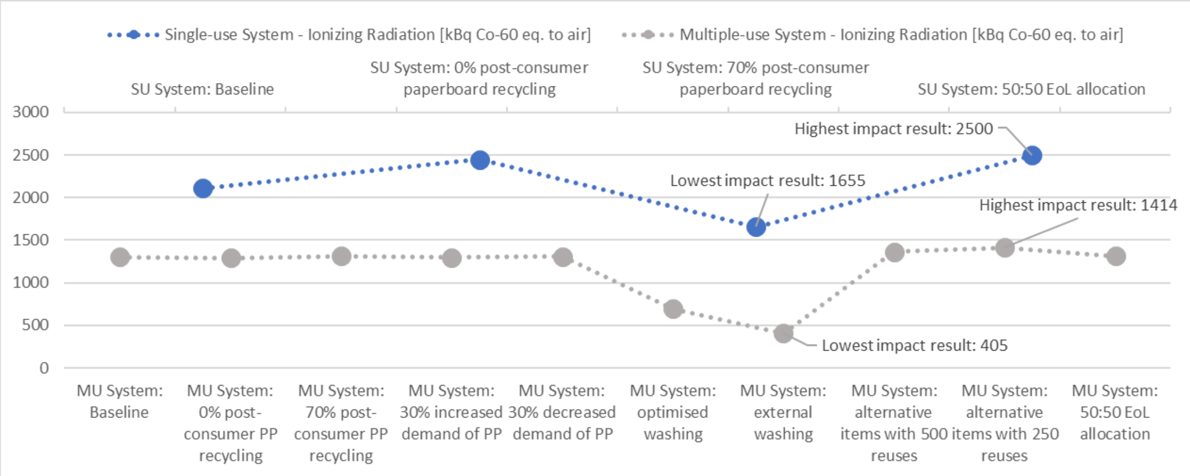

Figure 13: Summary of aggregated results for the impact category Ionizing Radiation of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

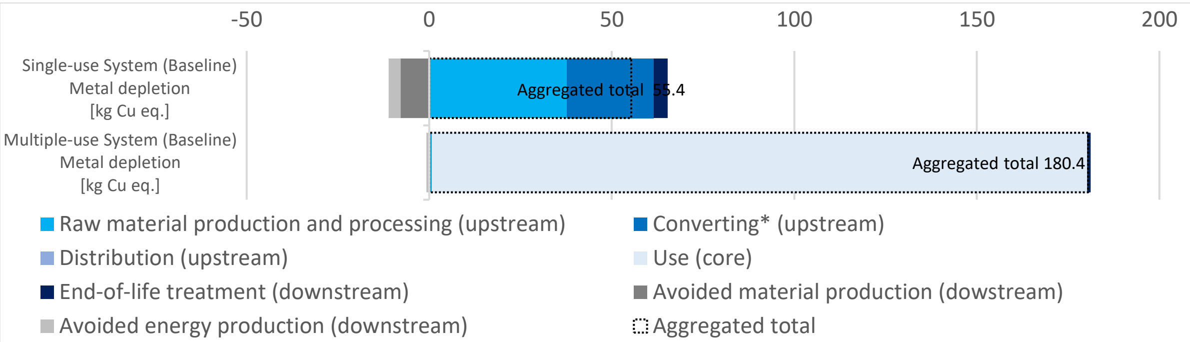

Figure 14: Baseline comparison results for the impact category Metal Depletion in kg Cu eq.

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 predominant contributor to metal depletion in the baseline scenario of the multiple-use system are the chemicals used in detergent and rinse agent for the washing process of multiple-use items. This is due to one specific chemical (potassium hydroxide), which accounts for more than one third of the detergent quantity. Electricity demand is the second largest contributor, making up for about 16% of the total impact.

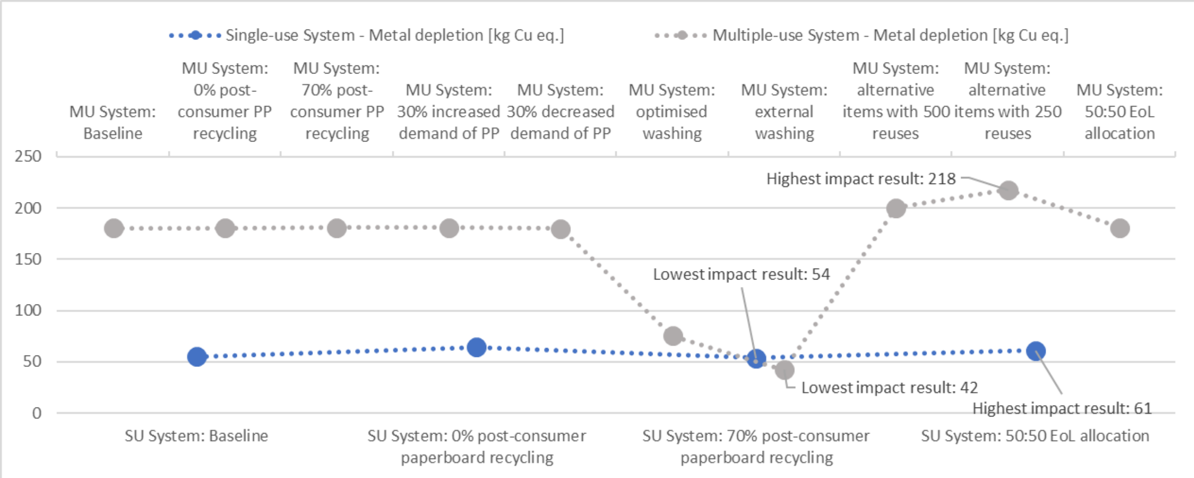

Figure 15: Summary of aggregated results for the impact category Metal Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

In summary, the multiple-use system shows on average **very significant** environmental benefits with regard to metal depletion. However, **moderate** environmental benefits are shown for the single-use system when external washing is assumed.

h) Stratospheric Ozone Depletion

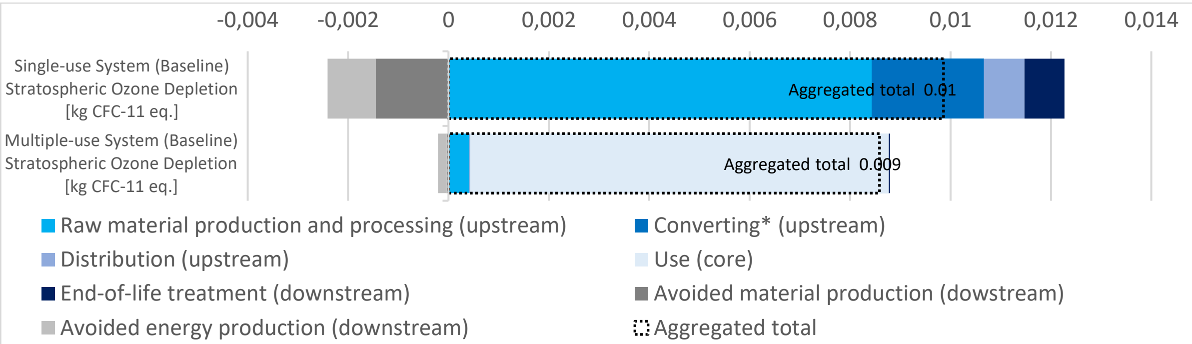

Figure 16: Baseline comparison results for the impact category Stratospheric Ozone Depletion in kg CFC-11 eq.

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.

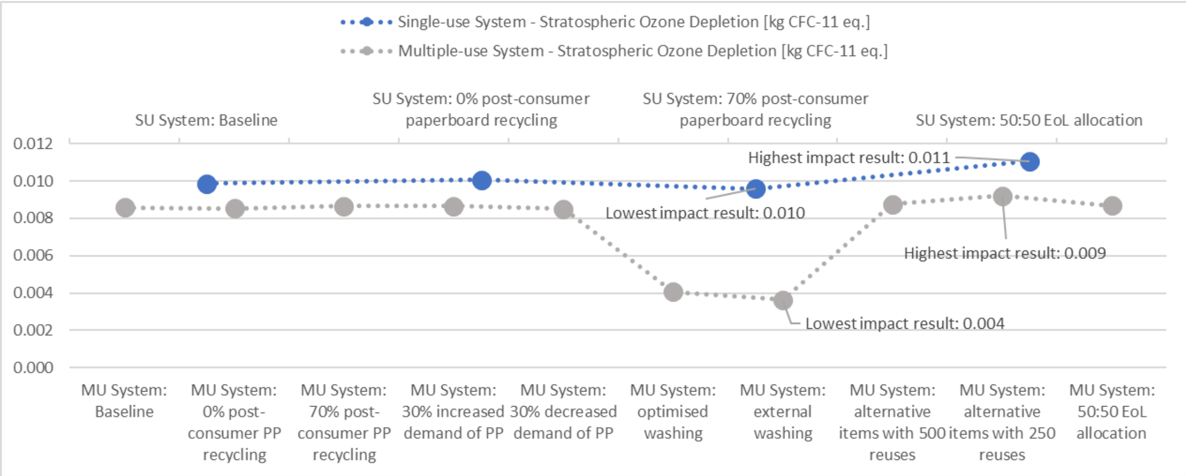

Figure 17: Summary of aggregated results for the impact category Stratospheric Ozone Depletion of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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

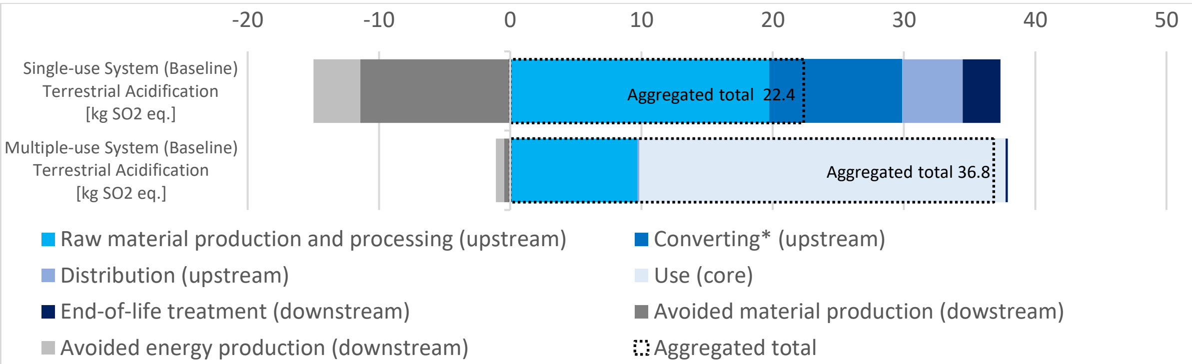

Figure 18: Baseline comparison results for the impact category Terrestrial Acidification in kg SO_2 eq.

<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.

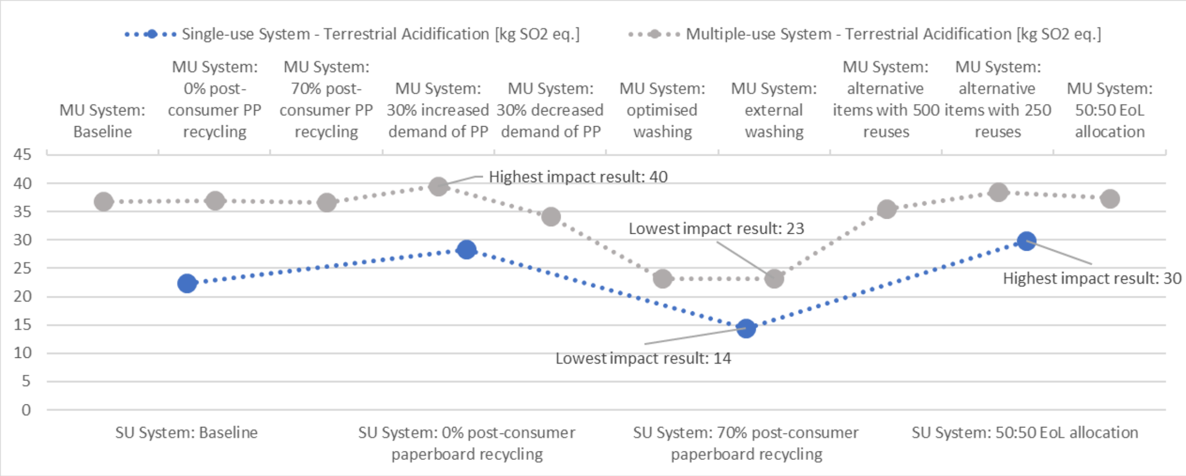

Figure 19: Summary of aggregated results for the impact category Terrestrial Acidification of all scenarios within both systems (the order from left to right follows the sequence of the respective report sections).

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.