1 General questions

What is this Life Cycle Assessment (LCA) study about?

This LCA assesses take-away services of foodstuff and beverages with single-use or multiple-use tableware in an average Quick Service Restaurant (QSR) for 365 days in Europe. Takeaway includes 4 selling channels (drive through, on-the-go, click and collect, home delivery). Tableware compared include cups, lids, containers, cutlery, carriers and bags.

For this comparative assessment, two fundamentally distinct systems are taken into consideration implying 17 different products: the current system for take-away services in QSRs based on single-use products made of paperboard, some of them with a polyethylene content lower than 10%, and their multiple-use alternative made of polypropylene.

The LCA model for this study is developed with open LCA software[1], using background data from Ecoinvent[2] (version 3.8) and scientific literature, primary data from European Paper Packaging Alliance and QSRs operators, and available public or commercial extension databases.

The LCA report is ISO 14040/44 compliant, and it has been subjected to:

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

Why is this study different from other LCAs on the same topic?

Main studies available in scientific literature adopt a product-focused approach in comparative assertions, mainly comparing single-use (SU) products with multiple-use (MU) products. This LCA adopts a system-focused approach with a holistic perspective on the comparison of single-use and multiple-use products in QSRs. 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.

Moreover, this study is based on extensive primary data collection among QSRs operators, which lays the basis of a robust study. The use phase in takeaway systems has been thoroughly investigated during this data gathering, by collecting information regarding distribution channels repartition, type of

[1] openLCA.org

[2] ecoinvent v3.8 – ecoinvent

washing and types of dishwashers, number of reuses of a product, return rates, means of transport and distances covered. Primary data and information for single-use system have been further obtained from EPPA members', whose market shares cover more than 65% of QSRs in Europe. Also, data from scientific papers published in peer-reviewed international journals have been considered for the modelling of both SU and MU systems.

An extensive sensitivity analysis has also been undertaken to test decisive assumptions: 9 scenarios have been investigated (5 for MU system; 4 for both systems) by including different number of reuses, different return rate, different assumptions related to take-back system, different washing scenarios, different EoL shares, different EoL allocation approaches. This LCA study could be therefore considered comprehensive and robust.

Representative data and robust assumptions are key strength features of this study also according to the opinion of the reviewers, as included in the critical review statement:

> *[…] In particular, they appreciate the specific data gathering implemented by the authors of the study. Subsequently, the reviewers consider the results and conclusions to be a sound and fair reflection of the potential comparative environmental impacts of the studied systems representing the use of single use and multiple use tableware for takeaway services in Quick Service Restaurants. The detailed sensitivity analysis provides transparency of the uncertainties and confidence in the overall robustness of the results achieved and conclusions drawn.*

It is crucial to acknowledge and highlight that this is a tailor-made and case-specific ISO-compliant comparative assertion (e.g., several specific modelling choices are applied - which are transparently documented and explained in the full report). As a consequence, results from this study are not directly comparable with other sources and results.

What are the main results of this LCA?

The study is a tailor-made and case-specific ISO-compliant comparative assertion. Based on the set of assumed specific conditions and hypotheses, the paper-based Single Use (SU) system shows significant lower impacts than the plastic reusable system (MU).

Comparative table for the baseline scenario (50 reuses)*:

		SU	**MU**	**MU vs. SU comparison (%)**	**MU vs. SU comparison (Times)**
Acidification	[mol H+ equivalents]	**77.5**	**167.6**	impacts of multiple-use are **116% higher** than the single-use	impacts of multiple-use are **2.2 times higher** than the single-use
Climate change, total	[kg CO2-Equivalents]	**20,811**	**39,788**	impacts of multiple-use are **91% higher** than the single-use	impacts of multiple-use are **1.9 times higher** than the single-use

Eutrophication, freshwater	[kg N equivalents]	**5.48**	**9.28**	impacts of multiple-use are **69% higher** than the single-use	impacts of multiple-use are **1.7 times higher** than the single-use
Eutrophication, marine	[kg P equivalents]	**37.8**	**49.6**	impacts of multiple-use are **31% higher** than the single-use	impacts of multiple-use are **1.3 times higher** than the single-use
Eutrophication, terrestrial	[mol N equivalents]	**254.5**	**449.3**	impacts of multiple-use are **77% higher** than the single-use	impacts of multiple-use are **1.8 times higher** than the single-use
Ionising radiation, human health	[kBq U235 equivalents]	**3,976**	**4,318**	impacts of multiple-use are **8.6% higher** than the single-use	impacts of multiple-use are **1.1 times higher** than the single-use
Ozone depletion	[kg CFC11 equivalents]	**0.00276**	**0.00561**	impacts of multiple-use are **100% higher** than the single-use	impacts of multiple-use are **2.0 times higher** than the single-use
Particulate matter	[disease incidence]	**0.00083**	**0.00188**	impacts of multiple-use are **129% higher** than the single-use	impacts of multiple-use are **2.3 times higher** than the single-use
Photochemical ozone formation	[kg NMVOC equivalents]	**69.8**	**213.5**	impacts of multiple-use are **206% higher** than the single-use	impacts of multiple-use are **3.1 times higher** than the single-use
Resource use, fossils	[MJ]	**314,931**	**581,979**	impacts of multiple-use are **85% higher** than the single-use	impacts of multiple-use are **1.9 times higher** than the single-use
Resource use, minerals and metals	[kg Sb equivalents]	**0.06**	**0.32**	impacts of multiple-use are **433% higher** than the single-use	impacts of multiple-use are **5.3 times higher** than the single-use
Water consumption	m3 ReCiPe 2016 Midpoint (H)	**136.8**	**224.5**	impacts of multiple-use are **64% higher** than the single-use	impacts of multiple-use are **1.6 times higher** than the single-use

The percentages and multiples included in the table are calculated taking the existing SU system as a point of reference (e.g. (MU-SU)/MU) so to realistically reflect how shifting to multiple use systems would impact the different impact categories.

Although technically correct these values differs from the relative differences in % reported in the Comparative LCA report, where the system with the associated highest impact for each category is set to 100% and the other system is normalized to this value: both tables are valid, while taking a different point of reference.

Under consideration of obtained impact results, it can be concluded that, for the baseline comparison between SU and MU, SU system shows lower impacts in all impact categories with very significant differences for the Climate Impact, Water consumption, Resource use fossil and minerals, particulate matter and acidification.

These results are mostly confirmed by the 9 sensitivity analyses undertaken: implementing an increase in number of reuse (100 reuses), an increase of the return rate (70%) or a reduction of take-back trips for multiple-use items (with 4 out of 5 trips are neglected), having no preliminary washing at home, using an external washing with band transport dishwasher, implementing 4 different end-of-life scenarios for both systems.

Performed sensitivity analysis shows that most of the tested scenarios provide results similar to those of the baseline, confirming a situation in which SU system shows lower impacts than the plastic MU. Some differences in the results can be obtained for:

- S03 scenario (according to which 4/5 of total trips to return MU items are neglected, i.e., 4 out of 5 people returning MU items in case of buying of another menu), whose effect is able to turn the results in favour of MU system for *Eutrophication marine*, *Eutrophication terrestrial*, *Ionising radiation, human health*, and *Ozone depletion* categories.
- S05 scenario (external washing), whose effect is able to turn the results in favour of MU system only for *Ionising radiation, human health* category.

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

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

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

This LCA is considering QSR only: to which extent is it valid for other types of restaurants?

QSRs are a specific classification of restaurants and entail certain high-volume food and beverage operations, as well as specific inherent features, as for example:

- QSRs operate under a standardized system that is long-established, quantifiable in robust data, and geographically sensitiveness.
- QSRs serve a high number of menus, drinks and food items 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.
- QSRs provide a referential for best-in-class dishwashers in the HORECA (hotel-restaurant-café) sector.
- Take away services (drive through, on-the-go, click and collect, home delivery) has fast grown (double digit) over the last few years representing up to 50% of the total sales.
- QSRs are open 365 days per year and opening hours can be up to 24/7.
- Food affordability is expected and critical for a large part of restaurant's users.

While some of the aspects reported above can be seen as valid also for other types of restaurants, others may not be reflected in specific case studies not referring to QSRs. In fact, it must be noted that this study is a tailor-made and case-specific ISO-compliant comparative assertion and as such it must be considered valid within the set of assumed specific conditions and hypotheses

Why are Climate change, Fossil resource use, Particulate matter and Ozone formation impact categories representing 80% of the environmental impacts? Why not the other categories?

In order to present the contribution to the total impacts, the Product Environmental Footprint Category Rules Guidance (version 6.3) reports a methodology for "Impact categories cumulatively contributing at least 80% of the total environmental impact (excluding toxicity related impact categories)". This methodology was used in the study to present the most relevant impact categories by applying normalization and weighting to the baseline results. Based on the normalized and weighted results, and excluding the toxicity related impacts (the exclusion of toxicity categories is required by the PEF methodology), the most relevant impact categories are for both SU and MU systems: Climate change, Fossil resource use, Particulate matter and Ozone formation (deriving from the entire life cycles of the two investigated systems (raw material extraction and manufacturing, converting, distribution, use phase and end of life) and in particular from respective hotspots. When taking into account the impacts of these categories in the two analysed systems, as well as normalization and weighting factors reported by the Product Environmental Footprint Category Rules Guidance (version 6.3), the contribution of these categories to the total environmental impacts is larger than the contribution deriving from other impact categories.

Why do you say that that considering Euro 4 cars for the baseline system is a "conservative assumption"? Why did you take Euro4 cars (2006) and not Euro 6 (2015) or Euro7 cars (2025)? What about electric vehicles?

Modelling of passenger cars is implemented through Ecoinvent 3.8 database by considering an average Euro 4 car taking into account different car sizes (small, medium and large) and fuel types (petrol, diesel and natural gas). Euro 4 is considered a "robust" assumption as it represents an average scenario for vehicles fleet in Europe, by assuming a standard lifetime.

According to data from EUROSTAT, in 2020 the number of vehicles with an age between 10 and 20 years was the 47.4% of total vehicles[3] and according with 2021 data from European Automobile Manufacturers' Association (ACEA) the average age of passenger cars in European Union is 11.5 years[4]. Therefore the Euro 4 standard appears to be a "robust" assumption.

In order to test the sensitivity of this assumption, a specific LCA comparison between Euro 4 and Euro 5 cars (in terms of impacts/km) has been made, as reported in **Table 1**. Results show that differences in all impact categories are negligible (less than 5%), with the unique exception of Particulate matter. Nevertheless, when taking into account the overall systems analysed in the LCA, this difference should not have an effect on the main conclusions of the study.

Table 1 Analysis of different environmental impacts with Euro 4 and Euro 5 passenger cars over a 1 km distance. Results are based on Ecoinvent 3.8 database.

Indicator	Euro 4 passenger car	Euro 5 passenger car	Unit	Percentage difference*
EF-Acidification	Confidential data	Confidential data	mol H+-Eq	-1%
EF-Climate change, total	Confidential data	Confidential data	kg CO2-Eq	2%
EF-Eutrophication, freshwater	Confidential data	Confidential data	kg P-Eq	0%
EF-Eutrophication, marine	Confidential data	Confidential data	kg N-Eq	-5%
EF-Eutrophication, terrestrial	Confidential data	Confidential data	mol N-Eq	-5%
EF-Ionising radiation, human health	Confidential data	Confidential data	kg U235-Eq	2%
EF-Ozone depletion	Confidential data	Confidential data	kg CFC-11-Eq	3%
EF-Particulate matter	Confidential data	Confidential data	disease incidence	33%
EF-Photochemical ozone formation - human health	Confidential data	Confidential data	kg NMVOC-Eq	-3%
EF-Resource use, fossils	Confidential data	Confidential data	MJ	2%
EF-Resource use, minerals and metals	Confidential data	Confidential data	kg Sb-Eq	0%
ReCiPe 2016 Midpoint (H)-Water consumption	Confidential data	Confidential data	m3	0%
*if the percentage difference is negative, Euro 4 cars have less environmental impacts than Euro 5 cars (and the other way around).				

Euro 6 vehicles have been introduced only recently in Europe (2015), and they cannot be representative for an average situation. Euro 7 standard regulation is not in use, and it will be applied in the future. In addition, Euro 6 and Euro 7 cars data are not available in Ecoinvent 3.8 database (which was the latest available version at the time of developing the LCA study) and therefore could not be implemented in the LCA model.

[3] Source : https://ec.europa.eu/eurostat/databrowser/view/ROAD_EQS_CARAGE__custom_3881603/default/table?lang=en
Data refer to EU-27 + UK and have been elaborated excluding vehicles older than 20 years.

[4] https://www.acea.auto/files/report-vehicles-in-use-europe-january-2021-1.pdf

Regarding electric vehicles, according to ACEA the share of electric passenger cars in 2021 in EU is around 1.2% (considering all electric vehicle types, i.e., Battery electric, Plug-in hybrid, and Hybrid electric) [5]. This means that the share of electric vehicles is still very low and not representative of an average share in EU.

Moreover, note that this study adheres to *attributional* LCA approach. Any assumption based on future scenario could be considered as a *consequential* LCA, which is out of scope of this study. Attributional LCA is "aiming to describe the environmentally relevant physical flows to and from a life cycle and its subsystems" whereas consequential LCA is "aiming to describe how environmentally relevant flows will change in response to possible decisions"[6].

The end-of-life phase is not an environmental hotspot for both SU and MU systems, and the different scenarios considered in the sensitivity analysis do not change the baseline results. Does this mean that recycling is not relevant?

The main environmental hotspots lie on the raw material extraction and converting life cycle stages for the SU system, and on the transport and washing life cycle stages for the MU system. Therefore, these life cycle stages should be considered with the purpose at reducing environmental impacts for both systems.

The end-of-life (EoL) stage is in this study not a main environmental hotspot. However, by increasing the recycling rate, the SU system shows higher benefits than the baseline scenario in some categories (e.g., Acidification, Particulate matter, Photochemical ozone formation). A hypothetical reduction of environmental emissions associated to the recycling process in the SU system could further reduce the overall impacts and having a beneficial effect on the overall results.

What about littering? Have you considered it in your study?

Littering occurs when a waste product is not discarded properly. Potential paper-based or plastic waste leakage through littering into the environment cannot however be adequately addressed by the underlying methodological possibilities of LCA (Federal Environment Agency Germany 2019). Therefore, littering is not included in the study.

[5] https://www.acea.auto/files/report-vehicles-in-use-europe-january-2021-1.pdf

[6] Source: https://www.intechopen.com/chapters/69212

Have you considered the impact on biodiversity and the impact on land use?

This study uses impact categories from the Product Environmental Footprint (PEF) methodology[7], that is the recommended method to measure and communicate the life cycle environmental performance of products (according to the revised recommendation adopted in December 2021 by EU Commission[8]).

Biodiversity impact category is not described by the Product Environmental Footprint (PEF) and therefore, no biodiversity impact category is included in this study. The reason for this is a lack of scientific consensus on data and methodologies.

Land use impact category is excluded since primary data of some paperboards (LCIAs) used in the SU system in this study is not compatible with these categories. If further data becomes available to support it in the future, it might be included. However, the sub-category "Climate change, land use and land use change" has been considered in the study (included in the "Climate Change" impact category).

Transport is a hotspot of the study: what assumptions have you taken?

Transport from QSR to point of consumptions is symmetrical for SU and MU systems and have been excluded from the analysis. The phase of transport back to QSR is exclusive of the MU system and therefore, its effects have been evaluated, under the following hypothesis:

- Distances:
  - an average distance between QSR and point of consumption of 3 km (as reported by QSRs in specific data gathering questionnaires, as well as in literature (Allen et al. 2021; Allen, Piecyk, and Piotrowska 2018; Corr 2019)) for on-the-go, click and collect and delivery selling channels.
  - an average distance between QSR and point of consumption of 1 km for drive through selling channel (it is assumed that food and beverages are consumed near the QSR and MU items are returned directly after consumption of food and beverages, covering a distance of 1 km), as a conservative assumption.
- Multifunctionality approach:

  Trips for returning MU items to QSRs can provide a multifunctionality, as a trip back can be intended not only to return the multiple-use products, but also for other shopping or convenience reasons. Multifunctionality is related to consumers' activities, decisions, and behaviour and there are limited studies that provide analytics on behaviour toward take-back program. In this LCA, the impacts associated with these return trips are only partially allocated to the system, assuming - in the baseline scenario - that only 50% of consumers make the average distances described above specifically for returning the multiple use items. According to this scenario, 1/2 of trips for take-back are neglected (e.g., 1 out of 2 people return MU items in case of buying of another menu). Given the unpredictability of customers' behaviour, a more conservative sensitivity scenario has been tested with only 1/5 trips for take back systems considered.
- Means of transport:

[7] https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

[8] Recommendation on the use of Environmental Footprint methods (europa.eu)

- on-the-go, click and collect and delivery: an equal share (1/5) of car, scooter, public transport, muscular bike, and walking.

  Note that the transport back to QSR using muscular bike and walking (2/5 of the total) do not determine direct impacts on the investigated system.

- Drive through: 100% cars.

It is assumed that cars, scooters and public transport vehicles are equipped with internal combustion engine, i.e., Euro 4 vehicles powered by fossil fuels. This is necessary since this study is an attributional LCA, which is based on average data in Europe based on known data and statistics. Nowadays, the share of electric vehicles in the average vehicles fleet is still negligible, while it might be relevant in future.

Any assumption based on future scenario could be considered as a consequential LCA, which is out of scope of this study. Attributional LCA is "aiming to describe the environmentally relevant physical flows to and from a life cycle and its subsystems" whereas consequential LCA is "aiming to describe how environmentally relevant flows will change in response to possible decisions". Other possible future scenarios including heavy electrification of transportation and decarbonisation of energy mix is very uncertain, considering an average EU scenario. In addition, modelling this scenario would be beneficial for both systems but it will require considering a full transition of the whole system, e.g.: decarbonisation of upstream production processes and converting, potential reduction of emissions of recycling industry, decarbonisation of energy generation, electrification of transportation, change of type of servings and packaging within QSRs industry, customers behaviours, etc. All of this is highly unpredictable.

How many reuses are considered?

For the baseline scenario, an average reuse rate of 50 is considered, as reported by QSRs operator (according to the results of a specific questionnaire). Reuse rate includes replacement reasons such as damages, stains, theft or loss. To test this assumption, a more conservative sensitivity scenario has been performed with 100 reuses.

A return rate of 50% for multiple-use items seems low. What happens if the return rate increases?

For the baseline scenario, an average return of 50% is considered, as reported by QSRs operator (according to the results of a specific questionnaire).

To test this assumption, a more conservative sensitivity scenario has been performed with 70% return rate, which results showed a higher impact for the MU system, increasing the delta between the two systems, since:

- a higher return rate means a lower impact for the production and end-of-life phase
- a higher impact for the transport use phase.

Since the transport use phase is the main hotspot of the multiple-use system, increasing the return rate implies more direct impacts than avoided ones, considering the investigated scenarios and the set of hypothesis.

In some impact categories (i.e., Resource use mineral and metals, Photochemical ozone formation and Particulate matter), environmental impacts associated to the SU system are much lower (over 50%) than impacts associated to the MU system. In other impact categories this effect is not so prominent. Why?

For some impact categories, there are hotspots that predominantly affect the results, while for other impact categories this effect is less evident, and the overall result depends on the combined effect of different life cycle stages.

In the case of Resource use minerals and metals, Photochemical ozone formation and Particulate matter impact categories, the difference between SU and MU systems is mainly driven by the "use-phase transport" life-cycle stage, which is a hotspot for MU system.

2 Questions for Single-Use (SU) system

Why does the converting phase present very high contribution for the water consumption impact category?

The converting life cycle stage contributes around 35% to the water consumption impact category (by excluding credits[9]).

In this category, direct impacts are associated to the consumption of water within processes, while indirect impacts can be associated to the consumption of water in upstream processes, such as:

- the manufacturing of auxiliary products required in the converting process (e.g., inks, corrugated board boxes, plastic film for packaging), and
- the electrical energy use. This latter contributes mostly to the environmental emissions in this impact category.

The emissions are mainly driven by upstream processes of electrical energy production. For example, the impacts in this category associated to the European electricity grid mix are mainly driven by different indirect upstream processes, such as nuclear electricity production in pressure water reactors, or in electricity production by hydro power plants, or in heat and power co-generation plants (source: documentation of Ecoinvent 3.8).

Same for eutrophication? What is the reason?

The contribution of the converting life cycle stage to the eutrophication impact categories can be explained as for the Water consumption. Electrical energy consumption associated to the converting process is the main driver for these emissions. Impacts associated to the upstream processes until the production and distribution of energy to the converting plants are considered.

There are 3 categories of eutrophication in the study. Could you describe them?

[9] The percentage refers to all life cycle stages with the exception of credits from EoL (since they have a negative value and should be accounted separately)

The Environmental Footprint (EF) impact assessment method is used in the study. Eutrophication impact categories account for "eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilizers, combustion, sewage systems". These emissions are evaluated through three different categories for eutrophication[10]:

- Eutrophication, terrestrial, which accounts the accumulated exceedance of nitrogen in the soil.
- Eutrophication, marine, which accounts the fraction of nutrients reaching freshwater end compartment.
- Eutrophication, marine, which accounts the fraction of nutrients reaching marine end compartment.

3 Questions for Multiple-Use (MU) system

Transport back to the QSR seems to be particularly important?

The main contributor to the impacts of the multiple-use system is the use phase, i.e., the use phase transport (to take-back MU items to QSRs) and the washing of items. In particular, the use phase transport shows a contribution to overall results of MU system ranging from 77% (in *Ozone depletion* and *Resource use, minerals and metals* categories) to 20% (in *Water consumption* category).

Even though the average distance of a trip to take-back MU items is relatively short, impacts related to use phase transport can be explained by the high number of trips: every sale made by the QSR entails a trip (by means of car, scooter, bike, public transport or by walking). Every year a QSR makes thousands of transactions in the take-away selling channels[11], resulting in thousands of trips to take-back MU items.

For this reason, the sensitivity analysis included a specific scenario (S03) according to which 4/5 of total trips to return MU items are neglected, i.e., 4 out of 5 people returning MU items in case of buying of another menu), whose effect is able to turn the results in favour of MU system for Eutrophication marine, Eutrophication terrestrial, Ionising radiation, human health, and Ozone depletion categories, while for the 7 other impact categories SU system still present lower impacts. In this sense, it must be noted that considerations regarding take-back system of MU items and features of related trips (distance, multifunctionality (i.e., the fact that a trip is made specifically to return MU items or not), allocation of burdens (i.e., how to "assign" the impacts for multiple functions inside and outside the system boundaries)[12]) strongly depends on customers' behaviour and might represent a decisive factor when considering overall environmental performance of MU system.

The impact of the use phase transport varies significantly depending on the impact category considered: Could you give an explanation for this?

Among direct impacts, transportation is mostly associated with emissions of greenhouse gases, nitrous oxides (NOx) and particulates. In addition, there are also indirect impacts deriving from fuels and vehicles production. Consequently, these contributors can have a major effect in some impact

[10] Source: https://ec.europa.eu/environment/eussd/smgp/pdf/EF%20simple%20guide_v7_clen.pdf

[11] The exact figure has been gathered as primary data from QSRs operators and it is not disclosed due to confidentiality of the data.

[12] Allocation of burdens represent the process of assigning to each of the functions of a multiple-function system only those environmental burdens and impacts that each function generates (Azapagic and Clift, 1999).

categories such as *Photochemical ozone formation, Resource use, minerals and metals, Particulate matter, Climate change* and others.

What are the assumptions that you have taken for the washing phase?

For the baseline scenario, used MU tableware is assumed to be preliminary washed at home (i.e., preliminary washing phase) by customers and then professionally washed in-store by QSRs operators.

For preliminary washing, an average scenario is used to reflect different possible processes. It considers an equal share of handwashing, dishwashing, cold rinsing and dry wiping, and is applied to half of total items (50%) taken back to QSRs (with the exception of those bought by means of drive through, which are assumed to be returned directly after consuming food and beverages as conservative assumption).

Preliminary washing is not considered for MU items not returning to QSR (i.e., those for which the return rate does not apply).

For professional washing, washing, rinsing and drying processes are performed in QSR by means of hood-types dishwashers; inputs to these processes are based on literature values for water, energy, detergent and rinse agent demand. An average scenario for dishwashers is used to reflect different grades of devices' efficiencies.

Moreover, an average rewashing rate for all items of 10% is also considered: this assumption is to consider the presence of persistent residues that might remain after washing (Antony and Gensch, 2017). The presence of persistent residues is a peculiarity of take-away systems, since items could be returned in a long-time frame (e.g., weeks) after food consumption, which leads to food/beverages encrustations.

Have you considered external washing?

External washing has been tested through a sensitivity analysis as, according to QSR, this option is not to be considered relevant for the baseline scenario. Results shows that some environmental benefits can be obtained for the following impact categories:

1. *Ionising radiation*, whose impacts are associated mainly with electricity consumption. Since external washing entails the utilisation of more efficient dishwashers, MU system is able to perform environmentally better than SU in this category when considering this scenario.
2. *Eutrophication, freshwater* and *Water consumption*, whose impacts are associated both with electricity consumption and with direct water consumption. Since external washing entails the utilisation of more efficient dishwashers, MU system is able to match (for *Eutrophication, freshwater*) or almost match (for *Water consumption*) the environmental performance of SU system in this category when considering this scenario.

Why the impact of the washing phase varies significantly depending on the impact category considered?

Impacts associated with washing phase are predominantly driven by the electricity demand, as well as by water and chemicals demand and wastewater treatment. These aspects have different impacts in different impact categories, resulting particularly impacting in *Ionising radiation*, *Eutrophication, freshwater* and *Water consumption* impact categories.

There are some cases in the sensitivity analysis where MU is having a lesser impact than SU: could you explain why in those very specific cases?

The main differences in the sensitivity analysis are obtained when considering a variation in the take-back system of MU tableware: in the baseline, 1/2 trips to return MU items are neglected (multifunctional approach), while in the sensitivity only 1/5 trips to return MU items are considered (i.e., 4 out of 5 people return MU items in case of buying of another menu). This scenario is able to provide a variation in the results for some impact categories since the transport associated to take-back system of MU tableware is the hotspots of the MU system. Thus, reducing such transport has an effect in the reduction of overall impacts associated with MU system.

Other relevant variation of results for some impact categories are associated with the sensitivity scenario analysing the effect of external washing instead of washing in-store. When taking into account this scenario, some environmental benefits can be obtained for the following impact categories:

1. *Ionising radiation*, whose impacts are associated mainly with electricity consumption. Since external washing entails the utilisation of more efficient dishwashers, MU system is able to perform environmentally better than SU in this category when considering this scenario.
2. *Eutrophication, freshwater* and *Water consumption*, whose impacts are associated both with electricity consumption and with direct water consumption. Since external washing entails the utilisation of more efficient dishwashers, MU system is able to match (for *Eutrophication, freshwater*) or almost match (for *Water consumption*) the environmental performance of SU system in this category when considering this scenario.

References

ACEA – European Automobile Manufacturers' Association (2021) "Vehicles in use in Europe – January 2021". Available at: https://www.acea.auto/files/report-vehicles-in-use-europe-january-2021-1.pdf

Allen, J. *et al.* (2021) 'Understanding the transport and CO2 impacts of on-demand meal deliveries: A London case study', *Cities*. Elsevier, 108(September 2020), p. 102973. doi: 10.1016/j.cities.2020.102973.

Allen, J., Piecyk, M. and Piotrowska, M. (2018) 'AN ANALYSIS OF THE SAME-DAY DELIVERY MARKET AND OPERATIONS IN THE UK'. Available at: https://westminsterresearch.westminster.ac.uk/item/v3x35/an-analysis-of-the-same-day-delivery-market-and-operations-in-the-uk

Azapagic, A., and Clift, R. (1999). Allocation of environmental burdens in multiple-function systems. Journal of Cleaner Production, Volume 7, Issue 2, Pages 101-119. Doi: 10.1016/S0959-6526(98)00046-8

Corr, G. (2019) 'Food for Thought: the Rise of on-Demand Food Delivery Services and Growing Need to Switch These Journeys From Motors To Muscle, a Case Study of London'. Available at: https://tps.org.uk/public/downloads/FZBCJ/Food%20for%20thought%20the%20rise%20of%20on-demand%20%20food%20delivery%20services%20and%20growing%20need%20to%20switch%20these%20journeys%20from%20motors%20to%20muscle%20-%20G%20Corr.pdf

Federal Environment Agency Germany (2019) *Untersuchung der ökologischen Bedeutung von Einweggetränkebechern im Außer-Haus-Verzehr und mögliche Maßnahmen zur Verringerung des Verbrauchs*. Available at: https://www.umweltbundesamt.de/publikationen/oekologische-bedeutung-einweggetraenkebecher