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Exploring the environmental performance of alternative food packaging products in the European Union

Life cycle impacts of single-use and multiple-use packaging

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Contents

Abstract

The aims of this study are aligned with the EU's objectives of reducing the impacts of packaging waste, in line with its ambition to transition to a circular economy and with the objectives of the proposal for a new Packaging and Packaging Waste Regulation. Life Cycle Assessment (LCA) models, structured in accordance with the Environmental Footprint method, were used to establish benchmark results and to scrutinise the variability of parameters through sensitivity analyses.

The research incorporated six case studies, categorised into four scenarios. These studies evaluated the environmental impacts of both single use and multiple use packaging products, including packaging used in the hotel, restaurant and catering sector, such as cups, trays, beverage containers, and glass bottles used for alcoholic and non-alcoholic beverages. In addition, the study assessed the environmental performance of single use and multiple use packaging in a dine-in restaurant case study.

The LCA results revealed that the performance of the packaging products varied, depending on the specific case study and Environmental Footprint impact category evaluated, with single use and multiple use packaging products demonstrating either lower or higher impacts. Benchmark scenarios focusing on single use takeaway carton packaging showed that it had a lower Climate Change impact than its multiple use counterpart. However, the latter manifested a lower Water Use impact and a slightly lower aggregated Single Score. Conversely, scenarios assessing the environmental performance of glass bottles and the dine-in restaurant scenario consistently showed that multiple use packaging products had lower impacts across most impact categories and the majority of the sensitivity analysis simulations.

A further examination, involving the use of different life cycle datasets for cartonboard manufacturing, highlighted the large influence of these datasets on the final LCA results for single use packaging. In particular, when considering life cycle datasets for cartonboard with low environmental impacts, the performance of single use packaging was clearly better, especially for the Water Use impact category, and also to a lesser extent for the Climate Change impact category and the aggregated Single Score. Notably, the study identified additional relevant aspects (and assumptions) that could affect the performance of single use and multiple use packaging products, particularly those related to consumer behaviour regarding the return of multiple use packaging to the point of sale, the number of reuses and the impact of washing operations (for multiple use packaging).

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Executive summary

This study aims to support the EU's goals of reducing the impacts of packaging and packaging waste and to address the knowledge gaps identified in existing literature on the topic. The present Joint Research Centre (JRC) study assesses the life cycle environmental performance of a selected group of case studies. These studies were chosen specifically to focus on certain reuse targets set in the proposal for a Packaging and Packaging Waste Regulation.

The research was conducted with reference to the modelling and impact assessment as in the Environmental Footprint method, which quantifies 16 impact categories, including Climate Change and Water Use, and also considers an aggregated Single Score index. The model developed by the JRC incorporated several parameters to calculate 'benchmark' results for the scenarios considered. Subsequently, a sensitivity analysis was conducted to assess the degree to which the model and results depended on a number of parameters.

Policy context

The 1994 Directive addressing packaging and packaging waste management was amended in 2018 with revised measures aimed at transitioning towards a circular economy. These measures focus on preventing the production of packaging waste and promoting the reuse, recycling and other forms of recovery of packaging waste. In November 2022, the Commission proposed a revision of the 2018 Directive in alignment with the objectives of the European Green Deal and the 2020 New Circular Economy Action Plan and the commitments of the 2018 European Plastics Strategy. The proposal for a Packaging and Packaging Waste Regulation (PPWR) is also aligned with the 2022 United Nations 2030 Agenda for Sustainable Development. It specifically addresses Sustainable Development Goal target 12.5 because of the suggested reductions in waste generation through preventive measures and improvements in waste reduction, recycling and product reuse.

The aim of the present study is to bring new scientific evidence that is potentially relevant in the context of the 2022 PPWR. In particular, the proposal included measures aimed at reducing packaging waste and restricting over-packaging by setting out mandatory reuse targets – set for 2030 and 2040 – for economic operators in selected packaging groups.

Key conclusions

The findings from the present analysis underscore the importance of identifying and, potentially, optimising key parameters to enhance the life cycle performance of the packaging products assessed. Specifically, user behaviour significantly impacts the environmental performance of takeaway multiple use packaging products, particularly regarding the mode of transport used to return used packaging to retail points or washing facilities. This issue, however, is not relevant in the case of the dine-in restaurant scenario. Unlike takeaway meals, the dine-in option eliminates the need for transport to return the multiple use packaging. Furthermore, it allows a significantly higher number of reuses, as the multiple use packaging remains under the constant supervision of the restaurant operators, thereby minimising losses due to improper handling by users.

In addition, washing practices such as rinsing and rewashing can significantly affect the environmental performance of multiple use packaging products, especially when hot water is used. Impacts related to electricity usage are also significant for certain impact categories such as 'Resource Use, Fossil'. Hence, transitioning towards a cleaner energy mix could be instrumental in reducing these environmental pressures.

The analysis also focused on how the performance of the packaging studied depended on assumptions about recycled content and its recyclability at the end-of-life stage, with the latter playing a more prominent role in driving overall performance than other parameters, such as transport distances (e.g. transport distances from the manufacturing plant to the point of sale). The estimated number of reuses for multiple use packaging is naturally a key driver in the product's life cycle performance. However, assumptions about the number of reuses are crucial in scenarios that consider only a few rotations (e.g. as in the scenarios related to takeaway cups or trays). In the case of scenarios with much higher numbers of reuses (e.g. as in the dine-in restaurant scenario), increases in the number of rotations beyond a certain threshold have less influence than those below the threshold according to the results of the sensitivity analysis.

Main findings

The analysis of single use and multiple use packaging products yielded varying results depending on the specific scenario and case studies considered, as well as the impact category assessed. Scenarios examining cups, trays and beverage containers showed similar results for single use and multiple use packaging products, with either displaying lower environmental impact depending on the impact category. In particular, in the benchmark results for takeaway cups and trays, single use packaging exhibited lower life cycle impacts for certain impact categories (e.g. Climate Change), while multiple use packaging products exhibited lower life cycle impacts for other categories (e.g. Water Use). The results of the sensitivity analysis for the aggregated Single Score index suggested comparable life cycle impacts, with a majority of the simulations leading to lower life cycle impacts for the multiple use packaging only for the cups scenario.

In contrast, scenarios assessing glass bottles and restaurant meals consistently showed lower environmental impacts for multiple use packaging than for single use alternatives for almost all the assessed impact categories.

Further additional analyses considered various life cycle datasets related to cartonboard production, including an Environmental Footprint dataset and datasets retrieved during the stakeholder consultation. In particular, when considering life cycle datasets for cartonboard with low environmental impacts, the performance of single use packaging was clearly better, especially for the Water Use impact category, and also to a lesser extent for the Climate Change impact category and the aggregated Single Score. However, cartonboard datasets were provided as fully aggregated datasets without accompanying documentation and metadata, and therefore it was not possible to assess their compliance with the Environmental Footprint method and their overall consistency with other datasets used in the study.

The study also identified a significant number of factors (and assumptions) that can influence the performance of single use and multiple use packaging products. Among these, assumptions about consumer behaviour (particularly regarding the return of multiple use packaging to the point of sale), the number of reuses and washing operations (for multiple use packaging) and assumptions about the mass and recyclability of materials (especially for single use packaging) are especially pertinent.

Related and future JRC work

The present report is the deliverable of a JRC project supporting the development of scientific evidence for the Circular Economy Action Plan. It relates to several work streams of the JRC and other services of the European Commission. It is also related to JRC’s continuous research on the methodological improvement of the Environmental Footprint method and its use and implementation in EU policies.

1 Introduction

1.1 Packaging reuse in Europe

In recent years, the concept of reusable packaging has been discussed as a viable means of reducing environmental impacts and meeting climate targets. However, recent analysis showed a general decrease in multiple use packaging penetration in the EU market for the year 2018 compared with 1999 (Eunomia, 2022). Packaging is undeniably essential for the protection, transport and, in some cases, consumption of goods. At the same time, concern is increasing among the public and policymakers about their potential environmental impacts in terms of waste production and overall life cycle impacts (EC, 2018a, 2019). The prevailing business model of low reuse and low recycling of packaging could present a barrier to establishing circular economies in the EU (EC, 2022). A circular economy for packaging could facilitate the decoupling of natural resource use from economic development and aid the EU in achieving its climate neutrality target by 2050. In recent years, the regulation of packaging and packaging waste has been at the forefront of EU policy actions. In 1994, the European Parliament put forward a Directive (EC, 1994) tackling the management of packaging and packaging waste, with the aim of improving the quality of the environment by preventing and reducing the impact of packaging and packaging waste on the environment. That directive was last amended in 2018 (EC, 2018b) with updated measures to achieve a circular economy, such as measures to prevent the production of packaging waste and to promote the reuse, recycling and other forms of recovery of packaging waste. In November 2022, the Commission proposed a revision of the 2018 Directive in view of the objectives of the European Green Deal (EC, 2019) and the New Circular Economy Action Plan (EC, 2020) and the commitments of the European Plastics Strategy (EC, 2018a). This 2022 proposal (EC, 2022), referred to in this report as the proposal for a Packaging and Packaging Waste Regulation (PPWR), not only included measures devoted to packaging waste reduction and restriction of over-packaging but also proposed mandatory reuse targets (for the years 2030 and 2040) for operators in selected packaging groups. The proposed PPWR is also aligned with the United Nations 2030 Agenda for Sustainable Development (UNEP, 2022), particularly regarding Sustainable Development Goal target 12.5, because of its proposed reductions in waste generation through preventive measures, improvement in waste reduction measures, and product recycling and reuse.

1.2 State of the art on packaging reuse

In 2020, the amount of packaging waste generated was estimated to be 177.9 kg per EU inhabitant (Eurostat, 2023). From 2009 to 2020, ‘paper and cardboard’ was the main packaging waste material generated in the EU (32.7 million tonnes in 2020), followed by plastic and glass (15.5 million tonnes and 15.2 million tonnes, respectively, in 2020) (Eurostat, 2023). As the amount of single use packaging continues to rise, that puts pressure on the current EU waste management system. Although certain single use packaging products can be recycled, the presence of complex materials (e.g. involving layers of different material within the same product) and the lack of proper management infrastructures can hamper the quality and amount of recycled materials at the end of their life (Grant et al., 2020; Antonopoulos et al., 2021; Zero Waste Europe, 2022).

Understanding the best approaches to tackling packaging waste is a complex task, especially considering the increasing popularity of food deliveries and takeaway food. This trend was further amplified during the COVID-19 pandemic, intensifying the urgency to find solutions to this growing environmental issue. Despite these challenges, it is crucial to investigate strategies that would enable the packaging value chain to operate more efficiently and mitigate its environmental impacts in a life cycle perspective. In recent years, it has been recognised that reducing the quantity of single use packaging, combined with an increase in the use of reusable containers, could serve as a promising strategy for improvement (Hitt et al., 2023). However, the environmental performance of reusable packaging products has proven to be largely affected by assumptions for certain life cycle stages, for instance the washing phase, potentially offsetting their benefits compared with single use alternatives (Fetner and Miller, 2021). The existing literature comparing single use and multiple use packaging products lacks consistency particularly concerning (i) the methodological approaches used to compare single use and multiple use packaging (i.e. with different studies assessing different system boundaries including/excluding specific life cycle phases), (ii) the heterogeneity and often non-comparability of the approaches used to conduct the environmental life cycle assessments of the systems in the studies, (iii) the limited range of environmental impact indicators covered, usually focusing solely on Climate Change, and (iv) the lack of sensitivity analyses on key model parameters, especially for highly uncertain input data. For instance, although transport of takeaway packaging products (especially by car) during the use phase plays a key role in the environmental performance of multiple use packaging, there is no consensus on how these impacts should be accounted, and they have also been neglected in certain studies (Gallego-Schmid et al., 2019; Greenwood et al., 2021). In addition to the washing phase, customer behaviour during the use phase of refillable or returnable containers and packaging has been recognised as a key determinant of the impacts of multiple use packaging (Coelho et al., 2020; Hitt et al., 2023).

1.3 Objectives and scope of the study

The Joint Research Centre (JRC) has been commissioned by the European Commission's Directorate-General for Environment to evaluate the life cycle environmental performance of a selected subset of case studies, targeting certain reuse targets of the PPWR. The present study aims to contribute to fulfilling the EU's ambitions to reduce plastic packaging waste and to address some of the knowledge gaps identified in the existing literature on the subject.

In particular, the present study focuses on the targets in Article 26 of the PPWR on reuse and refill targets, which states the following.

- "The final distributor making available on the market within the territory of a Member State in sales packaging cold or hot beverage filled into a container at the point of sale for takeaway shall ensure that: (a) from 1 January 2030, 20 % of those beverages are made available in reusable packaging within a system for re-use or by enabling refill; ….";
- "A final distributor that is conducting its business activity in the HORECA [hotel, restaurant and Catering] sector and that is making available on the market within the territory of a Member State in sales packaging take-away ready-prepared food, intended for immediate consumption without the need of any further preparation, and typically consumed from the receptacle, shall ensure that: (a) from 1 January 2030, 10 % of those products are made available in reusable packaging within a system for re-use or by enabling refill; ….";
- "The manufacturer and the final distributor making available on the market within the territory of a Member State in sales packaging alcoholic beverages in the form of beer, carbonated alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, products based on spirit drinks, wine or other fermented beverages mixed with beverages, soda, cider or juice, shall ensure that: (a) from 1 January 2030, 10 % of those products are made available in reusable packaging within a system for re-use or by enabling refill; ….";
- "The manufacturer and the final distributor making available on the market within the territory of a Member State in sales packaging alcoholic beverages in the form of wine, with the exception of sparkling wine, shall ensure that: (a) from 1 January 2030, 5 % of those products are made available in reusable packaging within a system for re-use or by enabling refill; ….".

In addition, the study focuses on Article 22, Annex V.3, for the following target stipulating that:

- "… economic operators should not place on the market packaging in the formats and for the purposes listed in Annex V …," implying a switch to 100 % reusable packaging in the dine-in HORECA sector.

Each of the abovementioned PPWR targets is tackled in the present study by analysing a number of 'Scenarios'. For each of these PPWR Scenarios, one or more illustrative case studies were hypothesised, and for each case study key data and parameters were collected. The case studies focused on assessing the Life Cycle Environmental (LCA) impacts of Single Use (SU) packaging products and of possible alternative Multiple Use (MU) products. Part of the analysis aimed to understanding how the reusable packaging could be modelled to also reflect how consumers and operators might behave when (re)using such packaging.

In the present analysis, results were calculated for the 16 impact categories and the Single Score index, as recommended by the Product Environmental Footprint method (EC 2021a). The study produced a series of results on (i) the environmental performance of MU and SU packaging calculated with reference to assumed 'representative' values for a number of parameters (referred in this study as 'benchmark' parameters/results), (ii) a sensitivity analysis to assess the variation of results as determined by a number of parameters studied (assumed to be varying within defined ranges), and (iii) a set of additional specific analyses for certain Scenarios.

Case studies of life cycle assessments of SU and MU packaging products are presented, discussing the most relevant methodological aspects (including modelling steps, key assumptions and main limitations). Lessons learnt from the study are also discussed, including how to further increase representativeness of the models and how to shed light on the most critical aspects of the case studies.

This report focuses on selected illustrative case studies, which are not designed to offer definitive estimates of the environmental impacts or benefits linked to the PPWR targets. The case studies are instead product-specific analyses, rather than system-level evaluations. The analyses have been performed by compiling the results of LCA, based on primary data from stakeholders and data from the scientific literature. This compilation may serve discussion about which scenarios, and under which assumptions, certain MU or SU packaging use may have lower environmental impacts.

The report is structured as follows:

- Section 2 describes the methods employed for the identification of the case studies for each Scenario, the literature review and the stakeholder consultation, which were carried out to gather relevant data, and the details of the LCA of the environmental performance of the SU and MU packaging. Annexes 1 and 2 provide further details of the stakeholder consultation and the datasets used in the analysis, respectively;
- Section 3 provides the results of the LCA and sensitivity analyses of the case studies. Annex 3 contains further details on the results of each Scenario. In particular, Annex 3 is structured as a number of Factsheets that provide full details of the modelling assumptions and parameters, values and ranges employed for each case study and each packaging product examined;
- Section 4 discusses the results and assumptions of the case studies and compares them with those in the literature, highlighting strengths and limitations of the present study;
- Section 5 provides conclusions of the study.

2 Methods

This section details the method used in the study to quantify the environmental impacts of the selected Single Use (SU) and Multiple Use (MU) packaging case studies. In particular, this section provides:

- a description of the Scenarios and how they relate to the PPWR targets (Section 2.1);
- a literature review and explanation of how the representative case studies were identified for each Scenario assessed (Section 2.2);
- an overview of the stakeholder consultation carried out by the JRC (Section 2.3);
- the methodology of the Life Cycle Assessment (LCA) of the representative case studies (as identified in point 2), including data collection (Section 2.4);
- the sensitivity analyses conducted on the representative case studies (by means of a Monte Carlo simulation and the analysis of additional/alternative case studies) (Section 2.5).

2.1 Scenarios definition and their relationship with targets in the Regulation

This study aims to assess the potential environmental impacts of SU and MU packaging in the context of the targets described in the PPWR, focusing in particular on the reuse and refill targets described in Article 26 of the PPWR for the year 2030. In this report, each of these targets represents a 'Scenario' under which some representative case studies have been identified and assessed. The relationship between the Scenarios of the present study and the PPWR targets are as follows:

- 'Scenario 1': covers packaging for cold or hot beverages served in a container at the point of sale for takeaway;
- 'Scenario 2': covers packaging for takeaway ready-prepared food intended for immediate consumption without the need for further preparation;
- 'Scenario 3': covers the packaging for alcoholic and non-alcoholic beverages in the form of beer, carbonated alcoholic and non-alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, etc.;
- 'Scenario 4': covers the packaging for alcoholic beverages in the form of wine, with the exception of sparkling wine;
- the 'Restaurant Scenario': focuses on the use of packaging by economic operators in the dine-in HORECA sector.

The analysis of each 'Scenario' is conducted at the case study packaging product level.

Additional analyses, beyond the scope of the current analysis, could be dedicated to the assessment of the PPWR targets at the system level. This would use market data on the SU packaging products in use in the EU for each Scenario and all possible MU alternatives. To date, a detailed inventory of such Scenarios and all the underpinning data are lacking in the literature (due to the wide array of SU and MU packaging products and materials available). This study also does not investigate the economic viability or convenience of SU and MU packaging products.

2.2 Identification of case studies

By means of an in-depth literature review, a set of SU packaging products currently employed in the market for the abovementioned Scenarios was identified. The literature review targeted both scientific publications and reports assessing the environmental impact of different packaging alternatives used for serving food and beverages for takeaway or in-store consumption.

For the analysis of each Scenario, a limited subset of all potential SU packaging products was selected. The selection of case study packaging products was primarily driven by the availability of studies in the literature and, ultimately, by the availability of sufficient data to carry out the analysis. The lack of extensive market data for the packaging used in each Scenario reduced the ability to define fully representative SU packaging products. Therefore, the environmental analysis of the selected case study packaging products can only partially inform the consideration of all the packaging in that specific Scenario.

However, alternative MU packaging products were assumed for each of the selected SU packaging products based on the authors' expert judgement from information available in the literature and subsequently verified during a stakeholder consultation. In a similar way, the MU packaging products studied represent only some of the potential alternatives that could be envisaged in the future and cannot be considered fully representative of a certain Scenarios. Moreover, the authors acknowledge that the use of MU packaging in the market is still limited. The assumptions made for the LCA of MU packaging need to be verified in future when reuse systems are fully developed. To capture the variability of these systems, in Section 2.5 an extensive sensitivity analysis was performed, focusing on all the parameters identified as key drivers of the results.

Table 1 summarises the case studies analysed for each Scenario (including additional case studies for each Scenario, called 'CASEs'), detailing the SU and MU packaging products considered.

The Restaurant Scenario partly relies on the packaging products modelled in 'Scenario 1' and 'Scenario 2'. However, for the dine-in Scenario, beverage cups are usually used without a lid (2), so the lid has been excluded from the analyses of both SU and MU beverage cups modelled in the 'Restaurant Scenario'. Based on stakeholder feedback (Section 2.3), low-density polyethylene (LDPE) lining has also been excluded from SU trays in the 'Restaurant Scenario'. Furthermore, the SU carton trays used in the 'Restaurant Scenario' for hamburgers and fries are the same as the same as those used in 'Scenario 2 – CASE A' but scaled to the correct size (i.e. the volume and mass are smaller than those used in 'Scenario 2'). Finally, the MU polypropylene (PP) plate is considered only in the 'Restaurant Scenario'.

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(2) Based on the authors' direct observations in various fast-food restaurants, plastic lids are occasionally still used for dine-in services, particularly when a straw is used with the cup. However, according to feedback from some stakeholders, the use of lids in dine-in services is expected to be phased out gradually.

Table 1. Overview of the real-life case studies considered for each Scenario.

Scenario	**Case study**	**Single Use**	**Multiple Use**	**Additional details**
'Scenario 1'	-	Carton Cup with Low Density Polyethylene (LDPE) lining and carton lid (0.5 l)	Polypropylene (PP) cup with PP lid (0.5 l)	This Scenario covers packaging for cold or hot beverages served in a container at the point of sale for takeaway. The volume of the packaging assessed is equal to 0.5 l.
'Scenario 2'	'CASE A'	Carton tray with LDPE lining	PP clamshell tray	This Scenario covers packaging for takeaway ready-prepared food, intended for immediate consumption without the need for further preparation. The volume of the packaging assessed is 1.1 l.
	'CASE B'	Aluminium tray and carton cover with LDPE lining	PP clamshell tray	
'Scenario 3'	'CASE A'	Aluminium can (0.5 l)	Polyethylene terephthalate (PET) plastic bottle with PP cap (0.5 l)	This Scenario covers the packaging for alcoholic and non-alcoholic beverages such as beer, carbonated alcoholic and non-alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine. The volume of the packaging assessed is 0.55 l.
	'CASE B'	Glass beer bottle (0.5 l)	Glass beer bottle (thicker) (0.5 l)	
'Scenario 4'	-	Glass wine bottle (0.75 l)	Glass wine bottle (thicker) (0.75 l)	This Scenario covers the packaging for alcoholic beverages in the form of wine, with the exception of sparkling wine. The volume of the packaging assessed is equal to 0.75 l.
'Restaurant Scenario'	'Hamburger meal'	Single use hamburger meal composed of: ▪ A carton cup (with LDPE lining) for the drink ▪ A carton tray without LDPE lining for the hamburger ▪ A carton tray without LDPE lining for the fries	Multiple use packaging for hamburger meal composed of: ▪ A PP cup for the drink ▪ A PP plate with sections for both the hamburger and fries	This Scenario focuses on the use of packaging by dine-in operators in dine-in restaurants. For this Scenario, dedicated and specific assumptions on the masses and volumes of the various packaging products have been included (as detailed in Factsheet for the 'Restaurant Scenario' of Annex 3).

Source: JRC analysis of the literature and websites.

2.3 Stakeholder consultation

In October 2023, the JRC conducted a brief stakeholder consultation to collect feedback on the selected case studies and to collect primary data to model them. This additional methodological step was conducted to improve data quality, refine and critically review the data collected and improve the robustness of the results through the stakeholder inputs.

A questionnaire was prepared in Microsoft Excel and distributed to selection of stakeholders (3) to simplify the data collection and processing. The questionnaire included all seven case studies described in Table 1 by preparing specific tables devoted to checking the assumptions and data used in the initial analysis and gathering stakeholder data that were suitable for improving the modelling. These tables were structured to allow inputs from stakeholders in terms of data, ranges and references. By the end of the consultation period (4), 13 stakeholders had provided inputs, of which 8 provided inventory data in Excel, while other 5 referred to other studies and documents that could be useful in this study. All data received were carefully analysed and considered for the modelling of the case studies where possible. Further follow-up exchanges with some stakeholders and further data gathering and refinement was conducted until mid-December 2023. Annex 1 provides further details on the stakeholder consultation and an example of the tables used for data gathering.

2.4 Life cycle assessment of the selected case studies

The LCA method is increasingly being adopted for the assessment of the environmental impacts of products and value chains. Following the definition provided by the International Organization for Standardization (ISO) standard (ISO 14044:2006, ISO 14040:2006), LCA is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle. In the impact assessment phase of LCA, the results of the inventory analysis are associated to environmental impact categories and indicators through Life Cycle Impact Assessment (LCIA) methods, which firstly classify emissions into impacts categories (e.g. Climate change) and secondly characterise them in common units allowing comparison within the same impact category (e.g. kilograms of carbon dioxide equivalent: kg CO_2 eq.).

In the present study, the environmental impacts of each Scenario were assessed using the attributional LCA approach (5), following the rules of the European Product Environmental Footprint (PEF) method, as described in the EU Recommendation (EC, 2021a) and by modelling the end-of-life environmental impacts in accordance with the Circular Footprint Formula (EC, 2021b) (Section 2.4.4).

The PEF enables practitioners to measure the environmental performance of products based on reliable environmental information. The PEF method provides detailed instructions on how to model and calculate the environmental impacts of products and organisations. The modelling of the Scenarios was performed in Microsoft Excel employing EF3.1 datasets and the EF3.1 impact assessment method (6) (Andreasi Bassi et al., 2023). The resulting environmental impacts were also Normalised and Weighted in order to calculate the EF Single Score (SS), that is an index allowing the different environmental impacts of products or Scenarios to be aggregated and facilitates decision-making (7). Further details on the impact assessment approach are provided in Section 2.4.5.

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(3) The Directorate-General for Environment provided suggestions for potential recipients of the questionnaire, primarily including associations of manufacturers and some non-governmental organisations. These stakeholders were then encouraged to further distribute the questionnaire to other organisations that might be interested.

(4) From 11.10.2023 to 31.10.2023.

(5) According to UNEP-SETAC (2011), the attributional approach attempts to provide information on what portion of global burdens can be associated with a product (and its life cycle). The system analysed ideally contains processes that are actually directly linked by flows to the unit process that supplies the functional unit or reference flow.

(6) Namely [unit]: Climate Change (kg CO_2 eq.); Ozone Depletion Potential (kg CFC-11 eq.); Human Toxicity, cancer (CTUh); Human Toxicity, non-cancer (CTUh); Particulate Matter (disease incidences); Ionizing Radiation, human health (kBq U235 eq.); Photochemical Ozone Formation, human health (kg NMVOC eq.); Acidification (mol H^+ eq.); Eutrophication, Terrestrial (mol N eq.); Eutrophication, Freshwater (kg P eq.); Eutrophication, Marine (kg N eq.); Land Use (points (pt)); Ecotoxicity, Freshwater (CTUe); Water Use (m^3 water eq. of deprived water); Resource Use, Fossils (MJ); and Resource Use, Minerals and Metals (kg Sb eq.).

(7) Although the Normalisation, Weighting and aggregation of different impact categories is considered an optional step in ISO 14044, the calculation of the Single Score is recommended by the EU Environmental Footprint methods.

The following sections detail the LCA method and the assumptions used in the study to quantify the environmental effects (i.e. the ‘burdens’ or ‘savings’ (8)) of the case studies under consideration.

2.4.1 Functional Unit

The ISO standards define the Functional Unit (FU) as a quantifiable function of a product selected as the reference basis for system modelling in environmental assessment. The Functional Unit of the packaging product systems studied depends on the Scenario under assessment. In particular:

- For ‘Scenario 1’ the FU selected was ‘one serving of hot or cold takeaway beverage’;
- For ‘Scenario 2’ the FU selected was ‘one serving of takeaway food purchased from the restaurant or using home delivery’.
- For ‘Scenario 3’ the FU selected was ‘one bottle of alcoholic or non-alcoholic beverage purchased from retail and consumed at home’.
- For ‘Scenario 4’ the FU selected was ‘one bottle of wine purchased from retail and consumed at home’;
- For the ‘Restaurant Scenario’ the FU was ‘one meal consumed in the restaurant, taking into account packaging for both food and drink’.

2.4.2 Temporal and technological scope

The temporal and technological scope of this report focuses on analysing scenarios pertinent to the current European situation. The decision to employ models that reflect the current market situation at the time of conducting the LCA study, as opposed to future technologies, is endorsed by the EF method. As recognised by Cucurachi et al. (2022), predicting the future development of complex systems, such as those in which technologies are integrated, is a well-known challenge in prospective LCA, which can only be addressed through bespoke modelling and analysis.

The available EF3.1 datasets were employed to represent the ‘status quo’ of the modelled packaging products and their associated life cycle impacts. This approach was consistently applied to both the SU and MU packaging assessed. Because of the limited data currently available and the uncertainties surrounding future scenarios for packaging products, a sensitivity analysis was conducted on key model parameters (e.g. aspects that could change as a result of future technological advances, such as recycling rates and energy mixes).

2.4.3 System boundaries

The system boundaries of the Scenarios under assessment are described in this section, grouping Scenarios modelled with the same system boundary structure. System boundaries reflect the life cycle of the (whole) packaging products under examination in the case studies. When multi-material packaging was assessed (e.g. a carton cup with LDPE lining and carton lid in ‘Scenario 1 – CASE A’), the specific fate of each material was considered within the system boundaries described (e.g. contrary to the carton part, the LDPE lining of the cup considered in ‘Scenario 1 – CASE A’ was assumed not to be recycled). Dedicated Factsheets are included in Annex 3 and include the details of the system boundaries for each case study.

Information in this section is presented in parallel for SU and MU packaging to allow a rapid understating of the differences in the system boundaries of the two packaging products under study. The analysis covered the whole life cycle of SU and MU packaging, including the manufacturing stage (which focused on raw material sourcing, production of the components of the products and manufacturing of the final packaging product), the transport stage (covering transports from manufacturing site to point of sale), the reuse stage (only for the MU packaging product, including transport and washing operations) and the end-of-life stage (covering recycling, incineration and landfill).

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(8) In LCA, ‘burdens’ indicate the environmental pressures coming directly from the activities under analysis or indirectly from the background system related to production, transport, auxiliary processes, etc., needed to carry out the activities under analysis. The ‘avoided burdens’ (known as ‘savings’), indicate the environmental ‘credits’ (i.e. avoided impacts) obtained through avoiding the production of material and use of energy thanks to the activities under analysis.

In particular, the setting of the system boundaries for the packaging product systems studied assumed the following (9):

- In 'Scenario 1' (Figure 1) and 'Scenario 2' ('CASE A' and 'CASE B'; Figure 2), the raw materials are first produced and then transported to the manufacturing facility, where the final packaging products are manufactured. Following this stage, the products are first transported to a distribution centre, and from there to the point of sale, where the products are sold for their intended purpose. After the use phase, which is assumed free of burdens, SU packaging products are assumed to be discarded and reach the end-of-life stage, during which they are recycled, incinerated or landfilled. In the case of MU, the packaging products need to be returned to the point where they were bought. Based on consumer behaviour, this transport step could take place in different ways (e.g. on foot, by bike, by passenger car). The returned packaging products are washed and given to a new user a number of times ('number of reuses') after which they reach the end-of-life stage, during which they are recycled, incinerated or landfilled;
- In 'Scenario 3' ('CASE A' and 'CASE B'; Figure 3) and 'Scenario 4' (Figure 4), the packaging products are firstly manufactured (employing virgin and recycled raw materials) and then transported to the facility where the bottles or cans are filled. Following this stage, the products are transported first to a distribution centre and then to a retail outlet, where the products are sold for their intended purpose. After the use phase, which is assumed free of burdens, the SU packaging products are assumed to be discarded and reach the end-of-life stage, during which they are recycled, incinerated or landfilled. In the case of MU packaging, it needs to be collected to be washed and sanitised. Afterwards, the empty MU packaging may be brought back to the filling facility to be reused. After a certain amount of reuses, the MU packaging reaches the end-of-life stage, during which it is recycled, incinerated or landfilled.
- In the 'Restaurant Scenario' (Figure 5), the raw materials are firstly produced and then transported to the facility where the final packaging products are manufactured. Following this stage, the products are transported to a distribution centre and then to the restaurant for their intended purpose. In the case of SU packaging, it is assumed to be discarded after use and reach the end-of-life stage, when it is recycled, incinerated or landfilled. In the case of MU packaging, it is assumed to be collected at the restaurant after use (dine-in) and washed properly by restaurant staff within the restaurant facility. After a certain amount of reuses, the MU packaging products reach the end-of-life stage, during which they are recycled, incinerated or landfilled.

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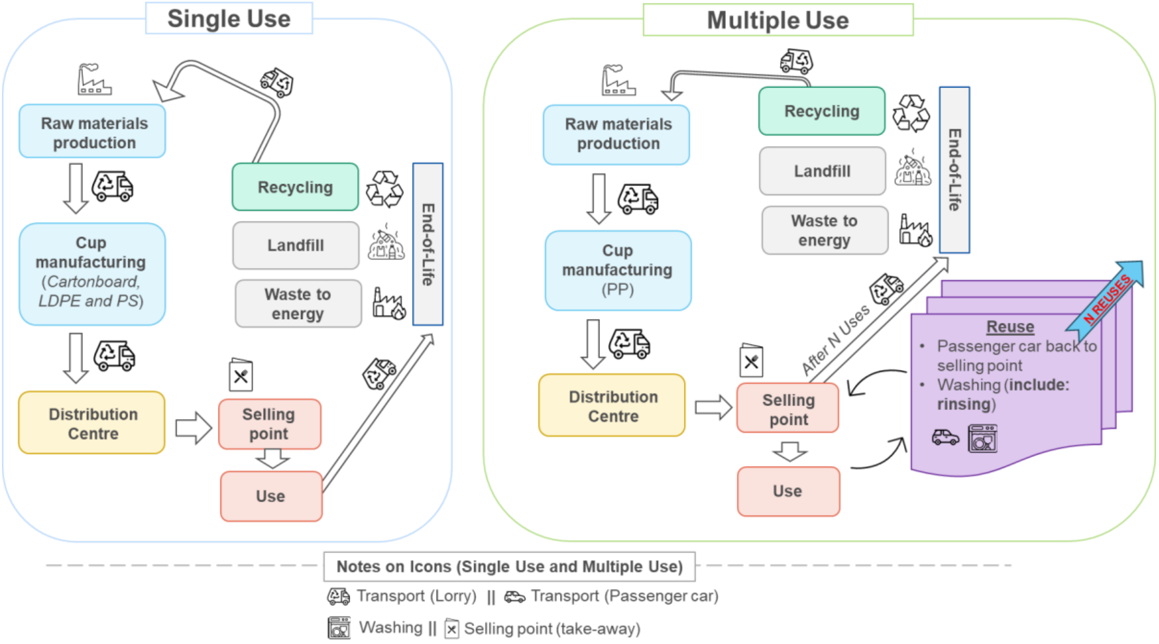
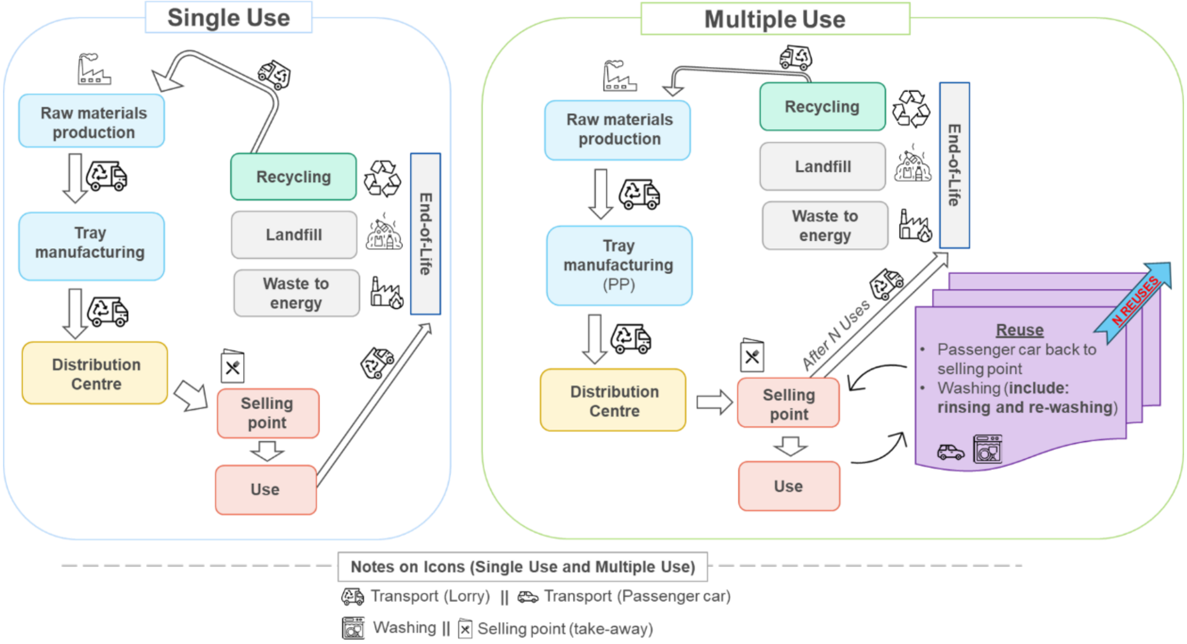
(9) Further information is provided in the Factsheets for each case study in Annex 3.

Figure 1. Single Use and Multiple Use system boundaries for case studies in 'Scenario 1'.



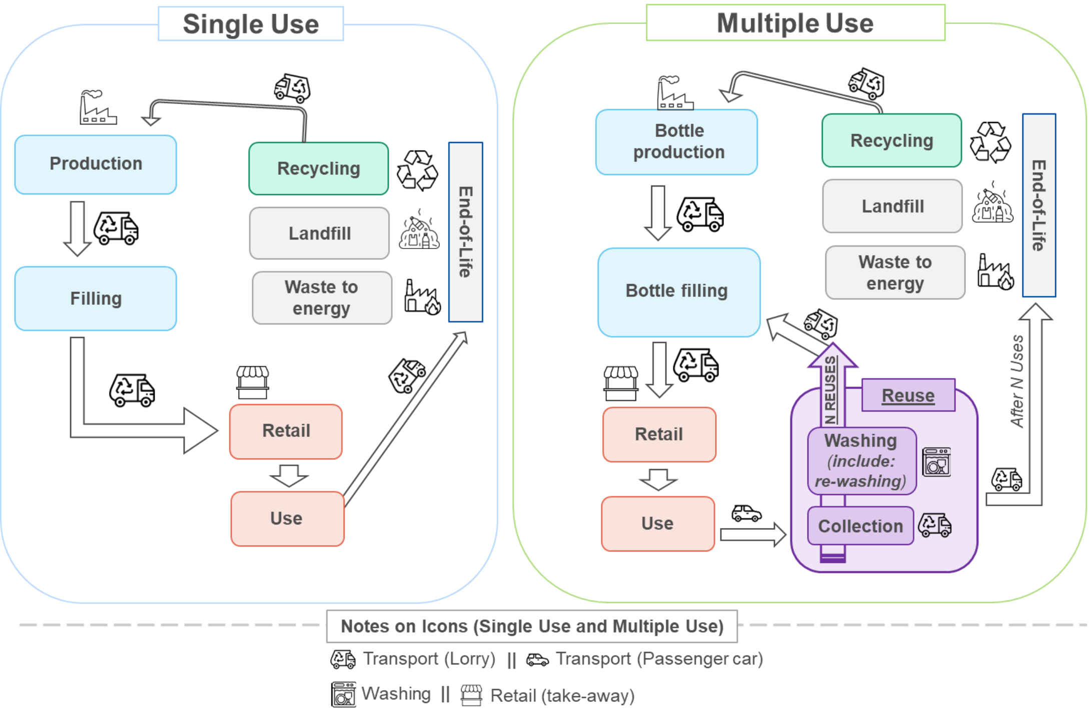
Source: JRC analysis.

Figure 2. Single Use and Multiple Use system boundaries for case studies in 'Scenario 2'.



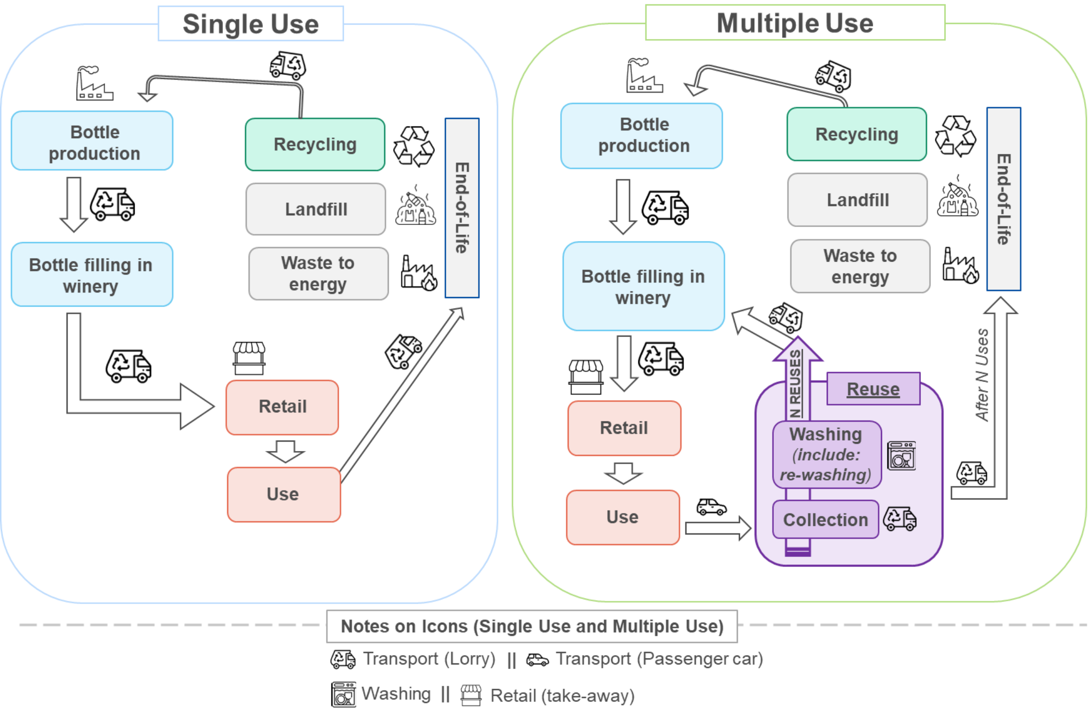
Source: JRC analysis. Note: The single use system boundaries are the same for the case studies 'CASE A' ('Single use carton tray (1.1 l) with LDPE lining') and 'CASE B' ('Single use aluminium tray (1.1 l) with carton cover').

Figure 3. Single Use and Multiple Use system boundaries for case studies in 'Scenario 3'.



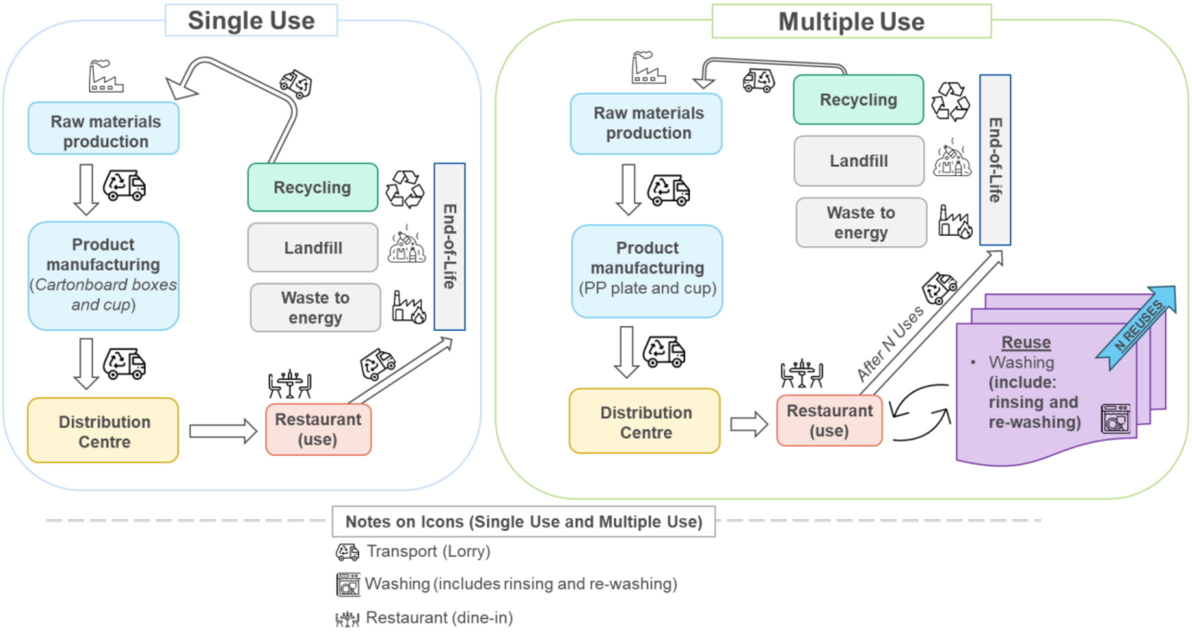
Source: JRC analysis. Note: The single use system boundaries are the same for the case studies 'CASE A' ('Single use aluminium beverage can (0.5 l)') and 'CASE B' ('Single use beer/beverage glass bottle (0.5 l)'). The MU multiple use system boundaries are the same for the case studies 'CASE A' ('Multiple use beverage plastic bottle (0.5 l)') and 'CASE B' ('Multiple use beer/beverage glass bottle (0.5 l)') .

Figure 4. Single Use and Multiple Use system boundaries for case studies in 'Scenario 4'.



Source: JRC analysis.

Figure 5. Single Use and Multiple Use system boundaries for case studies of the 'Restaurant Scenario'.



Source: JRC analysis.

2.4.4 Life cycle inventory

Following the selection of the case studies, the literature was reviewed to gather life cycle inventory data for the SU and MU models, as described in Section 2.2.

In the present report, the term ‘parameter’ is used to identify aspects of the packaging products’ life cycle for which inventory data have been collected. The data collection aimed to gather average values for the parameters (and to assess their variability, which is needed to model the life cycle of the SU and MU packaging products for each Scenario). The term ‘benchmark value’ is used for a certain parameter value (or for life cycle inventory datasets) to indicate the ‘reference value’ assumed for that specific parameter in the context of a given Scenario (i.e. the value that evidence suggests is representative of a certain Scenario for the EU). Benchmark values were identified from peer-reviewed literature, official reports, statistics and data provided by the stakeholders. Benchmark scenarios were therefore built as reference scenarios for the assessment and to further develop the sensitivity analysis.

Information on restaurant practices on the use of MU packaging was also gathered during an on-field visit at the JRC facilities in June 2023. These direct observations allowed researchers to gather information especially on washing practices (including rinsing with hot and cold water and procedures for rewashing), which are not well documented in the literature.

Lastly, values were collected from the literature to assess the variability ranges associated with each parameter. These ranges were used to run the sensitivity assessment, as described in Section 2.5.

Further details on all the assumptions and data sources for each life cycle stage are presented in the following sections. Inventory values are provided in Annex 3 in dedicated Factsheets for each case study. The datasets employed in the modelling are listed in Annex 2.

2.4.4.1 Manufacturing

In the present report, the manufacturing life cycle step includes the production of virgin and recycled raw material, their transport to the manufacturing site and the energy used in the manufacturing of the packaging products.

The raw material production was modelled selecting the most appropriate EF3.1 datasets (or stakeholder dataset in the case of cartonboard manufacturing) for each packaging product (Annex 2). It is important to point out that, with regard to the life cycle impacts of cartonboard manufacturing, the ‘Benchmark dataset’ used for the calculation of the benchmark results and the sensitivity analysis results was retrieved from data received at the stakeholder consultation (see Table 2 and Section 2.5.1). Other datasets (namely, ‘Alternative 1’ and ‘Alternative 2’) were employed to estimate alternative impacts associated impacts associated with cartonboard manufacturing processes, one (10) retrieved from the EF method (EF3.1) and another gathered during the stakeholder consultation (as described in Section 2.5.1). The EF3.1 dataset, in particular, was aggregated and accompanied by few metadata. As a consequence, it was complex to understand the full list of foreground and background processes included in the modelling. In the context of the present study and to avoid potential double-counting, it was assumed that the EF3.1 dataset already includes the impacts associated with the production of cartonboard and the further processing of cartonboard into carton (11). For this reason, in the alternative scenarios (12) employing the EF3.1 cartonboard dataset, impacts associated with the conversion of cartonboard into carton were excluded for the manufacturing of carton cups and trays. By contrast, datasets retrieved from stakeholders were related only to cartonboard manufacturing, although these datasets have not been declared as ‘EF compliant’. When employing the cartonboard manufacturing data retrieved during the stakeholder consultation, impacts associated with the conversion of cartonboard into carton were included for the manufacturing of carton cups and trays. Insights on cartonboard and carton manufacturing, and the related industrial processes, were retrieved from a study by the European Association of Cartonboard and Carton Manufacturers (ProCarton, 2023a).

The SU carton packaging products and aluminium food trays, as well as the PP MU packaging, were assumed to be made from only virgin materials in the benchmark analysis, while the SU aluminium cans, the glass bottles (in both ‘Scenario 3’ and ‘Scenario 4’), as well as the MU PET bottle were assumed to have a certain recycled content.

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(10) Namely “*Solid board, bleached; Kraft Pulping Process, pulp pressing, bleaching and drying; production mix, at plant; >220 g/m2*”.

(11) In the metadata available for this EF 3.1 dataset it stated that “... finally the pulp is dried and pressed into the desired shape ...” in the description of the foreground system of the model.

(12) Namely ‘Scenario 1’, and ‘Scenario 2’ and ‘Restaurant Scenario’, as detailed in the Scenarios Factsheets in Annex 3.

Recycled contents of the packaging products assessed in the case studies were retrieved from data collected during the stakeholder consultation or as gathered within the EF pilot phase (as presented in 'Annex C' described in Zampori and Pant (2019)).

Electricity used in the manufacturing step of carton packaging and aluminium cans has been assumed to refer to the EU average mix (13), aligning with the purpose of the study of assessing case studies that represent the EU context as far as possible. In the case of plastic packaging, a dataset related to blow moulding (Annex 2) was used to represent the impacts of the manufacturing of the final packaging product. In the case of glass bottle production ('Scenario 3' and 'Scenario 4'), an aggregated dataset including both raw material production and bottle manufacturing was used (Annex 2).

2.4.4.2 Transport

The transport stage refers to all transport occurring between the manufacturing and the use stage. The transport occurring during the use stage of the MU packaging have been included in the reuse step itself rather than the transport step. Assumptions on transport distances were based on the data gathered from the stakeholder consultation or on information from EC (2021a).

The impacts associated with transport related to raw material manufacturing processes and the transport related to the packaging manufacturing processes were already included in the associated datasets (in all Scenarios). The transport from manufacturing to use was assumed to follow the general assumptions applied in the EF method (14), whereby cups and trays are first transported from the manufacturing site to the distribution centre and then to the cafeterias or restaurants where they are sold to consumers for takeaway ('Scenario 1' and 'Scenario 2') or dine-in services ('Restaurant Scenario'). In the case of takeaway services, the transport from point of sale to the place of consumption was assumed to be equal for both SU and MU packaging products, and therefore it was not included in the analysis (15).

The manufactured and filled cans or bottles are assumed to be transported to the retail outlet and finally to the home for consumption ('Scenario 3' and 'Scenario 4'). Furthermore, in these case studies, transport from the retail outlet to home was assumed to be the same for both MU and SU packaging, and it was not included in the assessment.

2.4.4.3 Reuse

The reuse life cycle stage for all the Scenarios includes the impacts related to washing and sanitising activities, plus the impacts related to the transport of the MU packaging to the site for washing (except for the 'Restaurant Scenario' where it is assumed that packaging products are washed in the restaurant where they are used). In the case of takeaway packaging products ('Scenario 1' and 'Scenario 2'), it is assumed that the washing occurs in the facility where the products were originally sold (e.g. empty trays are returned to the takeaway restaurant where the user purchased them).

Specific assumptions for the return of empty packaging have been made for the various Scenarios, in particular for 'Scenario 1' and 'Scenario 2':

- Assumptions on the return of empty packaging to the point of sale can involve value choices. As the transport may be coupled with other user activities (e.g. a trip to buy more food or on the way to do other shopping), this is an example of allocating the impacts among different services/activities, and for which there is not an unambiguous way of modelling in the LCA. In the present study, when the return trip is made on foot or by bicycle, no impacts are allocated to the reuse of the MU packaging. In addition, for takeaways it was also assumed that food may be delivered to the home by delivery services, which could take away empty packaging while delivering more food (25 % of purchases) (16). It was then assumed that in (roughly) 10 % of cases, the MU packaging in 'Scenario 1' is transported back to the point of sale by passenger car, with no purpose other than returning the packaging, driving for an overall distance of 2.5 km. In the case of the MU packaging in 'Scenario 2' (both 'CASE A' and 'CASE B'), it was

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(13) This refers to the EF dataset named "*Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV*" (see Annex 2 for further details).

(14) See section 4.4.3 in EC, (2021) and section 4.4.3 in Zampori and Pant (2019).

(15) In this sense, this transport occurs equally for both MU and SU packaging, and therefore it is independent from the type of packaging used and not relevant for the present analysis.

(16) In these cases, it may also be assumed that no impacts should be allocated to the returning of empty packaging for reuse. The home delivery rate is estimated to be around 25 % of purchased food (Kearney, 2023).

then assumed that in (roughly) 25 % of the cases the empty containers are collected by the same delivery services. Therefore, in only 75 % of the cases are the items returned by consumers, and it was assumed that in 10 % of these cases transport was by car for an overall distance of 5 km and the journey had no purpose other than returning the packaging. In addition, it was assumed that five items are returned at the same time (17) for the MU packaging in 'Scenario 1' and in 'Scenario 2' (both 'CASE A' and 'CASE B'). It is important to note that, as shown by the results in the next sections, the impacts of MU packaging are largely influenced by such assumption about passenger car transport. For this reason, these assumptions have been further analysed via specific analysis aimed at assessing the assumptions influence on the results. These assumptions could be further cross-checked in future when additional information will be available on the reuse systems in place.

In the case of bottles ('Scenario 3' and 'Scenario 4'), the following assumptions were made:

- The washing was assumed to occur in a centralised facility; therefore, the impacts of the following journeys have been included:
    - transport from home to collection point (e.g. supermarket or other point of sale);
    - transport from the collection point to the washing facility;
    - transport from the washing facility to the bottle filling facility (e.g. winery, brewery).
- Concerning the transport from home to collection point, assumptions similar to those in the 'Scenario 1' have been made, meaning that transport impacts were allocated to the MU bottles only in 10 % of the returning trips. In these cases, it was assumed that 5 wine bottles ('Scenario 4') or 12 beer bottles ('Scenario 3') are returned in each return trip. Transport from the collection point to the washing facility and transport from the washing facility to the bottle filling facility were both assumed to be by 7.5 t articulated lorry (Annex 2). For the case studies in 'Scenario 3' and 'Scenario 4', assumptions on the transport distances from the washing facility to the filling station were developed during the stakeholder consultation (the same distances were considered for 'Scenario 3 – CASE B' and 'Scenario 4', while a different one was used for 'Scenario 3 – CASE A' because of the different packaging used in the case studies). The distance from the collection point to the washing facility was assumed to be 100 km for all case studies in 'Scenario 3' and 'Scenario 4'.

Other aspects included in the reuse step modelling considered the presence of specific washing practices:

- The washing of MU cups and trays in the benchmark scenarios was assumed to always include a rinsing stage (i.e. pre-washing of the item with cold water or warm water at 30°C) before regular washing in a dishwasher. Data on consumption during the washing stage were collected at the stakeholder consultation and cross-checked with the available literature and data retrieved from a visit to JRC facilities. The amount of water consumed per item during the rinsing was estimated to be equal to the water consumed by the dishwasher. In all scenarios including a rinsing step, the potential use of cold water in place of hot water was considered in the sensitivity analyses (Section 2.5).
- The washing of MU bottles was modelled using data from stakeholders and from sources in the literature (Cleary, 2013; Ramboll, 2022a), and the same assumption was made for 'Scenario 3' and 'Scenario 4'.
- Some additional washing steps (i.e. rewashing) may be added if the MU packaging is not thoroughly cleaned during the washing. Assumptions about rewashing vary between scenarios. In 'Scenario 1', it is assumed that rinsing cups before washing is sufficient to prevent further rewashing, whereas in the case of food trays it is assumed that additional washing may be needed (in 1 % of cases). For bottles ('Scenario 3' and 'Scenario 4') the rewashing rate was based on data from the stakeholder consultation, namely 2 % for glass bottles and 0.5 % for PET bottles (18). In the 'Restaurant Scenario' it is assumed that 1 % of the plates are rewashed.

Lastly, regarding the life cycle impacts of the detergents used during the washing of MU packaging, a proxy dataset was calculated for (i) the washing of bottles and (ii) the washing of all other MU packaging products, as detailed in Annex 2.

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(17) Thus, the impacts of the passenger car trip are supposed to be divided among five MU packaging items.

(18) This difference in the assumptions is justified by the fact that removing labels may be easier for plastic bottles than for glass bottles.

2.4.4.4 End-of-Life

The end-of-life stage includes recycling, incineration and landfilling (as well as the related transport to the facilities).

The modelling of the end-of-life stage has been done for all the scenarios with the Circular Footprint Formula of the EF method as detailed in Figure 6.

Figure 6. The Circular Footprint Formula and its main components (Zampori and Pant, 2019) (19).

Material

$$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P}\right)$$

Energy

$$(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Disposal

$$(1-R_2-R_3) \times E_D$$

Source: Environmental Footprint method (Zampori and Pant, 2019).

Recycling rates were retrieved from stakeholder inputs, from 'Annex C' of the EF method (EC, 2021b) or from the literature. For example, for SU cups and trays it is assumed that 15 % of the carton is recycled after use (Kearney, 2023), whereas the LDPE layer is separated and is disposed of or processed in energy recovery facilities. Materials that are not recycled are assumed to go to incineration (45 % in mass) or landfilling (55 %) (Zampori and Pant, 2019), reflecting the current 'status quo' rather than expected future trends in end-of-life waste management (for more details, see Section 2.4.2).

2.4.5 Life cycle impact assessment

The life cycle impact assessment of the case studies was conducted with reference to the most up-to-date impact assessment methods recommended for the EF method (Andreasi Bassi et al., 2023) (20).

Given the wide range of environmental aspects covered by LCA, and the possible trade-offs between impact categories, it is recommended to perform the Normalisation and Weighting steps in the analysis of different product systems (De Laurentiis et al., 2023). Normalisation and Weighting allow to aggregate the different environmental dimensions to be aggregated into a so-called Single Score (SS) index (21).

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(19) Notes on the parameters in use in the CFF: **R_1**: the proportion of the material that has been recycled from the previous system; **R_2**: the proportion of the material that will be recycled in the end-of-life; **R_3**: the proportion of the material that will be used for energy recovery in the end-of-life; **A**: allocation factor of burdens and credits between supplier and user of recycled materials; **B**: allocation factor of energy recovery (applies for both burdens and credits); **Q_{Sin}**: quality of the ingoing secondary material; **Q_{Sout}**: quality of the outgoing secondary material; **Q_P**: quality of the primary material; **$E_{recycled}$**: emissions and resources consumed arising from the recycling process of the recycled material; **$E_{recyclingEoL}$**: emissions and resources consumed arising from the recycling process at end-of-life; **E_v**: emissions and resources consumed arising from the acquisition and pre-processing of virgin material; **E^*_v**: emissions and resources consumed arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials; **E_{ER}**: emissions and resources consumed arising from the energy recovery; **$E_{SE,heat}$** and **$E_{SE,elec}$**: emissions and resources consumed arising from the substituted heat and electricity; **E_D**: emissions and resources consumed arising from disposal of waste materials at the end-of-life; **$X_{ER,heat}$** and **$X_{ER,elec}$**: the efficiency of the energy recovery process for both heat and electricity; **LHV**: lower heating value. For further details. For further details, the reader is invited to refer to (EC, 2021).

(20) Compared with the previous version of the impact assessment method, EF3.0, the latest version, EF3.1, updated the assessment of impact categories such as Climate Change, Ecotoxicity Freshwater, Human Toxicity (cancer and non-cancer) at the level of Characterization Factors (CFs) and Normalization Factors (NFs).

(21) During the Normalization step, the life cycle impacts of a given impact category are divided by a specific NF related to that specific impact category. NFs can be calculated in various ways: for instance, a common approach is to divide the characterised results of a packaging product by the characterised total emissions and extractions linked to the production or the consumption taking place within a political or geographical boundary (De Laurentiis et al., 2023). It is common practice, following the normalisation step, to weight normalised results in the so-called Weighting step. During this step percentage-based dimensionless Weighting Factors (WFs) are applied to the normalised results. These factors can be derived in various way (e.g. by means of expert judgement, by means of monetisation approaches, by means of multi-criteria decision analysis) and aim to allocate a weight to each impact category. All the weighted impacts for of all impact categories may be summed up to give the Single Score index.

The Normalisation and Weighting steps are mandatory for the EF method (EC, 2021a) and were therefore performed in the present study using the EF3.1 Normalisation Factors (NFs) and Weighting Factors (WFs) provided in Andreasi Bassi et al. (2023).

The present study considered all 16 impact categories, as recommended in the EF method. However, the results presented in the following chapters mainly focus on the Climate Change ([22]) and Water Use ([23]) impact categories, because of their relevance for the case studies and packaging product systems examined. The results for all the impact categories are presented in the Scenario Factsheets.

Regarding the Water Use impact, the EF3.1 datasets used to model the scenarios refer to water retrieved from various sources (e.g. rivers, lakes, sea) and different geographical locations. The EF dataset for the EU average 'tap water' was used to model the water consumed during the washing of MU packaging. This dataset refers to the EU average mix of water used in different EU Member States calculated as the weighted average of water consumed in the EU considering (i) the share of EU Member States (in terms of tap water consumption) and (ii) the Characterisation Factors considering water scarcity or availability in each EU Member State.

2.5 Sensitivity analysis

A sensitivity analysis was conducted to evaluate how changes in the benchmark values of several parameters could impact the environmental performance of the packaging used in each case study ([24]). The sensitivity analyses were based on the Monte Carlo simulation ([25]). To perform a Monte Carlo simulation, it is necessary to attribute variability ranges to each parameter under examination and identify a probability distribution for these variability ranges. The Monte Carlo simulations involve randomly selecting values for each parameter, according to the variability range and probability distribution provided, and then storing the model's outcomes. This process is repeated for a thousand simulations, and it allows the analysis of the model's behaviour and its relationship with its parameters.

For the purpose of the present analysis, a uniform distribution ([26]) was applied to parameters assumed to vary within their respective ranges of variability. The uniform distribution was selected because of the absence of evidence supporting the choice of an alternative probability distribution. This type of distribution was applied consistently for both the SU and the MU packaging products analysed. This ensures that all the values (including the extreme minimum and maximum values) within the ranges are equally likely to be randomly selected in a given simulation of the sensitivity analysis. The choice was also driven by the lack of detailed information in the literature about the variability of the parameters for the business models under scrutiny.

Variability ranges associated with the parameters were determined based on values provided by stakeholders, based on data retrieved from literature or by considering ranges derived from the research team's own assumptions. For instance, the R_2 parameter of the Circular Footprint Formula (CFF formula) (Section 2.4.5) was assumed to vary in a symmetrical range (e.g. the R_2 of PET for the MU packaging product in 'Scenario 3 – CASE A' varied by 14 percentage points, from 33 % to 61 % considering a benchmark of 47 %) ([27]). Factsheets in Annex 3

([22]) The Climate Change impact category was modelled to be in line with the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (Forster et al., 2021). The consequences of emitting global warming substances include increased average global temperatures and sudden regional climatic changes. Climate Change is an impact affecting the environment on a global scale and is modelled considering radiative forcing as global warming potential (i.e. changes in Earth's temperature can be 'forced' by imbalances in the in–out equilibrium of atmospheric energy).

([23]) Water Use impacts are calculated through the AWARE method. The AWARE method is based on the quantification of the relative available water remaining per unit area once the demand of humans and aquatic ecosystems has been met, answering the question: 'What is the potential to deprive another user (human or ecosystem) when consuming water in this area?' (Boulay et al., 2018). Each water flow in the used datasets (i.e. in the background and/or in the foreground data) is characterised with its characterisation factor considering (i) the 'type' of water (e.g. river, lake, sea) and (ii) the water scarcity in the area from which water is being retrieved.

([24]) In the realms of statistics and LCA uncertainty, the analysis executed in this report incorporated a probabilistic uncertainty propagation and a corresponding discernibility analysis, based on clustering and performance assessment against specific thresholds. However, for the sake of simplicity and effective communication, the general term 'sensitivity analysis' was used throughout the report in lieu of the more specific term 'discernibility analysis'.

([25]) The Monte Carlo method (Metropolis and Ulam, 1949) is a probabilistic numerical technique employed for estimating outcomes that are dependent on uncertain processes or parameters. This approach was developed before the advent of computers and first presented in 1949 by Stanisław Ulam.

([26]) Uniform distributions are probability distributions with equally likely outcomes.

([27]) In some cases, parameters may be interlinked. For example, the recyclability (R_2) and the energy recovery (R_3) parameters of the CFF are linked to the residual fraction to disposal ($1 - R_2 - R_3$). This interrelationship must also be considered in the sensitivity analysis simulations, ensuring that the sum of the recycled, disposed of and energy recovered fractions equals 100 %.

provide for each case study the list of the parameters considered in the sensitivity analysis and their specific variability ranges.

In those case studies devoted to takeaway packaging products (e.g. 'Scenario 1' and 'Scenario 2'), the impacts associated with return travel were allocated to the MU packaging products under examination by considering the number of items transported during these journeys. The number of items transported was also considered to randomly change within a certain range during each sensitivity analysis simulation. Similarly, the number of reuses (of MU packaging) was assumed to vary, and the effects of such changes have been assessed in the simulations of the sensitivity analysis. A slightly different approach was adopted to assess the variability of the Electricity Energy Mix ('E-Mix'). The EF3.1 dataset for the EU territory ('Electricity grid mix 1 kV–60 kV; technology mix; consumption mix, to consumer; 1 kV–60 kV') was employed as a benchmark value to account for the impacts of the average kilowatt-hour of electricity produced in the EU (see Section 2.4.4). Subsequently, a set of four additional electricity mixes were considered in the analysis to represent EU Member States with vastly different electricity production systems and related environmental impacts. In particular, the electricity mixes of Poland, Germany, Belgium and Sweden were considered representative of countries with progressively larger fractions of energy from renewable sources and lower carbon footprints (EEA, 2023). EF datasets were used to account for the impacts of the different electricity mixes and named as follows: 'E-Mix1' (EU), 'E-Mix2' (Germany), 'E-Mix3' (Sweden), 'E-Mix4' (Poland), 'E-Mix5' (Belgium). In each simulation of the sensitivity analysis, one of these electricity mixes was randomly selected and used to model, for example, the impacts of electricity used during the MU packaging washing. Further details on these electricity mixes are reported in Annex 2.

Particular attention was given to the sensitivity analysis of parameters relevant for the reuse stage. Energy, water and detergent consumption during the washing of MU packaging products was estimated from values in the literature and primary data collected during the stakeholder consultation (Section 2.3).

The modelling of the reuse stage of MU packaging products also considered some additional washing operations such as rinsing (i.e. pre-washing) and rewashing. In the sensitivity analysis it was considered that only rinsing, only rewashing or both could occur. Moreover, the following assumptions were made:

- Rinsing may consume more water than the consumed amount by dishwashers per item. In 50 % of sensitivity simulations, warm water was assumed to be used, while cold water was assumed for the remaining simulations.
- Different rates were assumed for the rewashing of MU packaging in the different scenarios, considering the energy, water and detergent consumption that this additional washing operation would entail.

A total of 1 000 simulations (28) was run for each parameter considered and for each Scenario, calculating the different impacts of the case study packaging. Then, for each simulation the percentage difference between the life cycle environmental impacts of the MU and SU packaging was calculated according to equation 1:

$$Perc\_Difference_{MU\_vs\_SU_j} = \frac{MonteCarlo\_MU_{iteration_{i},j} - MonteCarlo\_SU_{iteration_{i},j}}{MonteCarlo\_SU_{iteration_{i},j}} \qquad (1)$$

where:

- $Perc\_Difference_{MU\_vs\_SU\ j}$ = percentage difference between the impacts of MU and SU packaging for the impact category "j" in the Scenario considered;
- $MonteCarlo\_MU_{iteration_{i,j}}$ = impact of the MU packaging (for the impact category "j"), in the sensitivity analysis simulation "i" of the Scenario considered;
- $MonteCarlo\_SU_{iteration_{i},j}$ = impact of the SU packaging (for the impact category "j"), in the sensitivity analysis simulation "i" of the Scenario considered.

Subsequently, it was estimated that:

- impacts of the MU packaging were considered lower than SU packaging if $Perc\_Difference_{MU\_vs\_SU}$ is ≤ -15 %;

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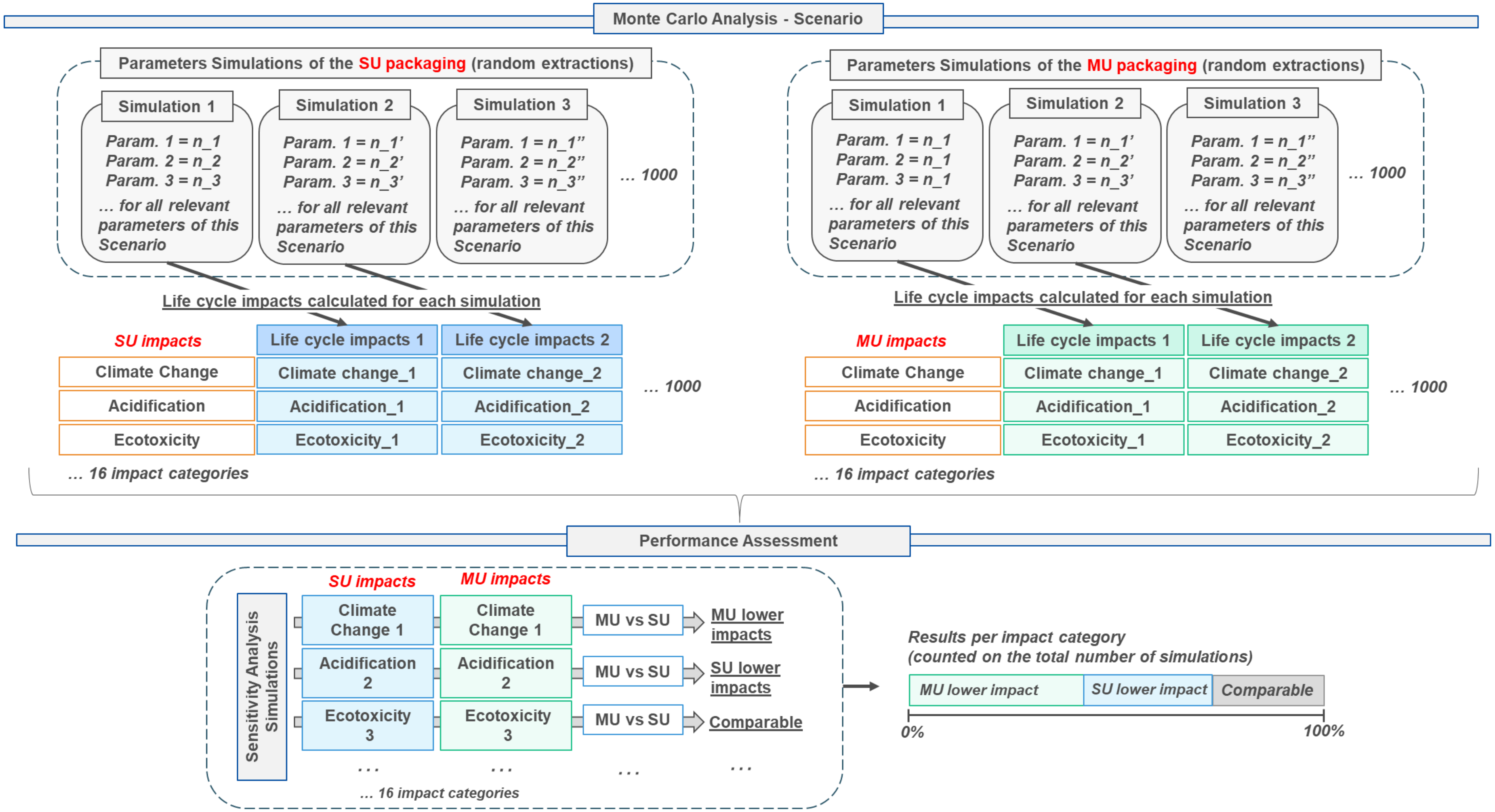
(28) This number of simulations was selected so that it was sufficiently large but also took account of the computational time of the software used. The results of the sensitivity analysis were observed to be stable once 800 simulations had been performed.

- impacts of the MU packaging were considered higher than SU packaging if $\text{Perc\_Difference}_{\text{MU\_vs\_SU}}$ is ≥ + 15 %;
- impacts of the two types of packaging were considered comparable if $- 15\ \% < \text{Perc\_Difference}_{\text{MU\_vs\_SU}} < + 15\ \%$.

This assessment was repeated for all the simulations ‘i’ and impact categories ‘j’ in all the scenarios considered. The results of the sensitivity analysis have been plotted in dedicated figures that visually capture how the environmental performance of the different types of packaging changed by varying a large number of parameters. The 15 % threshold was selected considering the uncertainties associated with the models and the data employed, and it was assumed that a percentage difference within the range of ± 15 % does not represent a significant difference between the life cycle performance of the packaging systems compared.

The model used for the sensitivity analysis is summarized in Figure 7.

Figure 7. Model used for the sensitivity analysis for a given Scenario.



Source: JRC analysis. Additional details: In the first phase of the analysis, the parameters used to model the impacts of the Single Use (SU) and Multiple Use (MU) packaging are randomly extracted 1 000 times within their specific variability ranges. Subsequently, for each iteration, the life cycle impacts of the SU and the MU packaging are calculated. Afterwards, the impacts of the SU and the MU packaging are compared for each impact category. Lastly, for each environmental impact indicator (including the Single Score) the number of iterations in which MU packaging had higher, lower or similar impacts to the SU is estimated.

2.5.1 Analysis of additional sensitivity scenarios

As well as the sensitivity analysis illustrated above in Section 2.5, a series of specific additional scenarios were analysed to further discover and understand the environmental performance of the SU and MU packaging products when certain parameters or assumptions were changed. The subsections below describe these analyses.

2.5.1.1 Use of alternative life cycle datasets for the analysis of cartonboard production

Given that the production of raw materials is one of the most significant life cycle stages, additional scenarios were developed to determine the extent to which changes in the impacts associated with modelling this process could impact the performance of the SU and MU packaging products. In particular, to evaluate the relevance of cartonboard production on the life cycle impacts of cartonboard-based packaging products, a dedicated analysis was conducted using different cartonboard life cycle datasets as inputs to the model.

Among the inputs received from the stakeholders during the consultation period (Section 2.3), some datasets related to specific cartonboard production processes based on primary industry data were received. These datasets provided life cycle impacts related to specific processes of the life cycle modelled, especially regarding the manufacturing step of the raw material employed in the cartonboard manufacturing. For confidentiality reasons, these datasets were provided fully aggregated by stakeholders (29).

It is important to notice that, as declared by stakeholders, the data provided 'cover approximately 80 % of all case scenario-relevant paper-based food packaging on the EU market'. However, separate datasets were provided by different stakeholders in aggregated format and without supporting life cycle metadata (or detailed explanatory notes) on how the LCA of these processes was conducted. Therefore, it was not possible to build a new dataset that would be fully representative of the whole EU market. This aspect could therefore be a subject for future investigations. As a consequence, it was decided to adopt one of the datasets received from stakeholders as the 'Benchmark dataset' (30) for modelling cartonboard manufacturing impacts. The influence of this choice was then tested in a dedicated analysis, considering alternative cartonboard production datasets (Section 2.5.1), including:

- a dataset available in the EF3.1 database and related to 'Solid board, bleached; Kraft Pulping Process, pulp pressing, bleaching and drying; production mix, at plant; >220 g/m2' (see Annex 2 for further details);
- an additional dataset provided by a stakeholder, fully based on primary industry data and built considering the industry-specific electricity mix (with remarkably high share of renewable energy sources).

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(29) As a consequence, it was not possible to assess their level of consistency with the EF method and other EF datasets used in the model.

(30) Based on information provided by the stakeholder, this dataset referred to a cartonboard production facility located in northern Europe. The dataset was described as fully based on primary industry data, although an EU average electricity mix was considered as input to the life cycle model. The Climate Change life cycle impacts of this dataset were aligned with impacts indicated in a recent study by ProCarton (Pro Carton, 2023b), excluding biogenic carbon flows. As a consequence, this dataset was deemed the best proxy currently available to represent the EU level.

Table 2. Overview of the alternative life cycle datasets used to model the impacts associated with cartonboard manufacturing.

Dataset used in the analysis	**'Benchmark dataset'**	**'Alternative 1'**	**'Alternative 2'**
Notes	*Industry dataset retrieved during stakeholder consultation. This refers to primary data collected by the industry in a facility and is assumed to model electricity consumption based on the average EU electricity mix.* *Impacts close to results from the ProCarton study (ProCarton, 2023b), at least concerning carbon footprint (excluding biogenic carbon emissions and carbon removals). Impacts for water use were estimated (1). In particular, impacts of water use were modified to make them consistent in terms of impact category considered in the study.* *The dataset has not been declared as 'EF compliant' by stakeholders and therefore not consistent with other background datasets used in the study.* *Additional energy needs related to converting cartonboard into carton were included when assessing this dataset.*	*EF3.1 dataset, consistent with other datasets used in the study. The dataset is representative of an average kraft pulping process in the EU (data from 2012) (2).* *Based on the available metadata, it was assumed that this dataset included impacts associated with cartonboard manufacturing and converting cartonboard into carton. For this reason, the energy needs required to convert cartonboard into carton were excluded in the calculations of life cycle impacts when using this dataset.*	*Industry dataset retrieved during the stakeholder consultation. This refers to primary data collected by the industry in a facility and is assumed to model electricity consumption based on the specific electricity mix claimed by the industry in such a facility.* *The dataset has not been declared as 'EF compliant' by stakeholders and therefore not consistent with other background datasets used in the study.* *Additional energy needs related to converting cartonboard into carton were included when assessing this dataset.*

Source: EF3.1 dataset and information received during the stakeholder consultation. Note: (1) The Water Use impact was calculated as the mathematical average of the Water Use impacts of 'Alternative 1' and 'Alternative 2'. (2) Concerning Water Use impacts, the value provided in the 'Alternative 1' dataset is 2.32 m^3 water eq. As a comparison, the range of Water Use impacts of other EF3.1 datasets is 0.19–2.33 m^3 water eq. for "containerboard production, fluting medium, semichemical; technology mix; production mix, at plant; 1000 kg" and "Solid board; Kraft Pulping Process, pulp pressing and drying; production mix, at plant; >220 g/m2" datasets, respectively. Water Use impacts for the EF3.1 datasets "Carton board; Kraft Pulping Process, pulp pressing and drying, box manufacturing; production mix, at plant; 280 g/m2" and "kraft paper; technology mix; production mix, at plant; kg" are equal to 2.32 m^3 and 0.34 m^3 water eq., respectively. When compared with datasets provided by other external databases such as Ecoinvent version 3.6, the Water Use impacts calculated with the AWARE method (Boulay et al., 2018) would be in the range of 0.32–0.38 m^3 water eq. for EU Ecoinvent datasets referring to corrugated box production; in the range of 0.38 0.99 m^3 water eq. for EU Ecoinvent datasets referring to folding boxboard/chipboard production; in the range of 1.29–2.19 m^3 water eq. for EU Ecoinvent datasets referring to solid bleached/unbleached board production and in the range of 2.08–2.13 m^3 water eq. for EU Ecoinvent datasets referring to kraft paper bleached/unbleached production. Such variability observed in literature data is captured by the 'Alternative 1' and 'Alternative 2' datasets employed in the present analysis, and by having the 'Benchmark dataset' as the average value of these two used to model benchmark scenarios.

2.5.1.2 Assumptions on the use and type of packaging lids

In the benchmark analysis performed in 'Scenario 1', a carton lid was modelled. An additional analysis was performed to test the influence of different assumptions about the presence and type of lid in use in case study packaging products in 'Scenario 1'. The steps performed in the specific additional analysis on lids can be summarised as follows:

- in the benchmark analysis, the mass of the SU packaging product amounted to 17.6 g (assuming that the lid has a total mass of 5.3 g and contains 0.5 g of LDPE lining), while the mass of the MU packaging product amounted to 48.3 g (PP cup with PP lid);
- in the alternative 1 analysis, it was assumed that a polystyrene (PS) lid was used for the SU case study; in this case, the total mass of the SU packaging product amounted to 14.04 g (including a PS lid with a mass of 1.8 g), while the total mass of the MU packaging product was kept the same as that in the benchmark analysis;
- in the alternative 2 analysis, it was assumed that an SU cup without a lid (having a total mass of 12.28 g) was used; similarly, an MU cup without a lid with a mass of 33.3 g was considered in this case.

The results of the additional sensitivity analyses are presented in Section 3.1.2.

2.5.1.3 *Influence of passenger car transport and related impacts*

During the analysis and modelling of the takeaway scenarios (especially related to 'Scenario 2 – CASE A' analysis), the relevance of the consumer behaviour on the overall accounting of the life cycle impacts of MU packaging products was acknowledged. In the benchmark scenario, a certain amount of impact due to transport by passenger car back to the point of sale was allocated to the MU packaging products. An additional analysis was developed assuming a scenario in which the impacts of transport due to the returning of the MU packaging products to the point of sale are removed. This analysis assumes, for instance, that all transport occurs either by transport means without impacts (e.g. on foot or bike) or that no impact of transport is allocated to the reusable packaging (supposing, for example, that the car trip to return the packaging was had a different purpose, e.g. returning to the point of sale to purchase new food products (31)).

This analysis has been applied to the packaging used in 'Scenario 2 – CASE A', and the results are presented in Section 3.2.2.

2.5.1.4 *Assumptions on end-of-life parameters and calculation of break-even points*

Results for a series of scenarios were calculated by modifying benchmark values for parameters used to model the end-of-life stage of the packaging. Then, Break-Even (BE) points were calculated, that is, the value of a certain parameter for which the SU and MU packaging products had the same impact. BE points were calculated for the Climate Change and Water Use impact categories and the aggregated Single Score, with reference to the 'Restaurant Scenario' (results presented in Section 3.5.2). The BE point analyses were as follows:

- BE point analysis 1: varying the value of the recycling at the end-of-life stage (parameter R_2 of the CFF) of carton material used for the SU packaging product in the 'Restaurant Scenario';
- BE point analysis 2: as in BE point analysis 1, but assuming improved recycling at the end-of-life stage of PP plastic used for the MU packaging;
- BE point analysis 3: varying the number of reuses of the MU packaging in the 'Restaurant Scenario'.

Regarding 'BE point analysis 1', the benchmark value selected for recycling at the end-of-life stage of carton was supposed to be 15 % (Kearney, 2023) (32). This value was employed in the benchmark analysis of all SU carton packaging included, for example, in the 'Restaurant Scenario' (i.e. tray for hamburger, tray for fries and cup). However, some Member States may achieve high collection rates for paper waste, and some recyclers may separate the carton and its lining and being able to achieve high rates of carton recycling. The 'BE point analysis 1' aimed to find the value of the end-of-life recycling rate of carton at which the impacts of the SU packaging product are equal to those of the alternative MU packaging product (33). This analysis was performed for all the alternative cartonboard production datasets presented in Section 2.5.1 (i.e. a set of three BE points were identified when different cartonboard datasets were considered). The changes in the assumptions about the recycling rates pertained only to the carton used in the cup and trays and not to the LDPE used for the lining, since this was assumed to be non-recyclable in all scenarios. The 'BE point analysis 1' was carried out as follows:

- The results of the scenario were recalculated each time assuming that the recycling rate (R_2) for carton increased from 0 % (worse case) to 100 % (ideal situation).
- All other parameter values were held constant, such as the recycled content (R_1) of carton remaining at 0 %, and the recycled content and recycling rate of the PP used in the MU cup was kept unchanged at 0 % and 41 %, respectively. In this analysis, it was also considered how the recycling rate might vary/increase depending on potential open-loop applications of the recycled material, while the recycled content could stay constant as a consequence, for instance, of the food grade requirements for these packaging products.

A second BE point analysis ('BE point analysis 2') was performed, assuming an improved end-of-life recycling rate (R_2) for the PP used in MU packaging products in the 'Restaurant scenario'. This alternative analysis aims to discover the potential effect of and how improved recycling of materials in the MU packaging products could affect the BE points. The assumptions in this new scenario were the same as those of the BE point analysis 1,

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(31) As an example, if the allocation of the impacts of transport for returning the packaging was based on economic factors, the value of the returned MU packaging could be considered negligible compared with the value of other products purchased during the same trip.

(32) A low recycling rate at the end-of-life stage may be the consequence of a low collection rate of the waste and the technical difficulties in recycling multilayer materials. Moreover, possible food and drink residues in the cups and trays may hinder recycling at the end of life (making it difficult to achieve high recycling rates).

(33) When the recycling rate (R_2) exceeds the break-even point, the impacts of the SU packaging are lower than those of the MU packaging product.

although the recycling rate of the PP in MU packaging products was assumed to increase up to 85 %. As for 'BE point analysis 1', 'BE point analysis 2' was performed for all alternative cartonboard production datasets (i.e. a set of three BE points were identified, when different cartonboard datasets were considered).

In the 'BE point analysis 3', the effect of a change in the number of reuses of the MU packaging products was explored for the 'Restaurant scenario'. Because of the nature of the dine-in meal modelled for the 'Restaurant scenario', and also based on the insights gathered from stakeholders and the literature, it is conceivable that operators could achieve high numbers of reuses for MU packaging products. In the 'Restaurant Scenario', it was therefore assumed that MU packaging products could be reused up to 100 times as benchmark. The 'BE point analysis 3' was developed to determine for which number of reuses the MU and the SU packaging had same impact. Apart from the number of reuses of the MU packaging products, all other parameters were kept constant in the analysis. As for the previous BE analyses, the 'BE point analysis 3' was repeated considering all the alternative cartonboard production datasets.

Table 3 summarises the three BE point analyses presented in this section.

Table 3. Overview of the Break-Even (BE) point analyses performed for the 'Restaurant Scenario'.

Packaging	Benchmark		"BE point analysis 1"	"BE point analysis 2"	"BE point analysis 3"
	End-of-life recycling rate	**No. of reuses**	**End-of-life recycling rate**	**End-of-life recycling rate**	**No. of reuses**
Single Use packaging in the 'Restaurant Scenario'	15 % *(carton)*	-	From 0 % to 100 % *(carton).* *All other parameter values do not vary*	From 0 % to 100 % *(carton).* *All other parameters' values do not vary*	-
Multiple Use packaging in the 'Restaurant Scenario'	41 % *(polypropylene)*	100 *(cup and tray)*	*All other parameter values do not vary*	85 % *(polypropylene).* *All other parameters' values do not vary*	From 5 to 200 *(both for cup and tray). All other parameter values do not vary*

Source: JRC analysis.

3 Results

This section provides an overview of the results of the analyses for all the scenarios, detailing the results of the LCA considering the benchmark values and the results of the sensitivity analyses.

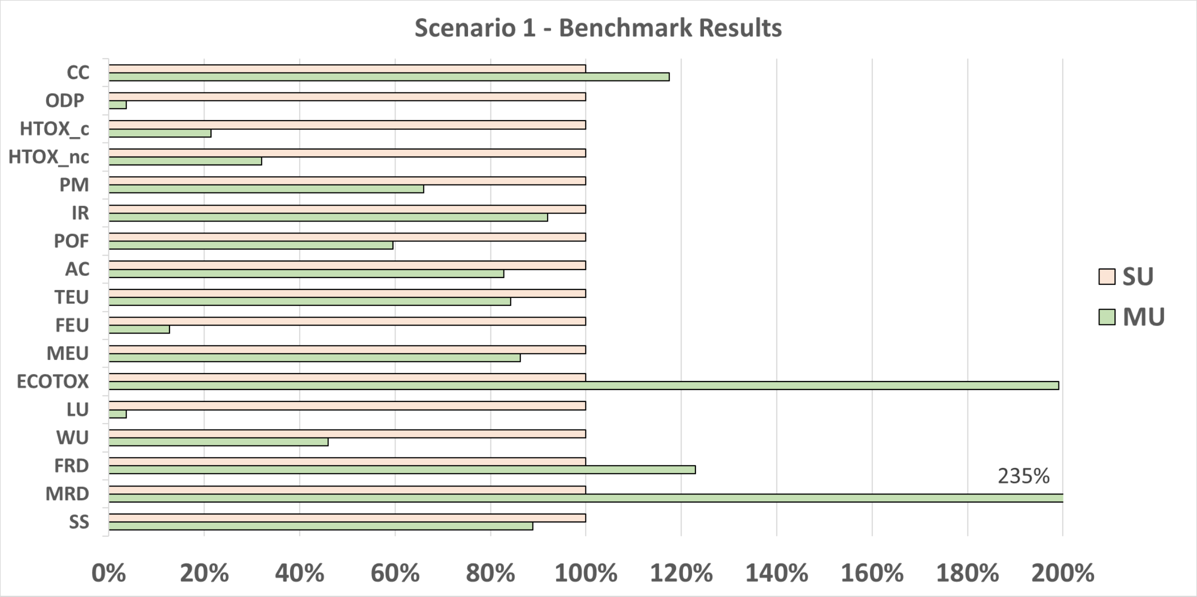
3.1 Results for Scenario 1

'Scenario 1' compares the environmental performance of packaging for cold or hot beverages served in a container at the point of sale for takeaway; further details are given in the 'Scenario 1' Factsheet in Annex 3. This Scenario focused on a comparison of the performance of a carton cup with LDPE lining and a carton lid (SU) with a PP cup and PP lid (MU).

3.1.1 Scenario 1 – Benchmark and sensitivity analysis

As explained in Section 2.4.3 (Figure 1), 'Scenario 1' analysed the life cycle impacts of takeaway SU carton and takeaway MU PP cups. The life cycle impacts in terms of the benchmark values are shown in Figure 8. The analysis shows that the MU packaging product has lower impacts for the majority of the impact categories, although the two packaging products had similar impacts for many indicators. Despite this, the life cycle impacts of the SU packaging product were lower for the Climate Change, Ecotoxicity Freshwater and 'Resource Use, Fossil' and 'Resource Use, Minerals and Metals' impact categories. High impact levels in these categories for MU packaging are mostly due to the plastics manufacturing and the passenger car used to return the reusable cups to the point of sale. The benchmark results show that, despite the water consumed during washing for reuse, the Water Use life cycle impact of the MU packaging was lower than for the SU life cycle. This is mainly due to the water consumption values assumed for the cartonboard production dataset. The aggregated Single Score indicates a slightly better performance of the MU packaging product.

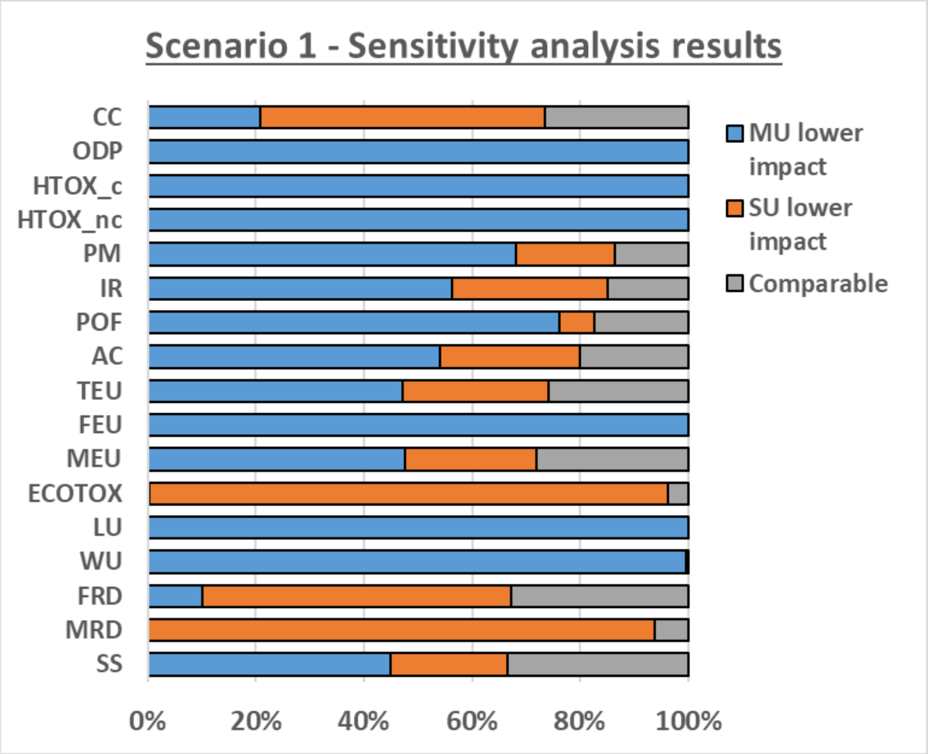
Figure 8. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 1'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 9 illustrates the results of the sensitivity analysis, based on the range of variation associated with each parameter in the model (see Factsheets in Annex 3 for the details).

Figure 9. Results of the sensitivity analysis for 'Scenario 1' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

According to the results of the sensitivity analysis for the aggregated Single Score, the MU packaging had lower impacts in around 40 % of simulations, with SU and MU packaging products comparable in about 30 % of the simulations, and in the remaining simulations SU had lower impacts. In the case of the Climate Change impact category, SU packaging products had lower impact in the majority of the cases (around 50 % of the simulations). In three impact categories (namely: 'Resource Use, Minerals and Metals'; 'Resource Use, Fossils'; and Ecotoxicity Freshwater) the SU packaging product exhibited significantly lower impacts than the MU packaging product. For other impact categories, the MU packaging product generally had lower impacts in the majority of the simulations.

Factsheets in Annex 3 provide additional results for this Scenario, comprising (i) an overview of the contribution of the various life cycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

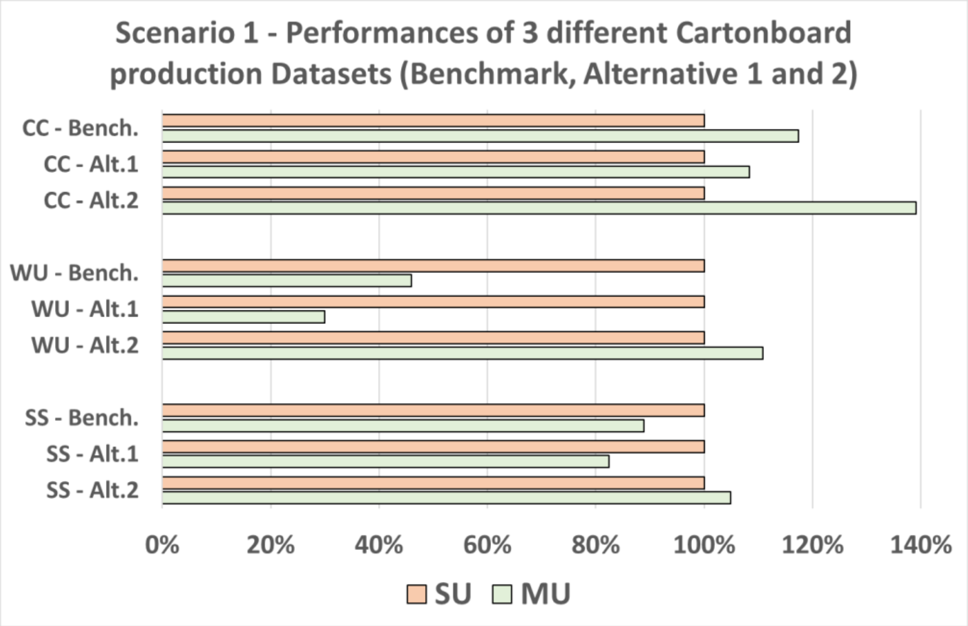
3.1.2 Scenario 1 – Additional analyses

3.1.2.1 Use of alternative life cycle datasets for the analysis of cartonboard production

As explained in Section 2.5.1, the influence of varying life cycle impacts associated with the production of cartonboard used in the manufacturing of the SU packaging product in ‘Scenario 1’ was tested in a dedicated analysis. This compared the results obtained with the ‘Benchmark dataset’ (retrieved during the stakeholder consultation; see Table 2), with ‘Alternative 1’ (referring to the EF3.1 solid board bleached production dataset) and ‘Alternative 2’ (based on an alternative dataset retrieved during the stakeholder consultation). All the parameters (and ranges) and inventory datasets have been kept constant in this analysis, and only the cartonboard impacts were varied.

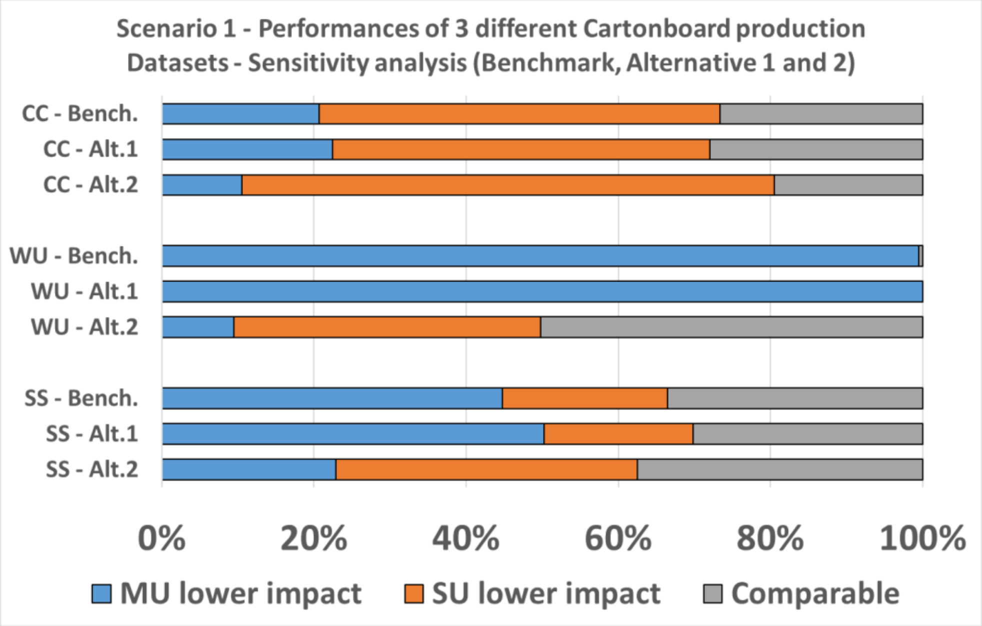
The modified results for ‘Scenario 1’ are presented in Figure 10 and Figure 11 (comparing the results of sensitivity analyses, keeping the same ranges and parameter values as for ‘Scenario 1’ in Section 3.1.1 and varying the cartonboard manufacturing impacts), focusing on the Climate Change and the Water Use impact categories as well as the aggregated Single Score. Complete results for all the impact categories are provided in Annex 4.

Figure 10. Results of the analysis of cartonboard impacts for the Single Use (SU) and Multiple Use (MU) packaging products. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = climate Change; WU = Water Use; SS = Single Score. The ’Benchmark dataset’ (Bench.) used in the analysis refers to a dataset retrieved during the stakeholder consultations; the ‘Alternative 1’ dataset refers to the EF3.1 dataset, the ‘Alternative 2’ dataset refer to a dataset retrieved during the stakeholder consultation. For further details see Section 2.5.1 and Annex 2.

Figure 11. Results of the analysis of cartonboard impacts, comparing the results of the Sensitivity analysis simulations for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; WU = Water Use; SS = Single Score. The 'Benchmark dataset' (Bench.) used in the analysis refers to a dataset retrieved during the stakeholder consultations; the 'Alternative 1' dataset refers to the EF3.1 dataset, the 'Alternative 2' dataset refer to a dataset retrieved during the stakeholder consultation. For further details see Section 2.5.1 and Annex 2.

Results for both Figure 10 and Figure 11 suggest how the effects of the two alternatives are particularly relevant especially when assessing the Water Use impact category as it is noticeable how both the 'Benchmark' and 'Alternative 1' datasets manifest a clear advantage for the MU packaging product, while in the case of the 'Alternative 2' dataset, the results are shifted in favour of SU packaging. In the case of the Single Score index, the importance of the choice of the cartonboard dataset is also noticeable to a lower extent, as for 'Alternative 2' the SU packaging performance improves compared to the 'Benchmark'. A similar result is observed for the Climate Change impact category.

Overall, the aggregated Single Score results for the SU packaging are improved in the case of the 'Alternative 2' dataset, while moving from the 'Benchmark' to 'Alternative 1' dataset generally increases the impacts of SU packaging in the majority of the simulations.

This analysis overall highlights how, in future studies, additional effort should be dedicated to developing datasets for cartonboard production that are as representative as possible of the EU context, also ensuring full methodological consistency with the EF method and with all remaining datasets (34).

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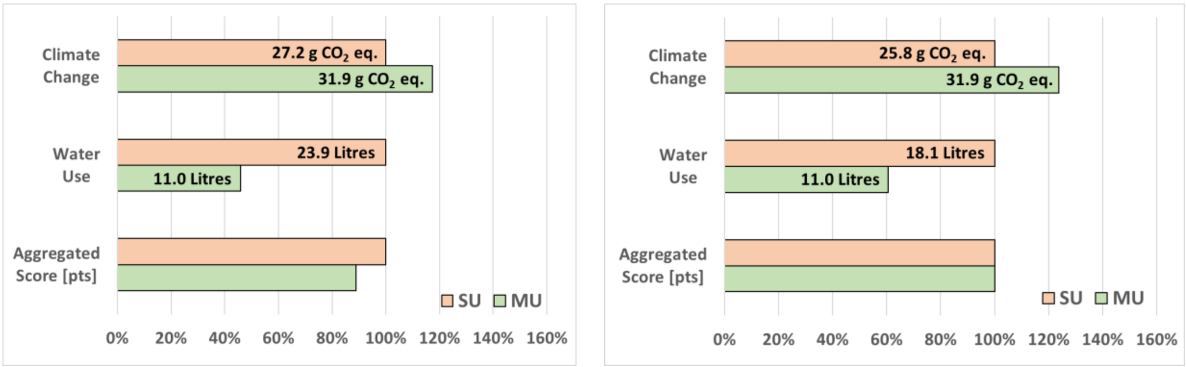
(34) Ideally, it is recommended that EF-compliant datasets are developed that are representative of the current market shares of cartonboard producers in the EU-27.

3.1.2.2 *Assumptions on the use and type of packaging lids*

As explained in Section 2.5.1, this specific analysis aims to discover the influence of the presence and type of lid on the environmental performance of the packaging in Scenario 1. Apart from the presence (or not) of the lid and its mass, all other parameters were kept constant in this analysis.

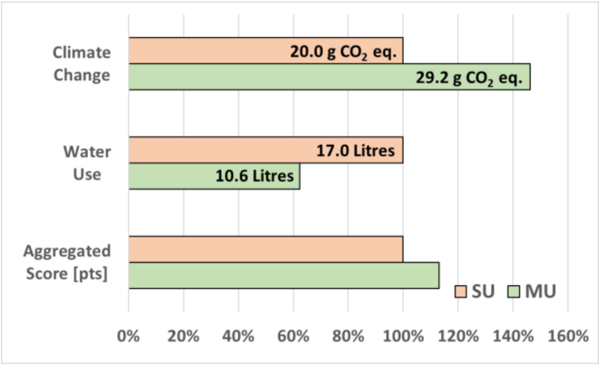
The results are illustrated in Figure 12 for the Climate Change, Water Use and aggregated Single Score (for the benchmark scenario in panel (a), the scenario with the PS lid in panel (b) and the one without the lid in panel (c)).

Figure 12. Results of the specific analysis of lid types for the Single Use (SU) and Multiple Use (MU) packaging products. The graphs illustrate the results for (a) SU packaging product including a carton lid with low-density polyethylene (LDPE) lining and (b) SU packaging including a polystyrene (PS) lid. The bottom graph (c) illustrates the results where both packaging products do not include any lid. SU impacts are set to 100 % for each impact category considered.


(a) Carton lid – Benchmark case

(b) PS lid

(c) No lid



Source of all images (a, b, c): JRC analysis.

The results suggest that the impacts of MU packaging for the Water Use impact category are lower than those of SU packaging in all three cases analysed. The opposite behaviour is observed for the Climate Change impact, where SU packaging shows lower impacts than MU packaging. Considering the Single Score, MU packaging shows lower impacts in the benchmark scenario than the SU alternative, while the reverse was observed in the scenario without a lid. These differences may be ascribed to the impacts related to the manufacturing of the different materials (PS and carton), and the different masses of the lids in the three scenarios (detailed in Section 2.5.1.2). Despite the potential advantages from a life cycle impacts perspective of having a PS lid, it must be noted that the use of plastics lids may be associated with additional environmental impacts (such as plastic littering) that are not captured in the present analysis. Moreover, the use of single material products could be preferable from an end-of-life treatment perspective, as it is generally more complex to separate and recycle multi-material waste. Overall, the assumptions related to the lid in the scenarios are less relevant than other assumptions (as analysed in the other sensitivity analysis and additional analysis for the various scenarios).

3.2 Results for Scenario 2

'Scenario 2' analyses the life cycle impacts of SU and MU packaging used for takeaway food. In particular, two case studies have been addressed:

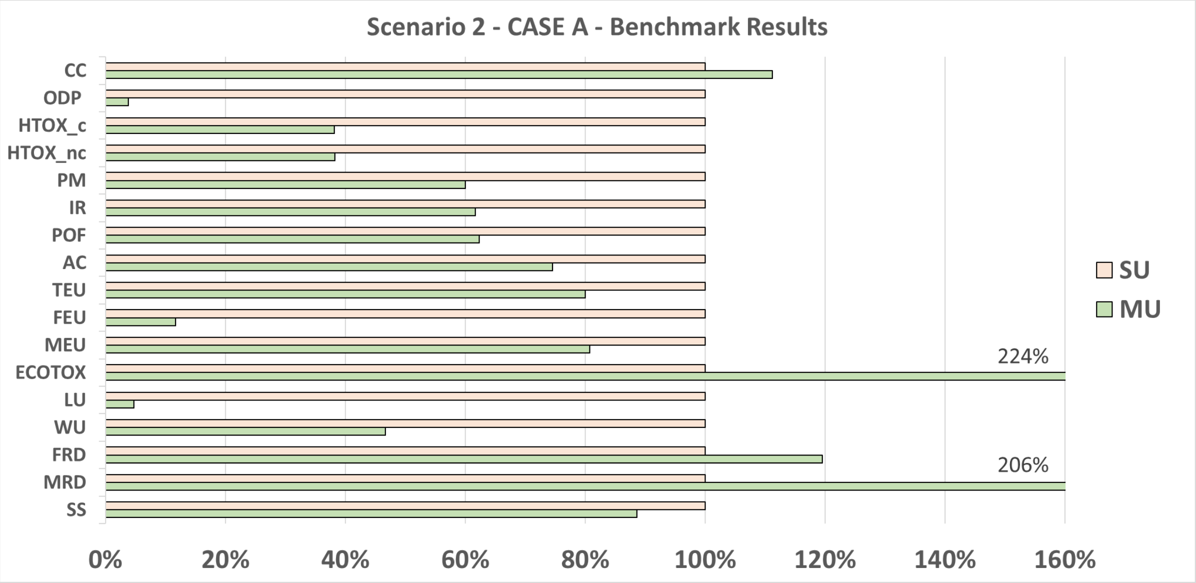
- 'CASE A': analysis of the impacts of a carton tray with LDPE lining (SU) and a PP clamshell tray (MU);
- 'CASE B': analysis of the impacts of an aluminium tray with carton cover and LDPE lining (SU) and a PP clamshell tray (MU).

Further details on 'Scenario 2' are provided in the two Factsheets in Annex 3.

3.2.1 Scenario 2 – CASE A – Benchmark and sensitivity analysis

As explained in Section 2.4.3 (Figure 2), the 'Scenario 2 – CASE A' covers the whole life cycle of the takeaway SU carton tray and the takeaway MU PP tray. Figure 13 illustrates the results of the life cycle impacts considering the benchmark values for 'Scenario 2 – CASE A'. The SU packaging exhibits lower impacts for the Climate Change, Ecotoxicity Freshwater, 'Resource Use, Fossil' and 'Resource Use, Mineral and Metals', whereas the MU packaging has lower impact for all the other impact categories. High impacts for Ecotoxicity Freshwater and 'Resource Use, Fossil' and 'Resource Use Minerals and Metals' for the MU packaging are mostly due to the plastics manufacturing and the passenger car used to return the packaging to the point of sale. The benchmark results highlight how the water requirements of the MU packaging life cycle led to lower impacts in the water use category than the SU life cycle. Lastly, the aggregated Single Score shows that the MU packaging product has overall slightly lower life cycle impacts.

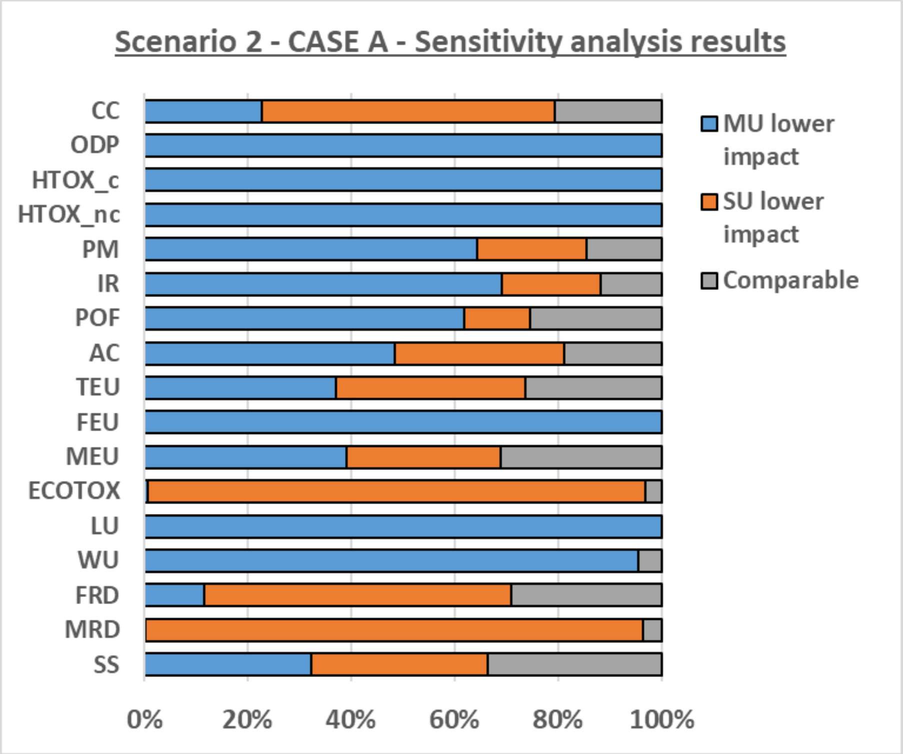
Figure 13. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 2 – CASE A'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 14 illustrates the results of the sensitivity analysis, based on the range of variation associated with each parameter in the model (see Factsheets in Annex 3 for the details).

Figure 14. Results of the sensitivity analysis for 'Scenario 2 – CASE A' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

The sensitivity analysis simulations indicate that the SU and MU packaging products are comparable in terms of the aggregated Single Score and also for other impact categories, such as the 'Eutrophication, Marine' and 'Eutrophication, Terrestrial' impact categories. Focusing on the aggregated Single Score, for approximately one third of the simulations, the SU packaging product has lower impacts, while for another third the MU packaging product has lower impacts. Lastly, in the remaining third of the simulations, the two packaging systems have comparable impacts.

In the case of the Climate Change impact category, the SU packaging product has lower impacts than the MU packaging in around 60 % of the simulations. For three impact categories (namely: 'Resource Use, Minerals and Metals'; 'Resource Use, Fossils' and Ecotoxicity Freshwater), the performance of the SU packaging product is significantly better than that of the MU packaging product. For all other impact categories, the MU packaging product had lower impacts than the SU packaging in the majority of the simulations.

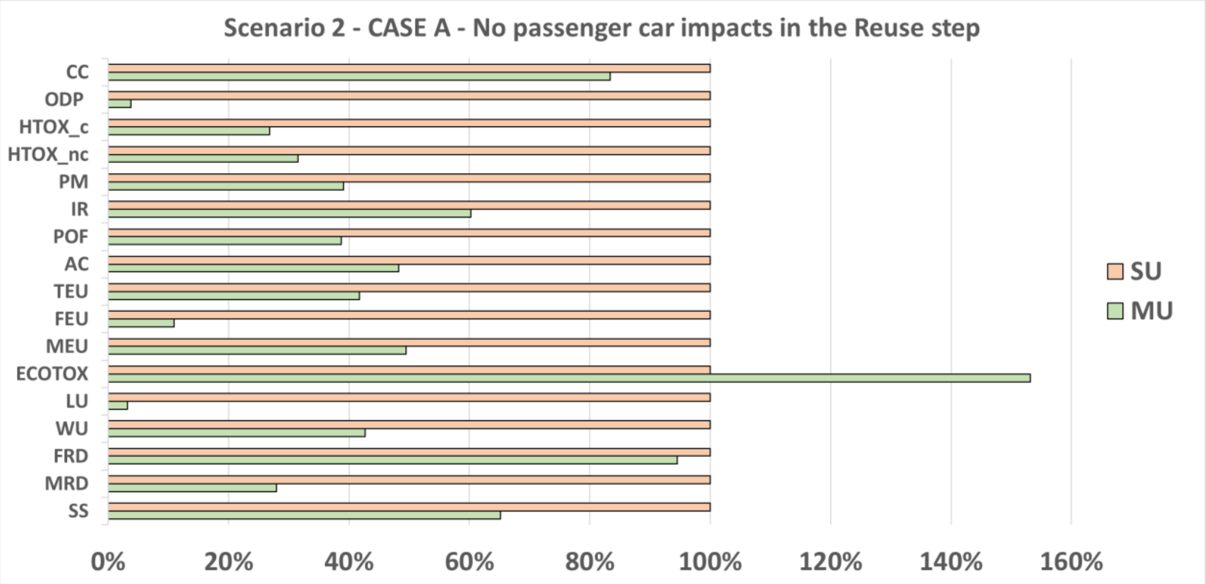
The Factsheets in Annex 3 provide additional results for this Scenario, comprising (i) an overview of the contribution of the various life cycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

3.2.2 Scenario 2 – CASE A – Additional analyses

3.2.2.1 *Influence of passenger car transport and related impacts*

As explained in Section 2.5.1, a dedicated scenario was assessed to discover the relevance of the assumptions related to transport by passenger car in the reuse step of the MU packaging product in 'Scenario 2 – CASE A'. The results for the benchmark values of the parameters are illustrated in Figure 15, while Figure 16 illustrates the results for the sensitivity analysis.

Figure 15. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 2 – CASE A', when the passenger car impacts of the reuse step of the MU packaging are excluded from the analysis. SU impacts are set to 100 % for each impact category considered.

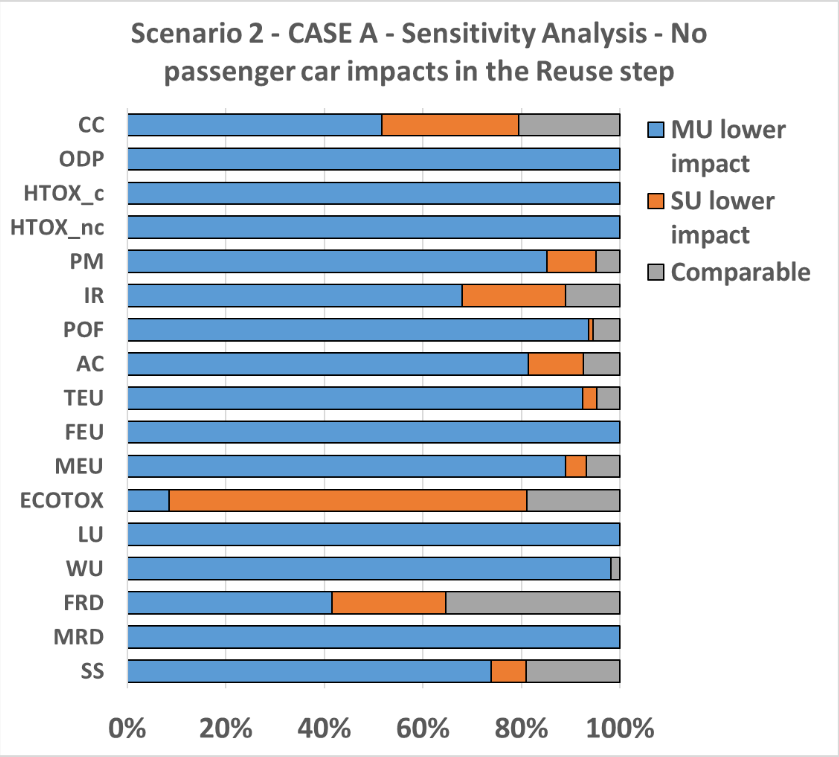


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

When the results in Figure 15 and Figure 16 are compared with the corresponding results in Section 3.2.1, it is evident how the assumptions about consumer behaviour in the reuse step play a crucial role in the performance of the MU packaging product. This is especially relevant for certain impact categories (such as Climate Change, 'Resource Use, Fossils' and 'Resource Use, Minerals and Metals') where passenger car transport plays a significant role in the overall life cycle performance. Overall, when the impacts associated with transport by passenger car are removed from the model, the MU packaging product's performance significantly improves and becomes favourable in almost all impact categories (Figure 16). For example, in the case of the aggregated Single Score, the results of the sensitivity analysis presented in Section 3.2.1 did not show a preference for any particular option (SU packaging having lower impacts in one third of cases, MU packaging having lower impacts in another third of the simulations, and the impacts being comparable in the remaining third of cases). By contrast, the results in Figure 16 show the impact of MU packaging as lower in a large majority of the simulations. A similar shift in the results is observed in particular for some impact categories, including Climate Change.

This sensitivity analysis underlined the relevance of the assumptions about consumer behaviour in takeaway packaging products during the reuse phase, especially those concerning the return of the packaging to the point of sale. The benchmark model assumes that in 25 % of the cases the items are collected by the delivery service. In only 75 % of the cases are the items returned by consumers and it was assumed that in 10 % of these cases the transport should be allocated to the packaging products under examination in this case study, and also assumes that five items are transported on each journey (Annex 3). Such assumptions were cross-checked with inputs from stakeholders during the consultation. However, as this is also a matter of allocating the impacts, there is not an unambiguous way of modelling them, as the assumptions are also based on value choices. It is recommended that more primary data from the business models in place in the market should be collected in future to properly capture consumer behaviour and better allocate the impact associated with this step.

Figure 16. Results of the sensitivity analysis for 'Scenario 2 – CASE A' for all impact categories of Single Use (SU) and Multiple Use (MU) packaging products, when the passenger car impacts of the reuse step of the MU packaging are excluded from the analysis.



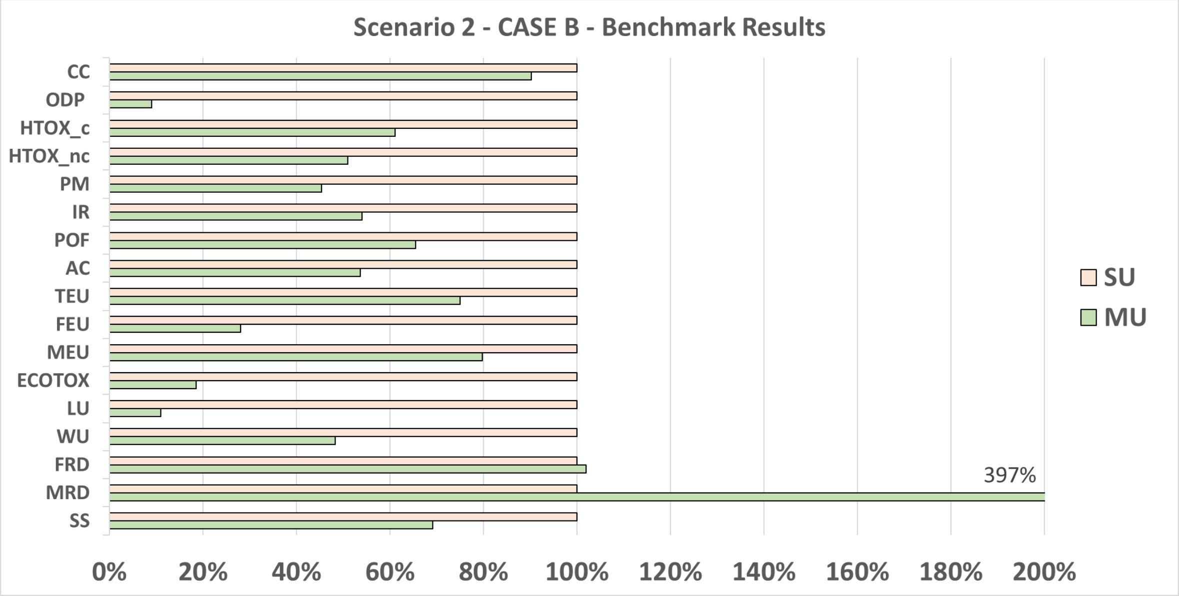
Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

3.2.3 Scenario 2 – CASE B – Benchmark and sensitivity analysis

As explained in Section 2.4.3 (Figure 2), 'Scenario 2 – CASE B' analyses the life cycle of a takeaway SU aluminium tray and a takeaway MU PP tray. Figure 17 provides the results of the life cycle impacts calculated for the benchmark values for 'Scenario 2 – CASE B'. The analysis shows that the MU packaging product has lower impacts for all impact categories, except for the 'Resource Use, Fossil' and 'Resource Use, Minerals and Metals' impact categories. The Benchmark for this scenario results also show that the Water Use impacts for the MU packaging life cycle are lower compared than those for the SU life cycle.

The aggregated Single Score shows overall lower environmental impacts for the MU packaging product.

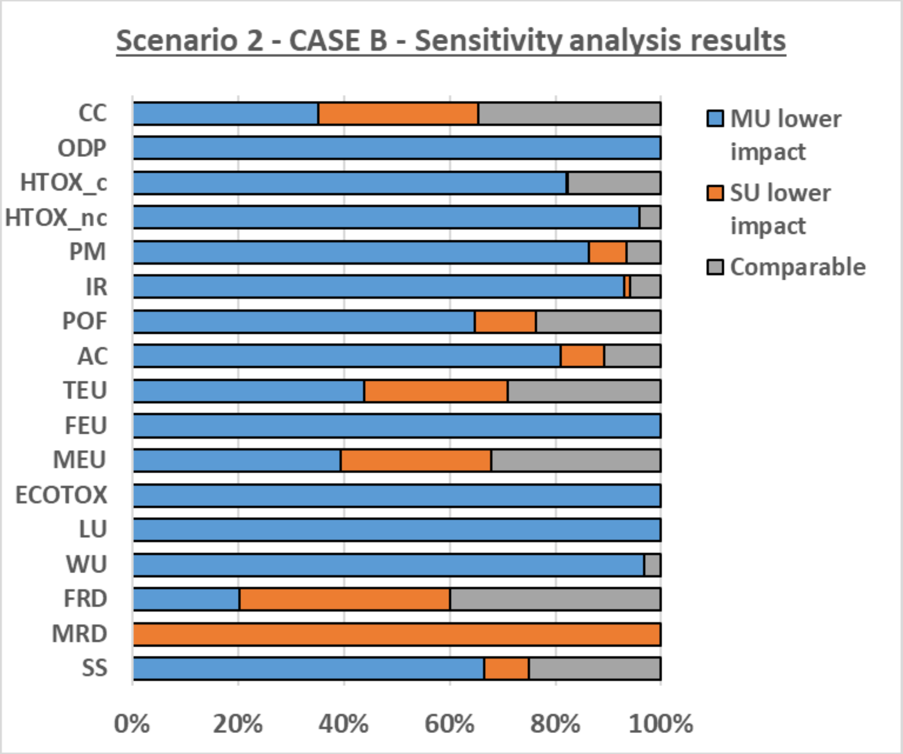
Figure 17. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products in 'Scenario 2 – CASE B'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Based on the ranges (i.e. minimum and maximum) associated with each parameter in the model (see Factsheets in Annex 3), the results of the sensitivity analysis are provided in Figure 18.

Figure 18. Results of the sensitivity analysis for ’Scenario 2 – CASE B’ for all impact categories for Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

According to the sensitivity analysis simulations, the impacts of the SU and MU packaging products are comparable for the Climate Change impact category (in roughly one third of the simulations). In the case of the aggregated Single Score, the MU packaging product had lower impacts in the majority of the simulations. Only in two impact categories (namely ‘Resource Use, Minerals and Metals’ and ‘Resource Use, Fossil’) the impacts of the SU packaging lower in the majority of the simulations or the impacts of the two packaging products are comparable.

The Factsheets in Annex 3 provide additional results for this Scenario, comprising (i) an overview of the contribution of the various life cycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

3.3 Results for Scenario 3

'Scenario 3' focuses on the analysis of the environmental performance of packaging for alcoholic and non-alcoholic beverages in the form of beer, carbonated alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, etc. Further details of 'Scenario 3' are provided in the two Factsheets in Annex 3. In particular, two case studies have been addressed:

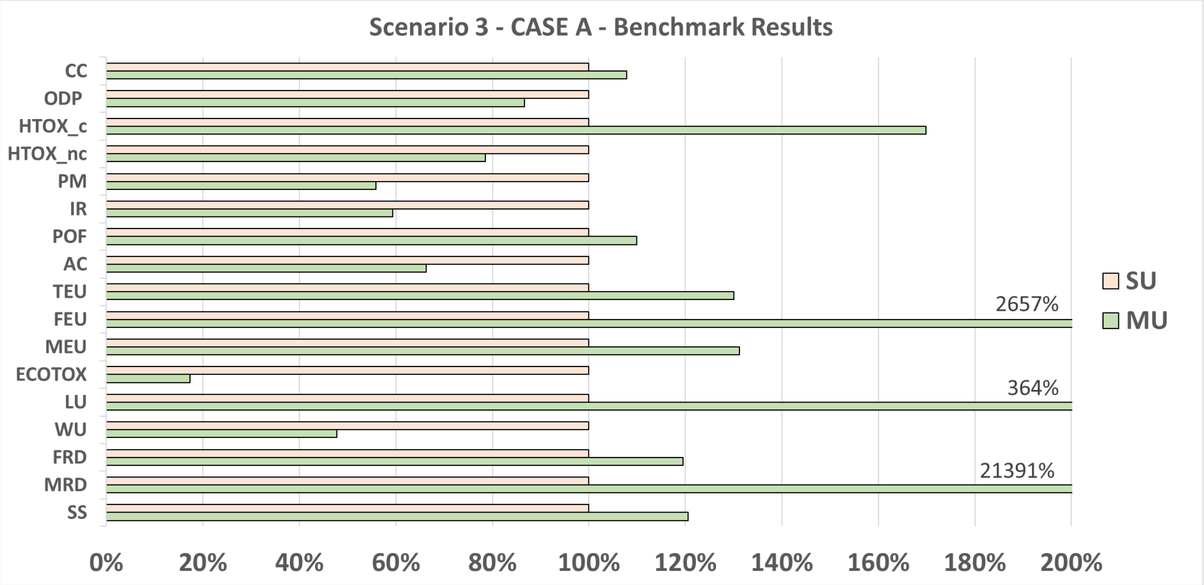
- 'CASE A': analysis of the impacts of an aluminium can (SU) and of a plastic bottle with a PP cap (MU);
- 'CASE B': analysis of the impacts of a glass bottle (SU) and a glass bottle (MU).

3.3.1 Scenario 3 – CASE A – Benchmark and sensitivity analysis

As outlined in Section 2.4.3 (Figure 3), 'Scenario 3 – CASE A' analyses the life cycle impacts of both an SU aluminium can and an MU plastic bottle. Figure 19 shows the life cycle impacts calculated for the benchmark values for 'Scenario 3 – CASE A'.

For the SU packaging the production of the aluminium is mainly driving the life cycle impacts across the various impact categories. The SU packaging had lower impacts in the majority of cases, especially for the Land Use, 'Eutrophication, Freshwater' and 'Resource Use, Minerals and Metals' impact categories. High impacts in these categories are due to the manufacturing of plastic components for the MU packaging, coupled with the passenger car used to return the bottles for washing (and related energy needs for the washing step). In contrast, the SU packaging impacts are higher, for instance in the case of the Water Use impact category (due to the substantial amounts of water consumed in the aluminium production) and the Acidification impact category. The aggregated Single Score shows the overall lower environmental impacts of the SU packaging product.

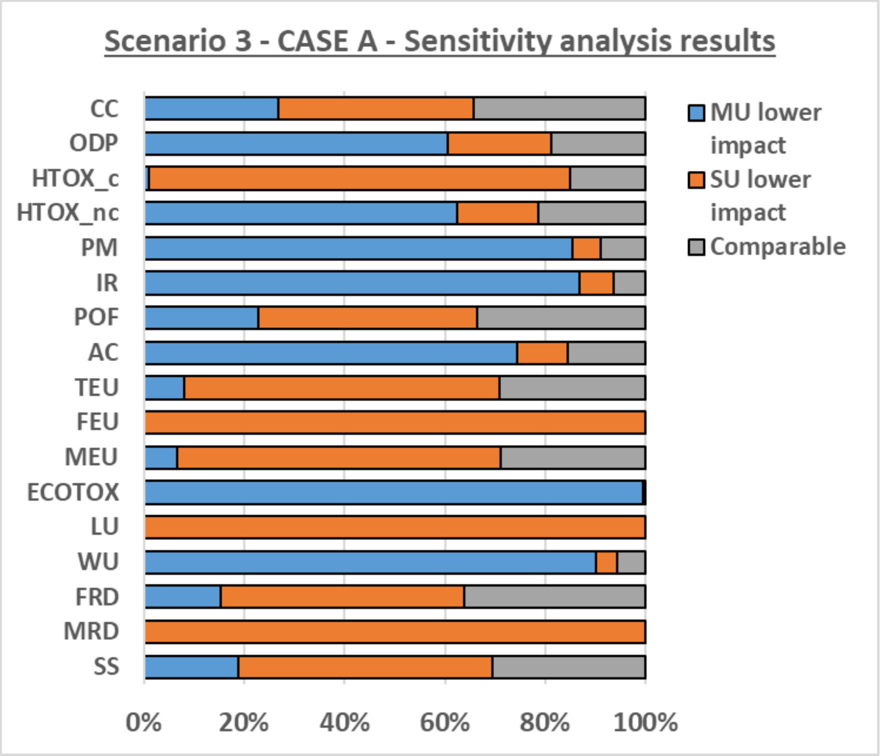
Figure 19. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 3 – CASE A'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 20 illustrates the results of the sensitivity analysis, based on the range of variation associated with each parameter in the model (see Factsheets in Annex 3 for the details).

Figure 20. Results of the sensitivity analysis for 'Scenario 3 – CASE A' for all impact categories of the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

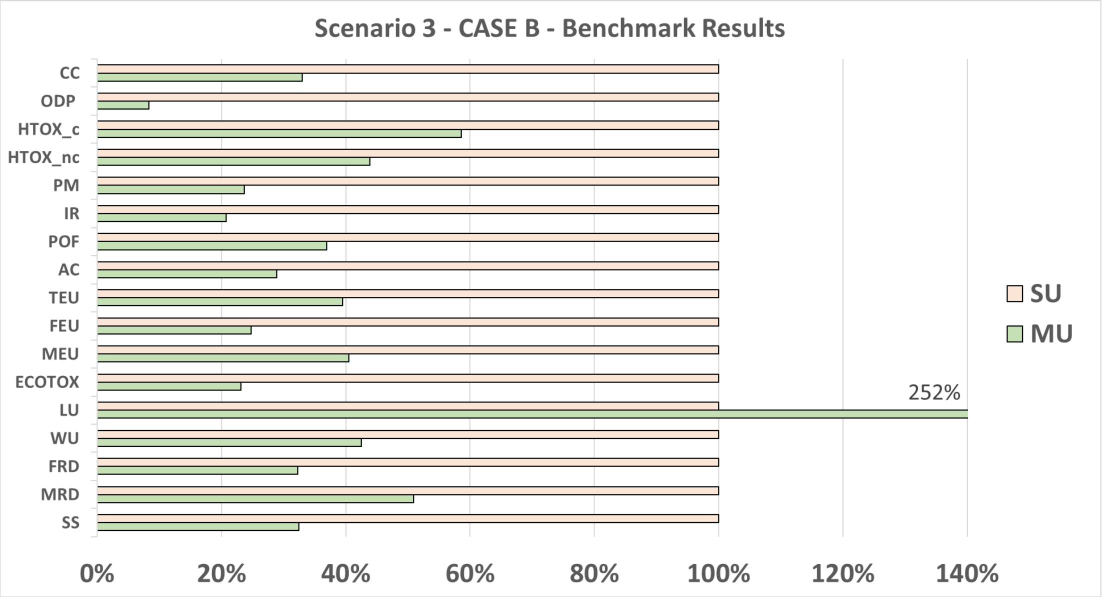
The results underline lower impacts of the SU packaging product compared with the MU alternative for several impact categories (e.g. 'Eutrophication, Freshwater' and 'Resource Use, Minerals and Metals'). By contrast, the MU packaging product exhibits lower impacts than SU packaging for other categories (e.g. Particulate Matter and Ionising Radiations). In the case of the Climate Change impact, the overall performance of the two packaging products is comparable. For the aggregated Single Score, the results indicate that the SU packaging product has lower impacts in about 50 % of the simulations, whereas in 20 % of the simulations the MU packaging has lower impacts, and in around 30 % of the simulations the impacts of the two packaging products are comparable.

The factsheets in Annex 3 provides additional results for this Scenario, comprising (i) an overview of the contribution of the various life cycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

3.3.2 Scenario 3 – CASE B – Benchmark and sensitivity analysis

As outlined in Section 2.4.3 (Figure 3), the ‘Scenario 3 – CASE B’ analyses the life cycle of both an SU glass beer bottle and an MU glass beer bottle; the latter has a greater thickness than the SU glass bottle. Figure 21 provides the results of the life cycle impacts calculated considering the benchmark values for ‘Scenario 3 – CASE B’. The results of the benchmark analysis underline the better performance of the MU packaging product compared with the SU product in almost all impact categories, except Land use (35). For all the other categories, the impacts of the MU packaging are always less than 60 % of the SU impacts. Similarly, the Single Score results show that the impacts of the MU bottle are lower overall.

Figure 21. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for ‘Scenario 3 – CASE B’. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Along similar lines to that observed in the benchmark results, the sensitivity analysis also highlights the better performance of the MU bottle compared with the SU bottle. Figure 22 illustrates the results of the sensitivity analysis, based on range of the variation associated with each parameter in the model. Apart from the Land Use impact category, the MU packaging generally had lower impacts for all the impact categories. In addition, the Single Score shows that the MU packaging had overall lower impacts in more than 95 % of the simulation.

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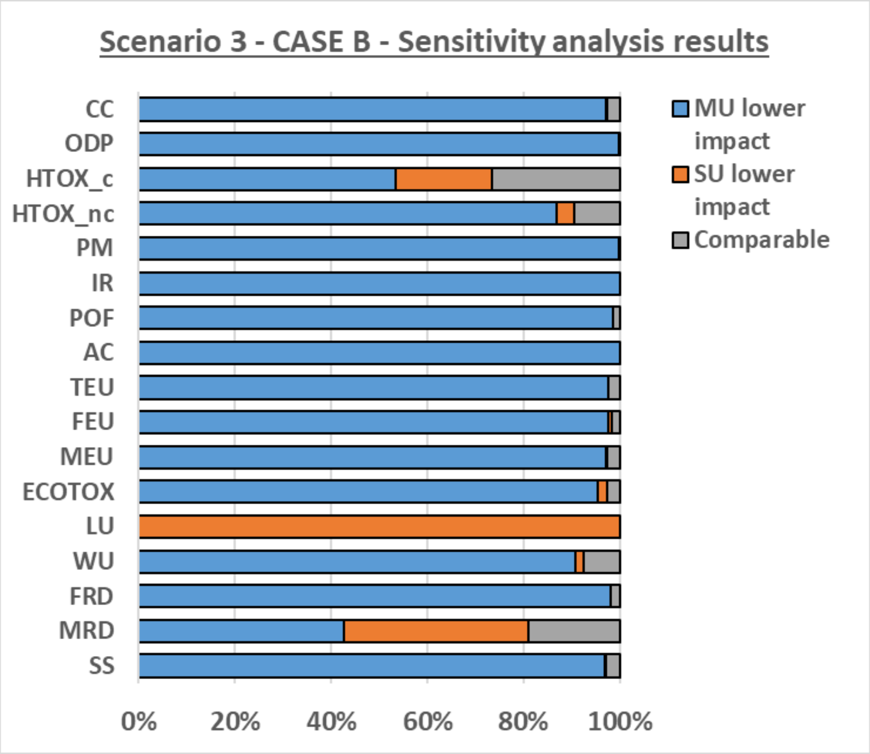
(35) The results for the Land Use impact category are affected by the credits in the aggregated EF dataset employed to model virgin and recycled glass manufacturing.

Figure 22. Results of the sensitivity analysis for 'Scenario 3 – CASE B' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheets in the Annex 3 provides additional results for this Scenario, comprising (i) an overview of the contribution of the various lifecycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

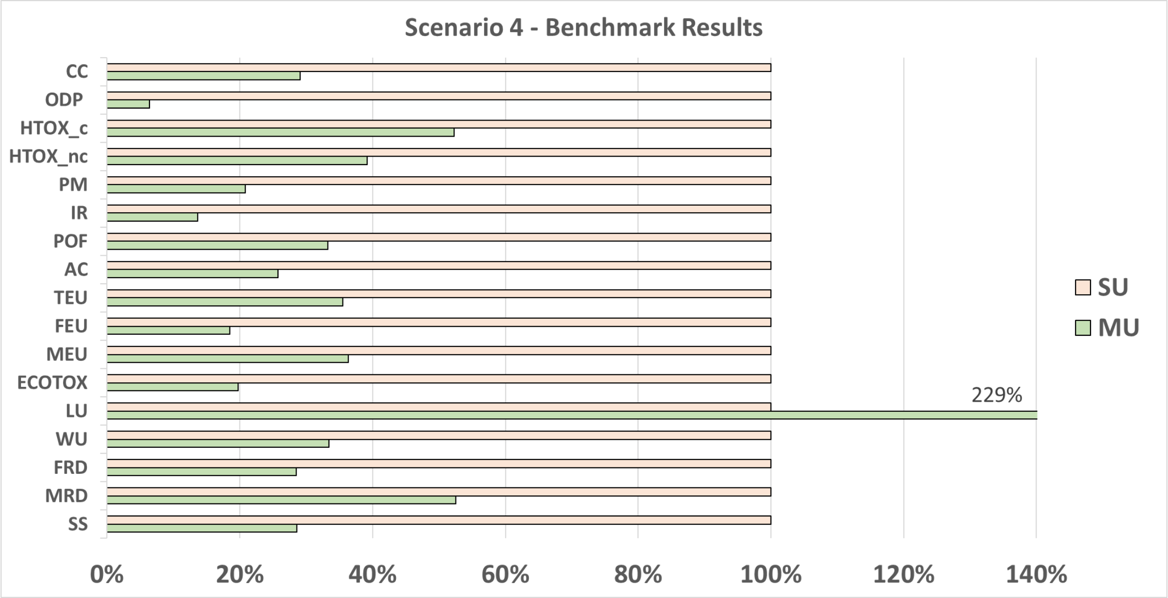
3.4 Results for Scenario 4

'Scenario 4' analyses the environmental impacts of bottles for alcoholic beverages in the form of wine (with the exception of sparkling wine). The results for 'Scenario 4' are further detailed in the Factsheets in Annex 3. In particular, a case study analyses the impacts of an SU glass bottle and a thicker glass bottle (MU).

3.4.1 Scenario 4 – Benchmark and sensitivity analysis

As outlined in Section 2.4.3 (Figure 4), 'Scenario 4' analyses the life cycle of both an SU glass wine bottle and an MU glass wine bottle, the latter being thicker than the SU bottle. Figure 23 shows the results for the life cycle impacts calculated considering the benchmark values. The MU packaging product has lower impacts than the SU packaging product for all impact categories, except Land Use. In particular, the impacts of the MU packaging are 60 % or less than those of the SU bottle.

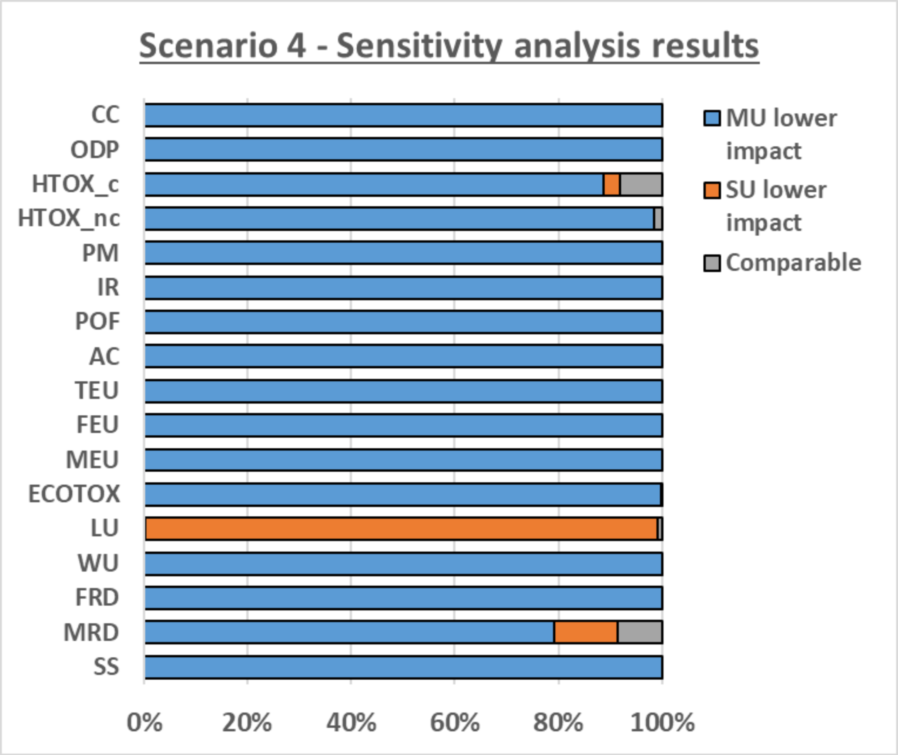
Figure 23. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 4'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 24 illustrates the results of the sensitivity analysis, based on the range of variation associated with each parameter in the model (see Factsheets in Annex 3 for the details). Apart from the Land Use impact category, the MU packaging has lower impacts than the SU packaging for all impact categories. Even the Single Score results point to the overall lower impacts of the MU packaging in almost all simulations.

Figure 24. Results of the sensitivity analysis for 'Scenario 4' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score

Factsheets in the Annex 3 provides additional results for this Scenario, comprising (i) an overview of the contribution of the various lifecycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

3.5 Results for the Restaurant Scenario

The ‘Restaurant Scenario’ provides a case study analysis of the environmental impacts of SU and MU packaging used by operators in the dine-in HORECA sector. A case study was investigated as follows:

- Analysis of a ‘hamburger meal’ provided with either SU or MU packaging. The SU packaging is composed of a carton cup with LDPE lining for the drink, a carton tray with LDPE lining for the hamburger and a carton tray with LDPE lining for the fries. The MU packaging is composed of a PP cup for the drink and a PP plate for both the fries and the hamburger.

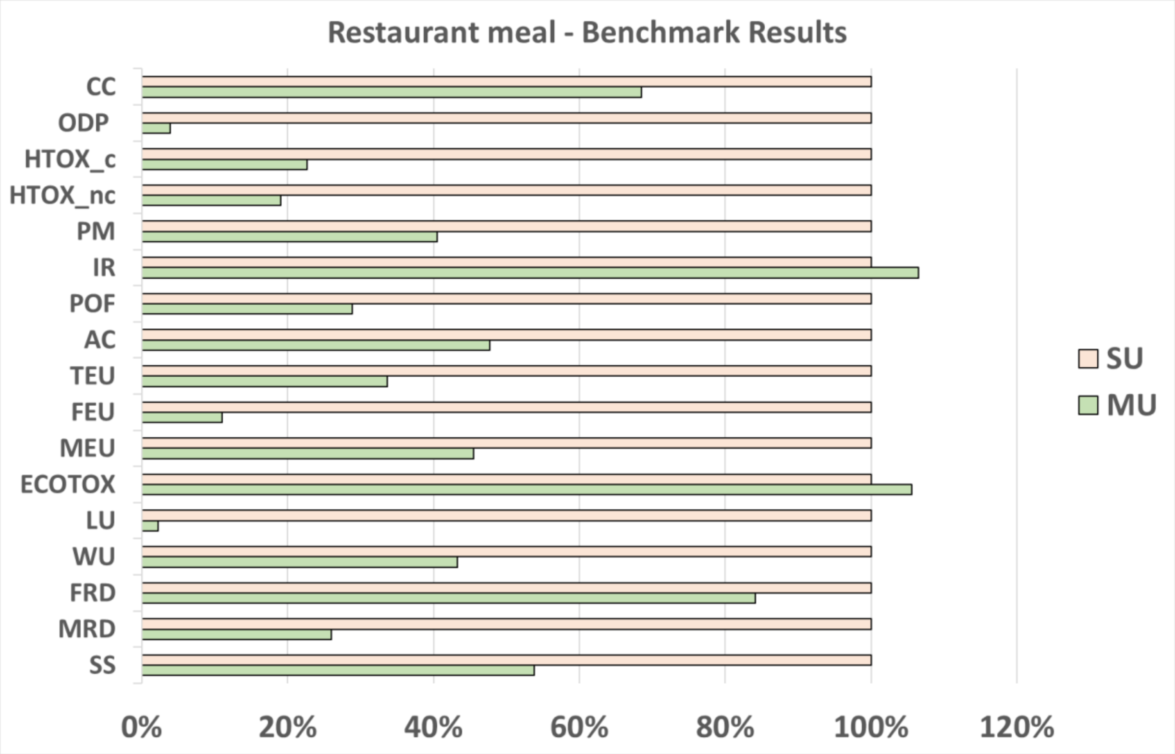
Further details are provided in the ‘Restaurant Scenario’ Factsheet in Annex 3.

3.5.1 Restaurant Scenario – Benchmark and sensitivity analysis

As outlined in Section 2.4.3 (Figure 5), the ‘Restaurant Scenario’ analyses the life cycle impacts of SU packaging used for a hamburger meal (composed of a carton cup, with LDPE lining and no lid, for the drink; a carton tray for the hamburger and a smaller carton tray for the fries) and of MU packaging used for the meal (composed a PP cup, without lid, for the drink, and a PP plate for both the hamburger and fries).

Figure 25 shows the results for the life cycle impacts calculated considering the benchmark values. The MU packaging has lower impacts than the SU packaging for almost all impact categories, except the Ionising Radiations and the Ecotoxicity Freshwater impact categories. Despite the water consumed during the washing for reuse, the MU packaging has overall lower impacts for the Water Use impact category. The Single Score index also shows that impacts of the MU are overall lower.

Figure 25. Comparison of the benchmark impacts of Single Use (SU) and Multiple Use (MU) meals for the ‘Restaurant Scenario’. SU impacts are set to 100 % for each impact category considered.

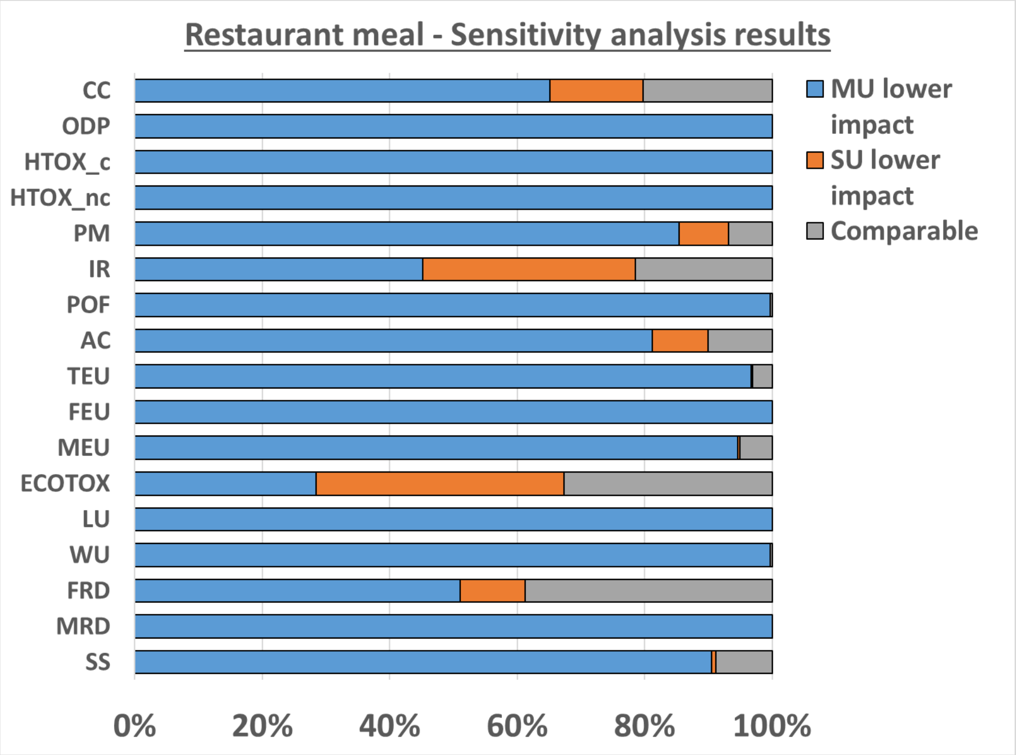


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 26 illustrates the results of the sensitivity analysis, based on the range of variation associated with each parameter in the model (see Factsheets in Annex 3 for the details).

The MU packaging has lower impacts for almost all impact categories and the majority of the simulations. For Climate Change impact, the MU packaging had lower impacts than the SU packaging in more than 60 % of the simulations, and the aggregated Single Score for of the MU packaging was lower in around 90 % of the simulations. Only for two impact categories (namely Ecotoxicity Freshwater and Ionising Radiation) did the simulations show comparable impacts for the SU and MU packaging products.

Figure 26. Results of the sensitivity analysis for the 'Restaurant Scenario' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheets in Annex 3 provides additional results for this Scenario, comprising (i) an overview of the contribution of the various lifecycle stages to the impacts of the SU and MU packaging and (ii) the breakdown of the impacts for the reuse stage of the MU packaging.

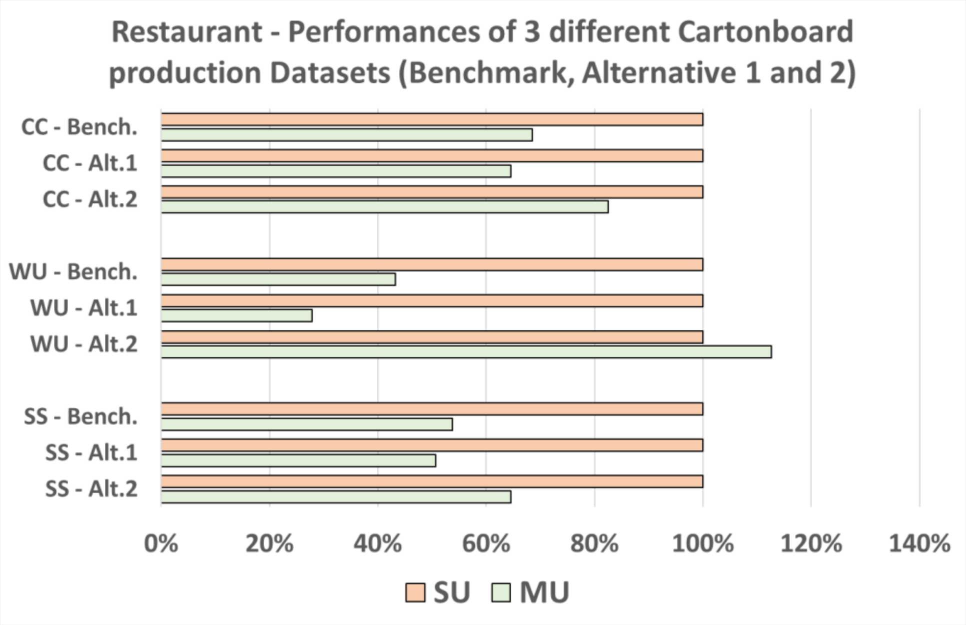
3.5.2 Restaurant Scenario – Additional analyses

3.5.2.1 Use of alternative life cycle datasets for the analysis of cartonboard production

As outlined in Section 2.5.1, this additional sensitivity analysis assesses the influence of using different input datasets for the production of cartonboard used in the 'Restaurant Scenario'. This analysis considered the 'Benchmark dataset' (retrieved during the stakeholder consultation; see Table 2) and the 'Alternative 1' dataset (referring to the EF3.1 dataset on solid board bleached production) and 'Alternative 2' dataset (an additional dataset retrieved during the stakeholder consultation). All other parameters (and ranges) and inventory values were kept constant in the analysis.

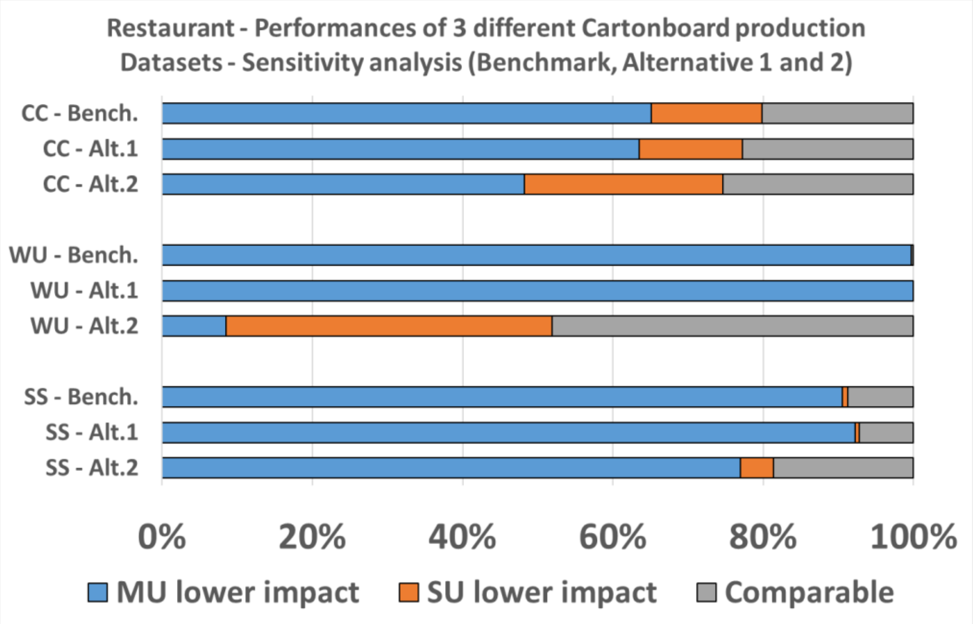
Figure 27 presents the results of the analysis (considering benchmark values for the parameters and varying the cartonboard manufacturing impacts), and Figure 28 presents the results of the sensitivity analysis (calculated keeping the same ranges and parameter values as for the base scenario in Section 3.5.1 and varying the cartonboard manufacturing impacts). The results are illustrated for the Climate Change and the Water Use impact categories and the aggregated Single Score. A complete set of results for all impact categories is provided in Annex 3.

Figure 27. Results of the specific sensitivity analysis for cartonboard impacts for the Single Use (SU) and Multiple Use (MU) packaging products. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; WU = Water Use; SS = Single Score. The 'Benchmark dataset' (Bench.) used in the analysis refers to a dataset retrieved during the stakeholder consultations; the 'Alternative 1' dataset refers to the EF3.1 dataset, the 'Alternative 2' dataset refer to a dataset retrieved during the stakeholder consultation. For further details see Section 2.5.1 and Annex 2.

Figure 28. Results of the specific sensitivity analysis for cartonboard impacts, comparing the results of the sensitivity analysis simulations for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; WU = Water Use; SS = Single Score. The 'Benchmark dataset' (Bench.) used in the analysis refers to a dataset retrieved during the stakeholder consultations; the 'Alternative 1' dataset refers to the EF3.1 dataset, the 'Alternative 2' dataset refer to a dataset retrieved during the stakeholder consultation. For further details see Section 2.5.1 and Annex 2.

The results shown in Figure 27 and Figure 28 suggest that the changes in the two alternative scenarios are particularly relevant, especially for the Water Use impact category. Switching to the 'Alternative 2' packaging dataset results in lower Water Use impacts for the SU packaging.

For the Climate Change impact category and the aggregated Single Score, the MU packaging has lower impacts for all the tested alternatives, although the differences with the SU impact are reduced when considering 'Alternative 2' dataset scenario.

Similarly, the results of the sensitivity analysis (Figure 28) show that MU packaging has lower impacts in the majority of the simulations, with the exception of water use in the 'Alternative 2' scenario, for which the SU packaging products had a better environmental performance.

3.5.2.2 Assumptions on end-of-life parameters and calculation of break-even points

As outlined in Section 2.5.1, a set of three additional scenarios for calculating the BE point were analysed for the 'Restaurant Scenario', looking at the effects of varying assumptions concerning recycling at the end-of-life stage (R_2 parameter of the CFF) of the carton ('BE analysis 1'), recycling at the end-of-life stage of the carton together with improved recycling at the end-of-life stage of PP ('BE analysis 2') and the number of reuses of the MU packaging ('BE analysis 3').

The results presented in Figure 29 illustrate the effect of varying the recycling rate at the end-of-life stage of the carton from 0 % to 100 %, considering the different alternatives for the input dataset for cartonboard (as described in Section 2.4.4 and in Section 2.5.1). Considering the 'Benchmark dataset' for cartonboard production (see Table 2 in Section 2.5.1), the BE point for the recycling rate of carton would be reached at around 75 %. This means that, when carton waste packaging is recycled at a rate of 75 %, MU and SU packaging have a similar carbon footprint; for recycling rates higher than 75 %, SU packaging has a lower carbon footprint.

In the case of the 'Alternative 1' (when the EF3.1 dataset is used in the model), the BE point would be reached at a lower carton recycling rate (around 70 %). This is because of the differences in the Climate Change impacts for the 'Benchmark' and the 'Alternative 1' dataset and the system boundaries of the carton production for this dataset.

By contrast, using the 'Alternative 2' dataset for cartonboard production, the BE point is reached at around 50 %. This can also be explained by the difference in the Climate Change impacts associated with the 'Alternative 2' dataset, which are lower than in the 'Benchmark' and 'Alternative 1' scenarios. Under the 'Alternative 2' scenario, SU packaging would have a lower carbon footprint than MU packaging when the recycling rate of carton waste packaging is higher than 50 %.

These results confirm the significant role of the impacts of cartonboard manufacturing, and the life cycle dataset used in the model. Using low-impact cartonboard for SU packaging and achieving a remarkably high recycling rate at the end-of-life stage will substantially improve its environmental performance, potentially resulting in lower impacts for SU packaging than MU alternatives, even in dine-in scenarios.

Figure 30 presents the results of an additional sensitivity analysis with all the assumptions as in 'BE analysis 1' with the exception of the end-of-life recycling rate of PP in MU packaging products, which is assumed to be largely increased up to 85 %. It is notable that the improved performance of the MU has an overall minimal effect on the values of the BE points, and the BE points remain almost unchanged for all cartonboard datasets.

Figure 31 (36) presents the results of the analysis when different number of reuses are assumed for the MU packaging products in the 'Restaurant Scenario'. In particular, the number or reuses is assumed to vary from 5 to 200, in combination with different datasets on cartonboard manufacturing (as described in Section 2.4.4 and in Section 2.5.1) used as inputs to the model. The results show that the BE point is reached at 20–30 reuses, when the 'Benchmark' cartonboard dataset is used. For a higher number of reuses, the MU packaging products have a lower carbon footprint than the SU packaging products. The BE point is reached at around 20 reuses (when 'Alternative 1' cartonboard dataset is assumed) or 40 uses (for the 'Alternative 2'). These results are aligned with the differences in the Climate Change impacts assumed for the three datasets: for instance, the lower Climate Change impacts associated with cartonboard in 'Alternative 2' dataset results in a higher BE point for number of reuses for MU packaging compared with the other alternatives.

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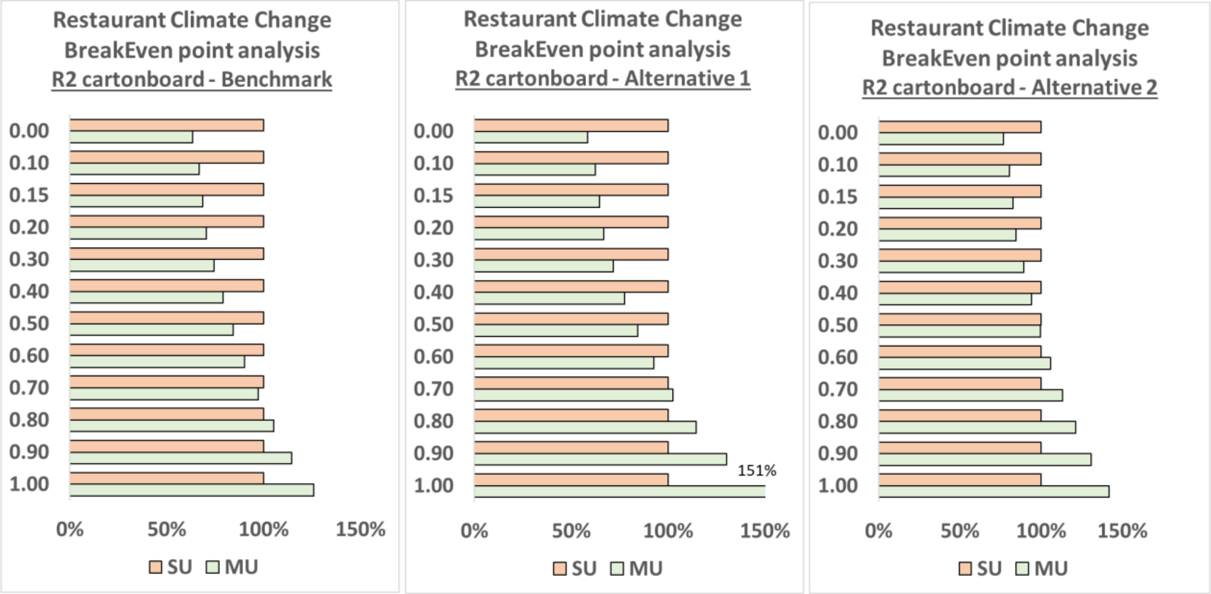
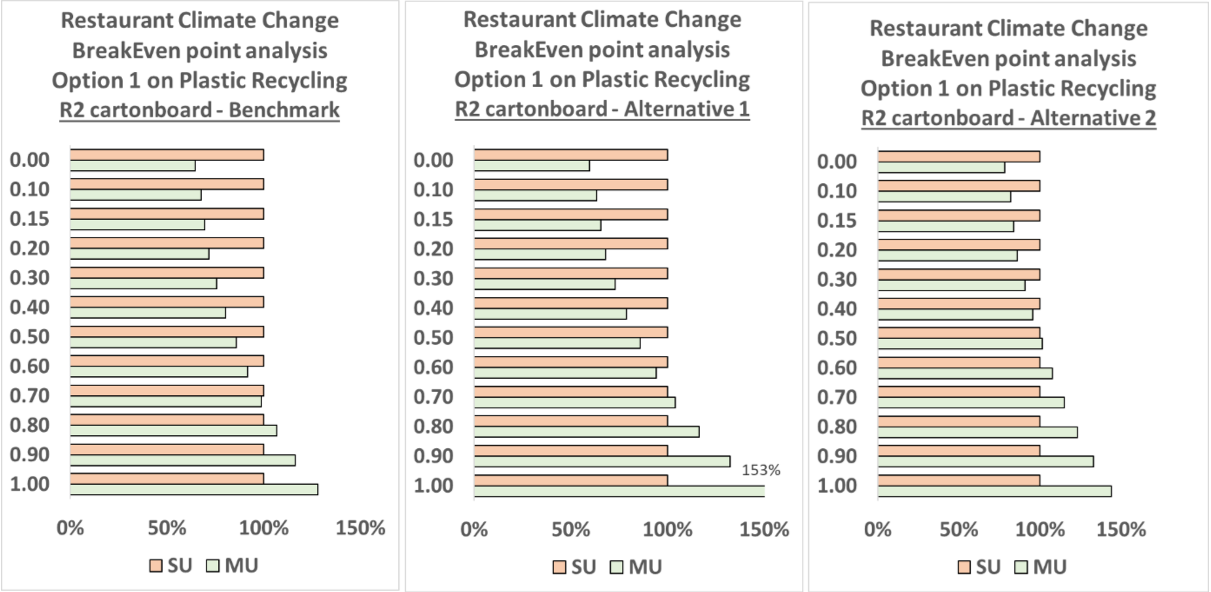
(36) The *y*-axis of the graphs have been adjusted to provide more detail for lower numbers of reuses.

Figure 29. Results for the additional analysis Break-Even (BE) points for the ‘Restaurant Scenario’, assessing the effects of varying the end-of-life recycling rate (R_2) for Single Use (SU) carton cups and trays. The end-of-life recycling rate of PP in Multiple Use packaging products is kept constant and equal to the benchmark value (41 %). All other parameters are kept constant.



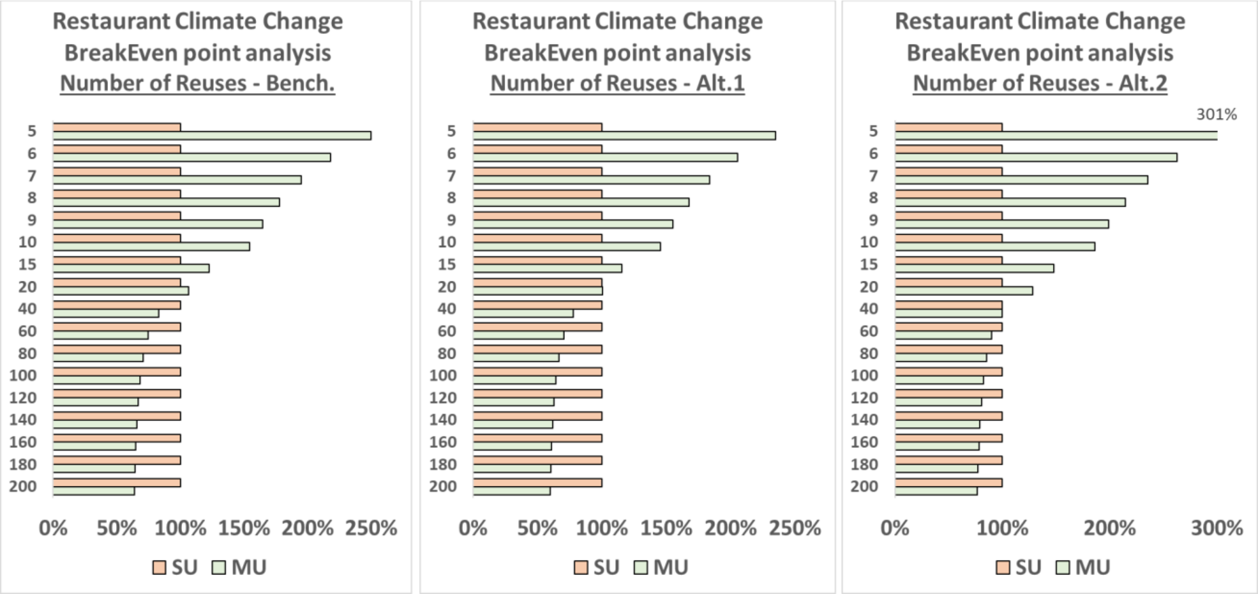
Source: JRC analysis. In this figure, “Benchmark” refers to the cartonboard production dataset used for the benchmark analysis and retrieved during the stakeholder consultation. The “Alternative 1” dataset refers to the EF3.1 cartonboard production dataset, while the “Alternative “2 dataset refer to an alternative cartonboard production dataset retrieved during the stakeholder consultation. Further details are provided in Section 2.5.1 and Annex 2.

Figure 30. Results of the additional analysis of Break-Even (BE) points for the ‘Restaurant Scenario’, assessing the effects of varying the end-of-life recycling rate (R_2) for Single Use (SU) carton cups and trays. The end-of-life recycling rate of PP in Multiple Use (MU) packaging is set at 85 %. All other parameters are kept constant.



Source: JRC analysis. In this figure, “Benchmark” refers to the cartonboard production dataset used for the benchmark analysis and retrieved during the stakeholder consultation. The “Alternative 1” dataset refers to the EF3.1 cartonboard production dataset, while the “Alternative “2 dataset refer to an alternative cartonboard production dataset retrieved during the stakeholder consultation. Further details are provided in Section 2.5.1 and Annex 2.

Figure 31. Results of the additional analysis of Break-Even (BE) points for the ‘Restaurant Scenario’, assessing the effects of varying the number of reuses of the Multiple Use (MU) packaging. Single Use (SU) impacts for each impact category are set to 100. All other parameters are kept constant.



Source: JRC analysis. In this figure, “Benchmark” refers to the cartonboard production dataset used for the benchmark analysis and retrieved during the stakeholder consultation. The “Alternative 1” dataset refers to the EF3.1 cartonboard production dataset, while the “Alternative “2 dataset refer to an alternative cartonboard production dataset retrieved during the stakeholder consultation. Further details are provided in Section 2.5.1 and Annex 2.

4 Discussion

In this chapter the main findings of the study are discussed and framed in the context of the existing literature. The mains strengths and limitations of the study are also explored.

4.1 Key findings from the Scenarios assessed

This JRC study focused on the analysis of several case studies dedicated to assessing the life cycle environmental performance of SU and MU packaging. The scenarios and related MU and SU case studies were selected from a wide array of possible alternatives, as they relate to the Commission's policy proposals on reuse targets (EC, 2022). Case studies were developed and modelled to be as up-to-date and representative of the European context as possible.

The analysis of the SU and MU packaging products showed variable results according to the specific Scenario and case study considered and also depending on the impact category assessed.

First, the research team analysed different SU and MU packaging materials for takeaway services in 'Scenario 1' and 'Scenario 2' ('CASE A' and 'CASE B'). The results for 'Scenario 1' and 'Scenario 2 – CASE A', showed that SU packaging (cups and trays, respectively) had lower Climate Change impacts than the alternative MU PP packaging. Lower impacts for the SU packaging products were also found for some other impact categories (such as the Ecotoxicity Freshwater and the 'Resource Use, Fossil' and 'Resource Use, Minerals and Metals'). However, in both these scenarios, MU packaging products had lower impacts than SU packaging in other categories, such as Water Use, Ozone Depletion Potential and 'Human Toxicity, cancer' and 'Human Toxicity, non-cancer'. Overall, with regard to the Single Score aggregated index, the MU packaging had lower impacts than SU packaging in around 40 % the simulations in the sensitivity analysis for 'Scenario 1' ([37]). Concerning the Single Score in 'Scenario 2 – CASE A', the MU packaging product had lower impacts in approximately one third of the simulations, while in another third, the SU packaging product had lower impacts, and in the remaining third the impacts of the two types of packaging were comparable.

Additional analyses were also performed with different life cycle datasets modelling the impacts associated with the cartonboard production process. These datasets proved to be significant for the results of the analyses, as the cartonboard manufacturing process is a key contributor to the overall life cycle impacts of the SU packaging products assessed in the present study. In fact, when using datasets for cartonboard manufacturing with low impacts, the environmental performance of SU packaging was clearly improved, especially for the Water Use impact category and, to a lower extent, for the Single Score. However, it must be noted that the cartonboard production datasets retrieved from the stakeholder consultation could not be guaranteed to be consistent or compliant with the EF method. Furthermore, changing assumptions about the presence and type of lid had a minor effect on the outcomes of the 'Scenario 1'.

Moreover, the study allowed a large number of factors (and assumptions) that may influence the performance of SU and MU packaging products to be identified. Assumptions about consumer behaviour are particularly relevant concerning the return of MU packaging to the point of sale. The packaging could be transported by various means, leading or not to certain impacts (e.g. transport by bike or on foot can be considered impact free, whereas transport by car can have relevant impacts, but more items may be returned in one trip). Allocating the impacts of transport for the return of MU packaging may turn into a LCA allocation problem ([38]), as the journey might also be made for other purposes (e.g. for purchasing more food). In the present study it was assumed, as default, that only a share of the transport occurred by car (e.g. 10 % in 'Scenario 1') and that more than one item was returned each time. The analysis revealed that such assumptions play a key role in the life cycle impacts of MU packaging products (especially in 'Scenario 1'and 'Scenario 2'). In an additional sensitivity analysis, the effect of excluding the impacts of transport from the life cycle of reused packaging products was tested (assuming, for example, that the journey to return the items to the points of sale would be made mainly for other purposes). In this case, the impacts of the MU packaging sensibly decreased. This underlines how the assumptions about user behaviour and the use of passenger cars to transport MU packaging items back to the point of sale may be crucial

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([37]) In this Scenario, the SU packaging product had lower impacts in 25 % of the simulations, whereas in the remaining simulations MU and SU packaging products had similar impacts.

([38]) Allocation problems are among the most debated aspects of LCA in the literature on the topic. Although some guidance is provided by standards (including ISO 14040/44 and the EF method), allocating impacts among different products or services (as in the case of returning MU packaging) is a complex issue entailing multiple assumptions and value choices.

for takeaway scenarios and should be further investigated in the future (i.e. when collection and reuse systems will be more established in the market and real-world data will be available).

Another analysis of takeaway packaging was carried out in 'Scenario 2 – CASE B', considering an aluminium SU packaging product. The MU case study packaging product was assumed to be the same in both analyses in 'Scenario 2'. Differences in material composition and mass resulted in an overall lower life cycle impact of the MU packaging product 'Scenario 2 – CASE B' than for the SU alternative. This is particularly evident in the sensitivity analysis for this Scenario, resulting in the MU packaging product having lower impacts in more than 60 % of simulations for the aggregated Single Score. However, the results of the sensitivity analysis for the Climate Change impact category were generally comparable, suggesting that the MU and SU packaging products can also have similar performance (in one third of the simulations). Similar to that observed in the case of 'Scenario 1' and 'Scenario 2 – CASE A', in 'Scenario 2 – CASE B', the environmental performance of the MU or SU packaging products depends on the business model in place and the values of the various parameters used to model the different impacts.

In the case of 'Scenario 3' ('CASE A' and 'CASE B') and 'Scenario 4', the washing step was supposed to occur in a centralised washing facility. The packaging products needed to be transported to the point of sale after use and then transported to the washing facility. Some impact allocation issues arise in the modelling, which have been tackled in a similar way as in the abovementioned scenarios (i.e. a fraction of the impact of car transport has been allocated to the MU packaging).

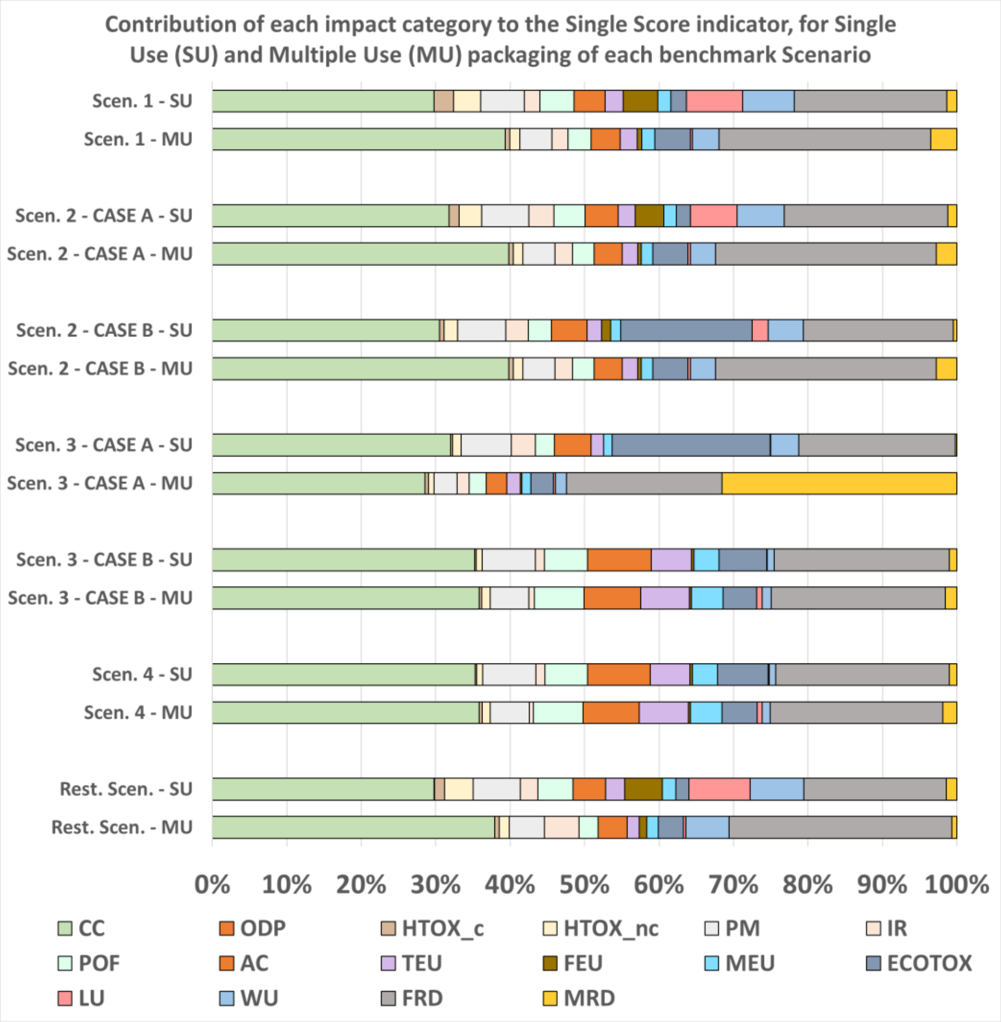
Overall, the results of 'Scenario 3 – CASE A' pointed to lower environmental impacts for the SU packaging product for several impact categories (e.g. 'Resource Use, Minerals and Metals'; 'Eutrophication, Freshwater'; 'Human Toxicity, cancer', etc.). In this Scenario, the sensitivity analysis for the aggregated Single Score showed lower impacts for the SU packaging product in around 50 % of the simulations (whereas the MU packaging had lower impacts in only around 20 % of the simulations and the two types of packaging were comparable in about 30 % of simulations). The assumption about the number of reuses for the MU packaging was found to be particularly relevant for 'Scenario 3 – CASE A'. Based on stakeholder input, nine reuses were assumed for the MU packaging product under analysis. Overall, this contributed to lower impacts for the SU packaging product. However, this result could be reversed if the number of reuses were considerably increased. Despite the number of reuses assumed, the MU packaging exhibited lower impacts for certain impact categories, for instance Water Use, Ecotoxicity Freshwater and Particulate Matter.

By contrast, in 'Scenario 3 – CASE B' and 'Scenario 4' on glass bottles, the MU packaging product showed lower impacts across almost all impact categories (apart from Land Use impact category and, to a lesser extent, the 'Resource Use, Minerals and Metals' and 'Human Toxicity, cancer' impact categories). It is also interesting to note that, in these scenarios, MU glass bottles resulted in lower impacts despite being heavier and assuming that they would need additional transport to a centralised washing facility. Moreover, for both wine and beer bottles, the outcome of the sensitivity analysis showed lower impacts for the MU bottles in more than 90 % of the simulations in the Climate Change impact category and the aggregated Single Score.

The results of the 'Restaurant Scenario' looked at the environmental performance of a set of SU packaging products (carton-based cup and trays) and MU alternatives (PP-based cup and plate), used to serve a simple dine-in 'hamburger meal'. The 'Restaurant Scenario' resulted in lower impacts for the MU packaging in the majority of impact categories and simulations. This can be primarily attributed to the inherent nature of the dine-in option. Unlike takeaway meals, the dine-in option eliminates the need for transport to return the MU packaging. Furthermore, it allows for a significantly higher number of reuses, as the MU packaging remains under the constant supervision of the restaurant staff, thereby minimising losses due to improper handling by users. The results underlined how the meal in MU packaging could be preferable in more than 60 % of the cases for the Climate Change impact category and more than 80 % of cases for the aggregated Single Score (see the results of the sensitivity analysis, described in Section 3.5).

Figure 32 illustrates the contribution of each impact category to the aggregated Single Score for each benchmark scenario. The Climate Change and 'Resource Use, Fossil' impact categories contribute the most to the Single Score (on average 34 % and 24 %, respectively). Overall, the contribution of Climate Change and 'Resource Use, Fossil' to the total Single Score was higher for MU packaging products than for SU packaging. However, impact categories such as Particulate Matter, Acidification and Ecotoxicity Freshwater each contributed on average no more than 6 % to the Single core, across all scenarios. The average contribution of the Water Use category to the single score was 4 % ([39]). The impacts associated with the manufacturing of the PET bottle (in the case of the MU packaging in 'Scenario 3 – CASE A', for MU packaging) was the main driver for the contribution of the 'Resource Use, Minerals and Metals' to the Single Score for this Scenario.

Figure 32. Contribution of each impact category to the Single Score index, for Single Use (SU) and Multiple Use (MU) packaging in each benchmark Scenario.



Source: JRC analysis. "Scen." = "Scenario". Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

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[39] Ranging for SU packaging products between a minimum of around 1 % for 'Scenario 3 – CASE A' and 'Scenario 4' and a maximum around 7 % for 'Scenario 1' and the 'Restaurant Scenario'; and for MU packaging products between a minimum of around 1 % for 'Scenario 3 – CASE A' and 'Scenario 3 – CASE B', and 'Scenario 4' and a maximum of around 6 % for the 'Restaurant Scenario'.

As tested in this report for 'Scenario 1' and the 'Restaurant Scenario' (Section 3.1.2 and Section 3.5.2, respectively), the impacts associated with the cartonboard manufacturing could affect the overall life cycle performance of SU packaging. Assuming a dataset with low impacts associated with cartonboard manufacturing plays a crucial role in the Water Use impact category, leading to more favourable results for the SU packaging products. By contrast, the outcome for the Climate Change impact category and the Single Score index were less affected by such a change in the cartonboard manufacturing dataset.

The assumption about the share of recycling at the end-of-life stage of the carton packaging could reverse the benchmark results in favour of the SU-packaged meal for recycling shares in the order of 70–80 % (50 % when considering the 'Alternative 2' dataset for cartonboard manufacturing), as tested in the 'Restaurant Scenario' (Section 3.5.2). The assumptions about the recycling at the end-of-life stage of materials in the MU packaging products were less relevant. If the recyclability of PP is assumed to increase from 41 % to 85 % (for both the MU tray and cup for the dine-in meal in the 'Restaurant Scenario'), the BE point (40) for Climate Change is almost unchanged for all cartonboard datasets. Such behaviour could be explained by the higher number of reuses expected in the case of the MU packaging products in the 'Restaurant Scenario', which reduces the dependence of these types of packaging on assumptions about their recyclability. Based on inputs received from stakeholders and literature data, 100 reuses were assumed for the MU packaging for the dine-in meal scenario. The performance of the MU-packaged meal is strongly influenced by the number of reuses in the range from 5 to 20, as the BE point for the benchmark scenario is reached at around 20 reuses (around 18 reuses if the 'Alternative 1' dataset for cartonboard production is employed, or around 40 if the 'Alternative 2' dataset is used).

Overall, the cases in which MU packaging products have a higher impact than SU packaging could be associated with:

- the impacts related to the transport of used packaging back to the collection or selling point, including transporting multiple items of packaging at the same time;
- the effect of the assumed number of reuses;
- the high energy and water needs associated with the reuse operations (mainly due to the impacts of washing).

In general, the results of the MU packaging product systems are affected by a subset of key assumptions and methodological choices in the modelling, such as:

- the type and efficiency of washing machine used;
- the distance between the consumption point and the take-back point;
- how the packaging is transported (e.g. by passenger car);
- how many items are transported at the same time;
- how the impacts of bringing packaging back to the collection or selling point are allocated between returning packaging and other purposes of the journey (e.g. buying new food products).

Concerning the analysis of the assumptions about cartonboard manufacturing, the present study highlighted that:

- assuming datasets with lower impacts of cartonboard manufacturing plays a crucial role, leading to a more favourable performance of the SU packaging especially for the Water Use impact category;
- the Climate Change impact category and the aggregated Single Score index were differently affected in 'Scenario 1' and in the 'Restaurant Scenario'. In the 'Scenario 1' the SU packaging had lower Climate Change impact independently from the cartonboard dataset selected, while for the 'Restaurant Scenario' the MU packaging had lower Climate Change impact independently from the cartonboard dataset selected. In the case of 'Scenario 1', employing a cartonboard dataset with low impacts led to lower Single Score for the SU packaging, while in the 'Restaurant Scenario' the MU packaging had lower Singe Score independently from the cartonboard dataset selected;
- future analyses could focus on using datasets for cartonboard production that are representative of the whole EU market and fully aligned with the EF method (particularly concerning the background datasets

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(40) The BE point here is the value of the recyclability of the carton waste when the SU and the MU had the same Climate Change impact (considering all the other parameters fixed as in the benchmark scenario). For higher values of carton recyclability, the SU packaging then had lower Climate Change impacts.

used and all the impact categories, including Water Use). It was indeed not possible to assess the level of consistency of ‘Alternative 1’ and ‘Alternative 2’ with the EF method and other EF datasets used in the model.

Additional details on the strengths and limitations of this analysis are provided in Section 4.3.

4.2 Framing of the study in the context of the literature

This section focuses on comparing the scenarios assumptions and system boundaries with those in the available literature studies in this field.

4.2.1.1 Cups – ‘Scenario 1’

The mass of the SU cups modelled in the context of ‘Scenario 1’ (17.58 g, according to input from the stakeholder consultation) is aligned with both the mass assumed in the CupClub report (CupClub, 2018) and the weight reported by the German Environment Agency in its final report of 2019 (respectively, 18.3 g and 17.8 g; Umwelt Bundesamt, 2019). The mass of the ‘Scenario 1’ MU cup is also aligned with the value reported by CupClub (2018), namely a reusable cup with a mass of 49.3 g, which is comparable to the 48.3 g employed in the present study (based on stakeholder input).

Considering the modelling assumptions of the reuse step in ‘Scenario 1’, the electricity consumption for the washing phase (0.021 kWh, received via stakeholder consultation) showed a good alignment with the value proposed by Eunomia (2023) of 0.021 kWh (for warm drinks), while being higher than the Eunomia (2023) value of 0.014 kWh (for cold drinks). Concerning the electricity requirements, those indicated in the KeepCup report (KeepCup, 2018), 0.025 kWh, are aligned with those of the present study, despite the KeepCup findings being focused on reusable coffee cups. Looking at the washing needs, the present study assumed 0.41 g detergent per MU cup wash cycle (figure received from the stakeholder consultation). That value is in line with the amount suggested in the report prepared by Ramboll for the European Paper Packaging Alliance (Ramboll, 2022a), which estimated a detergent demand of 0.43 g per cup washed.

In ‘Scenario 1, a total of 15 reuses was assumed for the benchmark MU cups that are actually returned to the point of sale, which is lower than the 25 reuses assumed by Eunomia (2022) for plastic cups. In addition, the assumption adopted by Ramboll (2022a) was 50 reuses for cups and other takeaway packaging products, although it is assumed that only 50 % of cups are returned. The Ramboll (2022a) study considered 50 reuses for a wide set of takeaway packaging products (e.g. cutlery, bags, clamshell containers for burgers). That assumption was employed notwithstanding the product-specific differences in terms of number of reuses that occur in real-life scenarios, thereby limiting comparison with the assumptions of the present report. In the sensitivity analysis of ‘Scenario 1’ (Annex 3), the number of reuses is assumed to vary between 10 and 25. Higher number of reuses were identified for KeepCup (2018) and CupClub (2018) (62.5 reuses and 132 reuses for PP cups, respectively). In the case of KeepCup (2018), the number of reuses was calculated considering the company’s own assumption that a reusable coffee cup is used around 62 times before being discarded. The 132 reuses estimated in CupClub (2018) are also the company’s own assumption considering the theoretical performance of CupClub cups and therefore is not directly comparable with the assumptions of the present study. Another report (Reloop and Zero Waste Europe, 2020) indicates that the number of reuses of cups was 1.7 (based on data gathered from a particular event for the study, which showed an extremely low return rate of 20 %), supporting the results of a case study of reusable cups at a major event in Barcelona in 2004 (Barcelona Universal Forum of Cultures; described in Garrido, 2007). These low values could be associated with the nature of the event and the specific consumer behaviour adopted on the occasion.

As previously mentioned, because of a lack of established EU business models, proper modelling of the transport distances and means of transport for the reuse step was complex and uncertain. In the Ramboll report (Ramboll, 2022a), various means of transport were considered, including car, scooter, bike and walking. Similarly, in the present study transport via car was assumed to be one of the options for returning used packaging and to be the one causing environmental impacts (compared, for instance, with transport by bike or on foot). In ‘Scenario 1’, it was assumed that MU cups were returned to the point of sale by passenger car on 10 % of occasions and for a total distance of 2.5 km. That distance falls between the 2 km assumed by Hitt et al. (2023) and Eunomia (2023) and the 3 km assumed by Ramboll (2022a). Furthermore, the same Ramboll study (Ramboll, 2022a) allocated 10 % of transport as occurring via car, which is aligned with the assumptions made in the present analysis.

The findings of KeepCup (2018) and CupClub (2018) both underlined how MU polypropylene cups could exhibit a lower environmental impact than SU carton cups. In particular, CupClub (2018) calculated environmental impacts using the ReCiPe midpoint method (Huijbregts et al., 2017) and found that MU cups exhibited lower impacts than SU cups for the three paper cups used in the midpoint categories considered (41). Similarly, KeepCup (2018) calculated environmental impacts in accordance with the ReCiPe method (hierarchist), and the midpoint results showed that MU cups have a lower environmental impact than SU cups for the Climate Change (42) impact category. The results of the present study showed lower environmental impacts for SU cups than for MU cups, for Climate Change impacts (in the benchmark scenario). However, the results for the other impact categories were more heterogeneous, with MU having lower impacts for the majority of other categories (including Water Use and Single Score). Such differences in the results could be explained by the different assumptions made for a number of aspects including end-of-life recycling rates: the present report assumed a recycling rate of 15 % for MU cups, while the CupClub report assumed a rate of 90 % and the KeepCup report assumed a rate of 50 %. In addition, the KeepCup report considered a lighter SU cup (12 g) than the mass assumed in the present analysis (17.5 g). Moreover, differences in the results could be also explained by differences in the number of reuses: 132 in the CupClub report, compared with 15 reuses in the present study.

4.2.1.2 Trays – Scenario 2 (‘CASE A’ and ‘CASE B’)

For the analysis focusing on packaging trays, the mass assumed for of the SU tray (carton and LDPE) for ‘Scenario 2 – CASE A’ was based on Verburgt (2021) and amounted to 27.3 g. This mass is higher than the 18 g assumed by Eunomia (2023) for a SU tray made solely of carton and of a smaller volume (1.044 l) than the one in the present study (1.1 l). For the SU trays in ‘Scenario 2 – CASE B’ (aluminium and carton), a total mass of 23.8 g was assumed (Verburgt, 2021). That mass is consistent with the one assumed by Hitt et al. (2023), namely 25 g. Looking instead at MU PP trays (‘Scenario 2 – CASE A’ and ‘CASE B’), a total mass of 172 g was assumed in the present study, as suggested by Verburgt (2021). The mass of the tray assumed in the current scenario is 30 % higher than that considered in the Eunomia (2023) report for burger boxes (119 g).

Regarding the washing stage of the reuse step for MU trays in ‘Scenario 2’ case studies, the Eunomia report (Eunomia, 2023) assumed a water requirement of 0.76 l and detergent amounting to 0.733 g per tray washed. Those values are aligned with those assumed in ‘Scenario 2’ case studies of the present report (0.606 l and 0.706 g, respectively; both retrieved during the stakeholder consultation). In ‘Scenario 2 – CASE A’ the recycling rate for carton trays was set at 15 %, based on Kearney (2023), which is half of the 30 % recycling rate assumed in the Ramboll (2022a) report. The recycling rate derived from Kearney (2023) represents one of the most recent findings relevant to the ‘Scenario 2’ SU packaging products. To capture part of the variability recognised in the literature, in the present study the recycling rate for cartonboard trays was assumed to vary from 5 % to 30 % in the sensitivity analysis. On the other hand, the recycling rate for MU PP trays was set at 41 % (employed in both ‘Scenario 2 – CASE A’ and ‘CASE B’; and derived from Ramboll (2022a)). That value is aligned with the recycling rate for plastic packaging reported by Eurostat in 2018 (41.8 %; Eurostat, 2023).

For MU trays in ‘Scenario 2’ (‘CASE A’ and ‘CASE B’), the reuse step (e.g. water, detergent and electricity needs) was modelled on the basis of direct input from stakeholders for reusable food and beverage packaging, including clamshell trays. As an example, the present analysis assumed that MU PP trays are reused 20 times in the benchmark case, a value that is consistent with the assumption made by Hitt et al. (2023) (25 times). However, the estimated number of reuses (on average 20 and varying between 15 and 25) was based on the research team’s own assumption because of a lack of data available from stakeholders. Notably, the study from Ramboll (2022b) reports the number of reuses as 24, although that refers to plastic crates.

The results for ‘Scenario 2 – CASE B’ demonstrated that MU PP trays could exhibit environmental impacts comparable to (e.g. for the Climate Change impact category) or lower than (e.g. for the aggregated Single Score)

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(41) As an example, the Climate Change impacts for SU paper cup in the CupClub (2018) report amounted to 8.368 kg CO_2 eq., while the MU cup exhibited impacts equal to 4.267 kg CO_2 eq. for the same impact category.

(42) The KeepCup report compared the environmental impacts of MU and SU cups across three different use scenarios: light use (250 coffees per year), medium use (500 coffees per year) and heavy use (750 coffees per year). For light use, the Climate Change (CC) impact range was 10–15 kg CO_2 eq. for SU cups and 2–5 kg CO_2 eq. for MU cups. For medium use, the CC impact was 20–35 kg CO_2 eq. for SU cups and 3 8 kg CO_2 eq. for MU cups. Lastly, for heavy use, the CC impact range was 30–50 kg CO_2 eq. for SU cups and 5–12 kg CO_2 eq. for MU cups.

those for SU aluminium trays. Eunomia underlined how such boxes could limit their use in washing machines, since their shape could limit the number of items that could be stacked and washed at the same time (thereby hindering the number of items washed per cycle). This limitation could also potentially apply to the MU trays considered in the present analysis, as clamshell trays were assumed.

The manufacturing step for the SU packaging and the professional washing stage for the MU containers were recognised by Eunomia (2023) as primary contributors to the greenhouse gas emissions of the packaging, especially for burger boxes.

The overall findings of the Eunomia report (Eunomia, 2023) indicated lower greenhouse gas emissions for MU trays than for SU trays. Notwithstanding the potential methodological differences in greenhouse gas emission accounting ([43]), the results of the present study underlined the comparable life cycle Climate Change impacts for the MU and SU trays in the 'Scenario 2 – CASE A'. Such divergence could be explained by the differences in weight assumed in the two studies and the difference in the assumptions used for modelling the reuse step. Eunomia assumed that almost all trays are returned in the MU packaging product reuse phase (despite providing data only on return rates rather than the number of reuses), leading to higher expected reuse rates compared to those assumed in the present study. This difference in the reuse phase, which is a key stage for MU trays, affects the overall environmental life cycle performance of MU trays compared with SU trays.

4.2.1.3 Beverage containers and bottles – 'Scenario 3' ('CASE A' and 'CASE B') and 'Scenario 4'

In the context of 'Scenario 3 – CASE A' focuses on beverage containers and an analysis the performance of SU aluminium cans and MU PET bottles. The mass assumed for the MU PET bottle (45.15 g; retrieved from stakeholder consultation) is consistent with that indicated by Amienyo et al. (2013) (47.9 g). In addition, the mass assumed for the SU aluminium can (15.9 g; retrieved from stakeholder consultation) is aligned with the can used in the UNEP (2020) report (13 g).
With regard to the beer bottles analysed in 'Scenario 3 – CASE B', the present study assumed an SU bottle of 280 g and a 23 % increase in mass for the thicker MU beer bottle (343 g). Poinsten et al. (2018) assumed a mass of 527 g for their 0.75 l MU glass bottle: if the volume of that bottle were scaled down to the 0.5 l bottle adopted in this study, the mass of the bottle used in Poinsten et al. (2018) would be equal to 351 g. That value would be in line with the one adopted in the present study. The mass of wine bottles assumed for 'Scenario 4' (542 g and 596 g for SU and MU packaging products, respectively) appeared lower than those suggested by Poinsten et al. (2018), namely a mass of 400 g for the SU and 527 g for the MU. In the case of 'Scenario 4', the 0.75 l bottle volume is aligned with the value suggested by Ferrara and De Feo (2020), indicating a volume range of 0.75 l to 1 l for wine containers. These are the volumes most commonly used for wine, according to the findings of Cleary (2013).

Looking at the assumptions associated with the washing step for the case studies on beverage containers and bottles (i.e. 'Scenario 3' – CASE A' and 'CASE B' and 'Scenario 4'), the electricity consumption was retrieved from stakeholders and amounted to 0.014 kWh per wash cycle. That value differs from the one suggested by Ponstein et al. (2018), who indicated a lower electricity consumption of 0.008 kWh. This difference may be explained by the diverse types and efficiencies of the industrial washing machines employed in the studies. This divergence was captured in the sensitivity analysis of the present study by considering the range of variability associated with the energy need (see Scenario 3 Factsheets in Annex 3; lower bound 0.007 kWh, upper bound 0.028 kWh).
In relation to the manufacturing process, the present study assumed a certain recycled content (7 %, as suggested by inputs from stakeholders) for the MU packaging PET 'Scenario 3 – CASE A'. That is lower than the value proposed by Eunomia (2022), indicating a recycled content of 12 % (based on BKV GmbH data, Plastic Concepts Recovery).

Considering the glass bottles in 'Scenario 3 – CASE B' (beer bottles) and 'Scenario 4' (wine bottles), a total of 20 reuses were assumed for both scenarios (retrieved from the stakeholder consultation). That value is lower than the one suggested by Ponstein et al. (2018) and by Eunomia (2022), both of which assumed 50 reuses. It is,

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([43]) However, the Eunomia (2023) report does not explicitly explain the method employed for the calculation of these greenhouse gas emissions.

however, particularly relevant to observe how, even at a lower number of reuses than those suggested in the literature, the present analysis still found a more favourable environmental performance for MU bottles for most impact categories (Section 3.3.2 and Section 3.4.1).
Regarding the end-of-life modelling of ‘Scenario 3 – CASE B’ and ‘Scenario 4’, it has been assumed that 75 % of glass bottles would be recycled (based on stakeholder consultation), which is consistent with the values reported by Ferrara and De Feo (2020). These authors suggested a share of 72.8 % of glass bottles being recycled at the end-of-life stage. According to data retrieved during the stakeholder consultation, it was assumed that 74.9 % of wine and beer bottles would be recycled at the end of their life, with the remaining 3.7 % incinerated and 21.4 % landfilled. The recycling and landfill rates assumed in the present study are aligned with those assumed in Ferrara and De Feo (2020), indicating a recycling rate of 72.8 % and a landfill rate of 27.2 %.

In relation to the ‘Scenario 3 –CASE A’, Amienyo et al. (2013) concluded that aluminium cans have a higher environmental impact in terms of Climate Change than PET bottles when using the CML (Centre of Environmental Science method; Guinée et al, 2001). By contrast, in the present study, Climate Change impacts were similar for SU and MU packaging products, although lower impacts for the SU packaging products were observed for other impact categories, including the aggregated Single Score.

The results of ‘Scenario 4’ indicated that the performance of MU packaging is generally lower than that of SU packaging for most of the impact categories of the EF, including Climate Change, Water Use and the aggregated Single Score. Such findings are aligned with those presented in the Reloop and Zero Waste Europe (2020) report, which estimated that SU glass bottles have higher carbon dioxide emissions than MU packaging. In Reloop and Zero Waste Europe (2020), the manufacturing phase has the highest environmental impact because of the high energy consumption of glass production, as also recognised in the present study.

4.2.1.4 Hamburger meal – ‘Restaurant Scenario’

In the ‘Restaurant Scenario’, the parameters associated with the washing step were overall aligned with data in the literature, especially for the energy and detergent needed for the MU plate washing. In particular, the energy consumption related to the MU PP plate was 0.033 kWh (retrieved from stakeholder consultation), which is slightly higher than the value of 0.027 kWh assumed in the Ramboll (2020) report. However, the detergent demand assumed by Ramboll (2020) (0.417 g) is slightly lower than that considered in the present study (0.510 g; retrieved from stakeholder consultation)

In the ‘Restaurant Scenario’, the benchmark value for the number of reuses (i.e. 100 for both MU cups and MU plates for the MU hamburger meal) was derived from data retrieved from stakeholders and further confirmed by several literature sources (as illustrated in Table 4).

Table 4. Comparison of the number of reuses (also called “number of rotations”) in various literature sources that could be compared with the dine-in ‘Restaurant Scenario’ of the present study.

Number of reuses	Note	Reference
100	General assumption for Multiple Use (MU) dine-in restaurant items (no difference between the articles)	Ramboll, 2020
200	General assumption for MU plastic food refill scheme boxes	Eunomia, 2022
142	Information from a different stakeholder, indicating a high return rate	Input to JRC stakeholder consultation (October 2023)

Source: JRC literature analysis and stakeholder consultation data.

Table 4 shows reuse rates from various sources and for various system assumptions and indicates that the 100 reuses selected for the present analysis of the dine-in ‘Restaurant Scenario’ is equal to the value assumed in the Ramboll (2020) report. The results of Table 4 show that this value is lower than, for instance, the one proposed by Eunomia (2022), referring to food refill scheme boxes. A set of BE point analyses were performed for the

‘Restaurant Scenario’ in the present study, focusing on recycling at the end-of-life stage, and varying the recycling rate of SU carton packaging products and the number of reuses of MU packaging products (Section 2.5). This BE point analysis illustrated that in the case of scenarios with much higher numbers of reuses (e.g. as in the dine-in restaurant scenario), increases in the number of rotations beyond a certain threshold have less influence than those below the threshold. A BE point analysis of the number of reuses for different packaging types (hamburger boxes and cups) was also performed in the Eunomia (2023) report. The results for greenhouse gas emissions showed that around 30 reuses for boxes and 6 for cups were necessary to reach comparable life cycle performance for the SU and MU packaging products (44). These findings are similar to the Climate Change results of the present study, which showed comparable emissions after around 20 reuses in the ‘Restaurant Scenario’ for SU and MU containers. Such results are particularly interesting, although the mass of the MU PP plate in the present study (170 g; based on data retrieved from stakeholder consultation) is greater than the mass assumed by Eunomia (2023), equal to 119 g.

4.2.1.5 Additional consideration from comparisons with literature sources

As well as the Eunomia studies (Eunomia, 2022, 2023), the Ramboll reports (2020, 2022a) also represented key literature sources in the context of the present study.

When the methodological assumptions and results of the Eunomia (2022) and Eunomia (2023) reports are analysed, a major difference is evident. The methodological approach employed in the Eunomia (2022) report served the purpose of supporting the finalisation of the legal proposal and the impact assessment for the review of the Packaging and Packaging Waste Directive. For this reason, a system-level comparison of packaging products was preferred in place of a product-specific comparative analysis. The latter analysis was employed in the more recent Eunomia (2023) report. Such product-specific detail enabled a more thorough comparison with the findings of the present report and was therefore prioritised as a source of information for this study over the Eunomia (2022) study. Furthermore, the findings of the Eunomia (2022) study refer to forecast scenarios rather than ‘status quo’ ones, which are included in the Eunomia (2023) report. The latter report concluded that, in relation to greenhouse gas emissions, the MU packaging products have a better environmental performance in the takeaway sector. However, Eunomia (2023) acknowledged that aspects such as consumer behaviour could play a key role in driving the environmental performance of the packaging products in the analysis.

Overall, it is worth bearing in mind that the food and beverage packaging used in the Ramboll studies (Ramboll, 2020, 2022a) is not fully comparable to that used in the ‘Restaurant Scenario’ in the present analysis, due to the different packaging products used (e.g. the present analysis does not consider the life cycle environmental impacts associated with a salad box). Furthermore, it is worth noting that the environmental impact assessment methods used in the Ramboll reports differed from those used in the current analysis (i.e. the EF3.1 method). Specifically, Ramboll’s in-store report (Ramboll, 2020) used the ReCiPe method (Huijbregts et al., 2017), and Ramboll’s takeaway report (Ramboll, 2022a) adopted the EF2.0 method. These differences should be considered when comparing the findings of the two reports with those of the present study. The key findings of the Ramboll reports (Ramboll, 2020, 2022a) show that, in the case of the SU packaging product, the main impact was due to upstream manufacturing of the SU packaging. By contrast, the primary contribution to the total life cycle impacts of MU packaging came from the reuse phase. These findings are consistent with those of the present study, which have been detailed for each Scenario in the respective Factsheets in Annex 3. Both Ramboll reports concluded that, with regard to the Climate Change impact category, the life cycle environmental impacts of SU packaging containers (assessed via system-level analysis) were lower than the MU alternatives.

Another recent relevant study is the report from the Ellen MacArthur Foundation (EMF, 2023). This report assessed four business-to-consumer packaging types, comparing SU and MU packaging for different applications (i.e. beverage containers, personal care product containers, fresh food containers and cupboard food containers). In contrast to the present report, the EMF (2023) models selected ‘France’ as a representative study area, and mostly compared SU packaging and returnable packaging products of the same material (e.g. SU PET bottle compared with MU PET bottle). Moreover, the study provides only a partial LCA of the different system

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(44) In the BE analysis, Eunomia (2023) compared SU and MU burger boxes and cups. The BE point analysis performed in Eunomia (2023) is a product-specific assessment of takeaway packaging (e.g. cup, burger box), while in the present study the BE point analysis was performed for the dine-in hamburger meal (served with SU and MU packaging products).

configurations, discussing the results for environmental and economic indicators (greenhouse gas emissions, water use and material use) for the alternative packaging. Overall, the results indicated that lower greenhouse gas emissions could be achieved by using the MU packaging analysed. The methodological differences between the Ellen MacArthur Foundation report (EMF, 2023) and the present study limit a thorough comparison of the scenarios assessed. However, it is interesting to note that the Ellen MacArthur Foundation report (2023) assumed a 100 % recycling rate for all the MU packaging products analysed. Such high rates are considered achievable thanks to the existence of a 'reusable packaging system' that facilitates collection, sorting and recycling. Such an assumption would also improve the performance of the MU packaging products assessed in the present study (which instead assumed a more cautious value of a 47 % recycling rate for 'Scenario 3 – CASE A'). The Ellen MacArthur Foundation study (EMF, 2023) also highlighted how practices such as shared collection points (45) and customer convenience (46) could help drive behavioural change and achieve higher return rates.

4.3 Strengths and limitations of the study

The present study focused on the analysis of possible packaging alternatives, representative of the EU context, and employed a combination of information from various sources to provide an up-to-date analysis of the considered Scenarios. As few established business models devoted to MU packaging products are currently in place, data collected during the stakeholder consultation were prioritised as far as possible and complemented when needed with data from the literature to model the key parameters of the life cycle of MU packaging products. In particular, little information related to washing practices during the reuse step was available. For this reason, data retrieved during the stakeholder consultation represented key information for properly modelling this step and the related demand for energy, water and detergents.

JRC facilities were also visited during the development of the present study. Such visits served the purpose of clarifying washing practices (such as rinsing and rewashing operations), which were not well documented in the literature. The results of the present analysis demonstrated how such washing practices have a significant role in the overall performance of MU packaging products.

Overall, the following procedure for data selection was employed:

- literature data were gathered and then combined with the research team's own assumptions to draft hypothetical, representative, comparative SU and MU Scenarios;
- such assumptions and Scenarios were presented to stakeholders (during a brief consultation) with a view to checking the scenarios and/or providing different insights and primary data;
- lastly, the initial scenarios and assumptions (and the underlining models or initial data gaps) were revised based on the stakeholder inputs received and used to analyse the life cycles of SU and MU packaging products and to develop sensitivity analysis.

This approach ensured a thorough understanding of the assumptions underpinning the various scenarios. Furthermore, as acknowledged in Annex 2, EF3.1 datasets were employed to ensure methodological consistency with the EF method (and impact assessment categories considered) but also to ensure the overall consistency and representativeness of all the background datasets used in the analysis. The EF3.1 datasets used in the modelling of the EU electricity mix and EU tap water used in the reuse washing step are assumed to be representative of the EU context and to represent the shares of different types of energy and water (e.g. ground, rivers, lakes) used in a generic (dine-in or takeaway) restaurant in the EU.

With regard to the end-of-life impact modelling, the present study adopted the CFF formula (Section 2.4.4) which ensures that all relevant end-of-life aspects are properly captured when assessing the life cycle impacts of a given packaging product (including modelling the share of recycled content, the share recycled at the end-of-life stage and the associated credits, the recycling quality factors, and the allocation of the burdens and credits of recycled and virgin material production between two life cycles). The values of the CFF parameters (Section 2.4.4) were either collected during the stakeholder consultation or retrieved from the literature and could be revised in future if additional and up-to-date data become available.

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(45) For instance, enabling the collection of multiple packaging products in the same place.

(46) For instance, standardisation of packaging design and the existence of return and deposit-return schemes could make the return of packaging a habit.

In the present report, benchmark scenarios were first analysed (by assuming average representative values for a number of the parameters considered). Next, to increase the robustness of the results, an extensive sensitivity analysis was conducted, based on the ranges of variability associated with each relevant model's parameters. This approach ensured that the intrinsic uncertainty and variability of each parameter was captured, analysed and considered when discussing the results for the SU and MU packaging products. Furthermore, an additional analysis of a set of scenarios (Section 2.5.1) was also performed to investigate the effects of specific changes in the packaging product that could play a decisive role in their performance (i.e. by testing the influence of passenger car transport in the reuse step of MU packaging products; by analysing the influence of alternative life cycle impacts associated with cartonboard manufacturing processes; by investigating the BE points for dine-in packaging when the share of recycling at the end-of-life stage of SU packaging is varied or the number of reuses of MU packaging is varied; or by assessing the influence of the type and presence of lid on cup scenarios).

Concerning the use of lids in the serving of takeaway beverages ('Scenario 1'), comments received from stakeholders suggested the use of carton lids in place of plastic ones. Such comments are supported by the progressive EU banning of SU plastics leading to the phasing out of plastic lids from the market. However, some fast-food restaurants and cafeterias may still use plastic lids, and therefore an additional sensitivity analysis on lids was conducted. The results of this analysis indicated that plastic-based lids could potentially reduce the overall SU packaging products' life cycle impacts (disregarding potential plastic littering issues). Furthermore, real-life observations coupled with stakeholder comments suggested that lids were not used in dine-in restaurants, and for this reason lids were excluded from the 'Restaurant Scenario'.

The results of the present report revealed that raw material production had a dominant role in the environmental impacts of packaging, especially for the SU packaging products (47). A specific analysis was performed in this study to investigate the relevance of the datasets used to model the impacts of the cartonboard used in some cartonboard-based products (i.e. packaging products in the 'Scenario 1' and the 'Restaurant Scenario'). Two datasets collected during the stakeholder consultation (48) were included in the study and used to build the 'Benchmark' and a potential further 'Alternative' scenarios (in comparison also with results obtained with an EF3.1 available dataset; further details are provided in Section 2.5). The 'Benchmark dataset' (Table 2) for cartonboard was assumed to be representative of EU production and, at least for the Climate Change impact category, in line with other available studies in the literature (e.g. ProCarton, 2023b). However, it is acknowledged that the 'Benchmark' value was not developed using EF3.1 datasets to model the background systems, and therefore it is not fully consistent with the other datasets used in the modelling of the present study.

Assumptions about the Water Use impact category for cartonboard manufacturing have proven to be uncertain and particularly sensitive. Only some of the data received from stakeholders on this subject were suitable for use in this study, as the datasets provided often pertained to a different impact category and/or were based on background datasets that were not entirely consistent with the EF3.1 datasets. Some stakeholders indicated that the dataset on cartonboard production, used in the EF3.1 database, may overestimate water impacts. The observed discrepancies in water impacts could be attributed to more recent data, stakeholders' use of more efficient technologies, or lower water scarcity in stakeholders' production regions. Therefore, the model and sensitivity analysis (for 'Scenario 1' and the 'Restaurant Scenario') was constructed to include the upper and lower values for the water scarcity impacts for cartonboard in the sensitivity analysis, using their average as a 'Benchmark value'. A similar range of variation was also observed in other life cycle datasets available in another database.

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(47) The selection of datasets for the raw materials used in the MU packaging products has, instead, a lower relevance, as the impacts of these materials are shared across the different uses of the packaging during its life cycle.

(48) These datasets provided the life cycle impacts related to the manufacturing of cartonboard used in the manufacturing of the SU case study packaging products.

The strengths and limitations of the datasets employed to model cartonboard manufacturing can be summarised as follows:

- 'Benchmark dataset' (see Table 2): the dataset was provided by a stakeholder and is fully based on primary data and representative of a European manufacturer of cartonboard for cups and other SU packaging products. The dataset uses as input the average EU mix for electricity (49) with regard to the foreground electricity production. This could make this dataset representative of a generic production process in the EU without using a specific electricity mix claimed by an industry (50). The Climate Change life cycle impacts of this dataset were aligned with impacts reported in a study by the European Association of Cartonboard and Carton Manufacturers (ProCarton, 2023a; excluding biogenic carbon flows (51). The dataset provided was not fully consistent with the impact categories used in the EF method, especially the Water Use impacts (which considered a different life cycle impact category from the EF3.1 method, which accounts instead for the water scarcity impact, as discussed in Section 2.4.5). The Water Use impact for the benchmark scenario was then estimated as the mathematical average of the impacts in the 'Alternative 1' and 'Alternative 2' datasets. This is acknowledged as a limitation of the present assessments. Moreover, the modelling approach adopted for calculating the life cycle impacts for the 'Benchmark dataset' was not fully consistent with the EF method, especially concerning the background datasets, which may have been derived from a different database (i.e. the life cycle datasets used to calculate this dataset may not be EF compliant and therefore not consistent with all the other datasets employed in the model).
- 'Alternative 1' dataset (EF3.1 dataset 'Solid board, bleached; Kraft Pulping Process, pulp pressing, bleaching and drying; production mix, at plant; >220 g/m2'; see Table 2): this EF dataset has been developed based on a mix of primary and secondary data collected by LCA data providers. This dataset is fully consistent with all other datasets employed in the modelling of the scenarios presented in this report (i.e. the datasets are compliant with the same set of EF rules). This is of relevance especially regarding the modelling of background impacts for SU packaging products. According to the data provider who developed the EF datasets, this is geographically representative of EU production. Furthermore, based on the available metadata, it was assumed that this dataset covered the impacts associated with cartonboard manufacturing and the processing of cartonboard into carton. However, this dataset refers to production process in the year 2012 and could be only partially considered as representative of the 'current' market concerning carton manufacturing. Moreover, the dataset refers to the production of 'solid board, bleached', which is not necessarily representative of the raw materials used to produce the SU packaging products under analysis in the present study. The Water Use impacts estimated in this dataset (amounting to 2.3 m^3 water eq.), and considered by some stakeholders as potentially high, may depend on several aspects, including the Characterisation Factors employed in the AWARE method used in the calculations; the background processes included in the models; and the underpinning assumptions about the supply of raw materials. However, additional analyses of this dataset were not possible, as it was provided as wholly aggregated and with a limited amount of detail in the metadata. 'Alternative 1' dataset has been therefore used only for conducting the additional alternative analyses.
- 'Alternative 2' dataset (see Table 2): this dataset also refers to a process for manufacturing cartonboard, as provided by a stakeholder supplying the EU market. In contrast to the 'Benchmark dataset', this alternative dataset has not been calculated considering an EU mix for electricity use, but considering the specific electricity mix claimed by the stakeholder in its facility. The dataset presented all impacts categories calculated consistently with the EF3.1 method (including Water Use impacts). However, it was not possible to check if the background life cycle data used to calculate this dataset were EF compliant. In this sense, the dataset may not be consistent with all the other datasets used in the model.

The effects of using alternative datasets for the modelling of the cartonboard manufacturing impacts were explored with a specific focus on the Climate Change and Water Use impact categories, as well as the aggregated Single Score. Results were derived both for the benchmark comparative analysis and for the sensitivity analyses for 'Scenario 1' (presented in Section 3.1.2) and the 'Restaurant Scenario' (Section 3.5.2). To achieve improved

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(49) The dataset was built using the Ecoinvent 3.9.1 dataset 'market group for electricity, high voltage | Europe without Switzerland'.

(50) It is worth of noting that, also according to the EF method, a company may claim a certain electricity mix in the inputs to its processes based on purchased certificates for electricity supply (the 'Guarantee of Origin' certificates) (EC, 2021).

(51) According to EF rules, biogenic carbon flows should not be accounted for in the Climate Change impact category (EC, 2021).

analyses in future, it is recommended that a dataset is developed for cartonboard production that is representative of the EU and aligned with the EF method, particularly concerning the Water Use impact category and background datasets.

Concerning the 'Restaurant Scenario', a set of BE points were tested (Section 2.5.1). The results indicate that improvements in the recycling rate of carton at the end-of-life stage of SU packaging products could lead to BE points in the range of 50–80 % depending on the choice of the cartonboard manufacturing dataset. However, it must be determined whether and how such high rates could be representative and achieved in the overall EU context and not only for specific best-case examples in specific areas, such as certain EU Member States or regions. The BE point for the number of reuses revealed that below 20 rotations (or below 40, using the cartonboard manufacturing dataset in 'Alternative 2') using MU packaging may result in higher impacts than SU alternatives, although those numbers of reuses may be reasonably exceeded in dine-in scenarios (in which restaurant operators have full control of the packaging during use and can therefore minimise any potential losses). Future studies on the restaurant sector could include data collected from broader studies of EU dine-in restaurants, further refining the key assumptions made and overcoming the limitations acknowledged for the Restaurant Scenario and discussed in the present section.

The results of the scenarios analysed also revealed the influence of certain assumptions related to the reuse step for MU packaging products. Assumptions about consumer behaviour in returning MU packaging after use could play a key role in the life cycle performance of the MU packaging, especially if journeys to return packaging are made by car. The number of items returned by users during each journey back to the selling point is also crucial. In general, the modelling of the impacts of these journeys may turn into an allocation problem (as the user's journey could be made for reasons other than returning the packaging, for instance the purchase of more food and drink). The modelling approach proposed in the present study was cross-checked during the stakeholder consultation, although the research team did not receive any additional evidence from stakeholders on the different assumptions. This aspect of the study is therefore recognised as potentially uncertain and relevant for future studies, which could focus on revising and refining it, especially including more in-depth analyses of user behaviour. The potential effects of using electric vehicles for returning packaging were not investigated. However, the use of electric vehicles by users (which is expected to increase in the near future) could potentially lead to a reduction in the impacts associated with transport in the reuse step for various impact categories (e.g. Climate Change), but potentially worse effects in other categories (e.g. 'Resource Use, Mineral and Metals') cannot be excluded.

An additional relevant aspect is the potential for multiple washing cycles (as the user may wash the MU items at home before returning them). This aspect was excluded from the analysis of takeaway scenarios in the present study (as investigated for instance in the Ramboll (2022a) study). Its influence could potentially be significant and could offset the benefits of centralised, efficient in-store washing in which items might be re-washed anyway once returned. Furthermore, home washing practices may vary widely among consumers, potentially leading to a considerable increase in the life cycle impacts if hot water is used.

Consumer behaviour could also significantly influence the environmental impact of reusable food and beverage packaging, since consumers actions are crucial in the reuse phase of containers (Corona et al., 2023). This is a relevant aspect flagged for future research. Moreover, as demonstrated by Eunomia (2023) through sensitivity analysis of changing the mass of packaging, product design and lower weight can play a key role in reducing the environmental impact.

The impact of secondary and tertiary packaging was not explored in the present study, although both have been recognised (Ferrara and De Feo, 2020) as potentially significant contributors to environmental impact in the case of certain system models (e.g. wine packaging). To determine the potential impact of these additional packaging systems in the context of the present study, the analysis should be improved by including such packaging within the system boundaries and emphasising their importance in the overall life cycle performance of certain scenarios.

As explained in Section 2.4.2, the temporal and technological scope of the present report is scenarios that are representative of the current EU market. This choice is a consequence of supported by the lack of reliable information on the future development of packaging systems, especially on the establishment of MU business models for packaging products. This choice is also in line with the recommendations of the EF method for the definition of representative products in study. Future revisions of the present study could introduce an analysis of future scenarios (e.g. including forecasts for the next decade) to be addressed via prospective LCA modelling.

For the sensitivity analysis of the present study, a uniform distribution was consistently applied to the parameters of SU and MU packaging products (Section 2.5). The effect on the results of the sensitivity analysis of applying different probability distributions (e.g. normal distribution, triangular distribution) could be further explored in further studies.

Concerning the material composition of MU packaging products, during the stakeholder consultation it was highlighted how Tritan (52) (or a combination of Tritan and PP) could also be used in the manufacture of MU packaging products such as beverage containers. No further details were provided regarding the specific market share of Tritan-based packaging products, and no EF3.1 datasets are available to date to support proper modelling of its manufacturing impacts. In addition, stakeholder inputs highlighted how recycling of Tritan is still not well established. Considering the above, in the present study, PP was selected as the material used in plastic MU packaging products.

The results of the present report should be considered in the context of the specific case study packaging products and scenarios. The results presented here cannot be considered representative of assessments at the system level (i.e. considering that substantial changes could occur in different sectors of society, including a variety of different packaging products in use for different purposes and services that could be potentially affected by the PPWR targets (Section 1.3)). Despite this, the results of certain scenarios exhibited significantly lower environmental impacts for MU packaging products than for SU alternatives. Such results were observed, for instance, in the case of the ‘Scenario 3 – CASE B’ and ‘Scenario 4’ and in the ‘Restaurant Scenario’. In addition, the results for the ‘Restaurant Scenario’ may also be considered potentially more robust than others, as they avoid making assumptions about the transport mode used to return MU items (which was found to be largely uncertain in other scenarios).

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(52) Tritan is a copolyester made from three monomers: dimethyl terephthalate, cyclohexanedimethanol and 2,2,4,4-tetramethyl-1,3-cyclobutanediol.

5 Conclusion and recommendations

The present study aimed to contribute to the EU ambitions related to reducing the environmental impacts of packaging by addressing some of the knowledge gaps identified in the existing literature on the subject. The JRC conducted an analysis to evaluate the life cycle environmental performance of a selected subset of case studies, targeting certain reuse targets set out in the proposal for a Packaging and Packaging Waste Regulation. The study was carried out following the recommendations of the EF method for the modelling and assessment of environmental impact, by quantifying 16 different impact categories (including Climate Change and Water Use impacts) and also considering an aggregated Single Score index. The JRC study described in the present report modelled and assessed several parameters for the calculation of benchmark case study results and defined parameter ranges for running a series of sensitivity analyses.

The analysis of the SU and MU packaging products showed variable results according to the specific scenario and case studies considered but also depending on the impact category assessed. Concerning benchmark results, in the case of takeaway cups ('Scenario 1') and trays ('Scenario 2 – CASE A' and 'CASE B'), SU packaging exhibited lower life cycle impacts for certain impact categories (e.g. for Climate Change in the case of 'Scenario 1' and 'Scenario 2 – CASE A'), while MU packaging products exhibited lower life cycle impacts for other categories (e.g. for Water Use for 'Scenario 1' and 'Scenario 2 – CASE A' and 'Scenario 2 – CASE B'). The results of the sensitivity analysis of the aggregated Single Score index suggested comparable life cycle impacts, notably with around 40 % of the simulations leading to lower life cycle impacts for the MU packaging in 'Scenario 1' and more than 60 % for the MU packaging in 'Scenario 2 – CASE B'.

The results for 'Scenario 3 – CASE A' analysis of SU aluminium beverage containers with PET reusable alternatives, overall highlighted lower environmental impacts for the SU packaging for certain impact categories (e.g. 'Human Toxicity, cancer' and 'Resource Use, Minerals and Metals'). By contrast, results for the Climate Change impact category showed instead that the performance of the MU and SU packaging considered was more comparable. The assumptions related to the number of reuses for the MU bottle play a key role in determining the life cycle impacts of the MU packaging product in this scenario.

By contrast, in 'Scenario 3 – CASE B' and 'Scenario 4' on glass bottles (for beer and wine, respectively), the MU packaging products showed lower impacts across almost all impact categories (apart from 'Land Use' and, to a lesser extent, 'Resource Use, Minerals and Metals' and 'Human Toxicity, cancer'). It is also interesting to note that, in such scenarios, MU glass bottles resulted in lower impacts despite their assumed greater mass and despite assumptions about additional transport to and washing in a centralised washing facility.

Based on the findings of these case studies it was not possible to conclude that certain packaging options have systematically lower impacts in all scenarios, whereas either SU or MU may have overall lower impacts when key parameters (that are the main driver of the overall packaging product life cycle impacts) are optimised for the life cycle of the examined packaging. Examples of key parameters for SU packaging products are the share of recycling at the end-of-life stage, the assumed mass of the item and the specific material composition. In the case of MU packaging products, the identified key parameters include the expected number of reuses, the energy and heat need in the washing phase of the reuse step (including practices such as rinsing and rewashing) and the overall mass of the packaging.

In particular, this study confirmed the key role of user behaviour in the life cycle impacts of takeaway MU packaging products, in the case of washing either at the point of sale or at a centralised washing facility. In fact, returning used packaging products by car significantly increased the life cycle impacts of the packaging products, compared with other means of transport such as bicycle or walking. The number of items transported is also an important parameter, as carrying multiple items on one journey lowers the environmental pressure on the system. In addition, there is not an unambiguous modelling approach that properly allocates the impacts among different services (e.g. if the packaging is returned on the way to a grocery store). The absence of large-scale established business models hindered the use of primary data for these assumptions and highlights the need for further refinement of the models when such data are available and representative of the EU scale.

Additional scenarios were analysed by considering different life cycle datasets modelling the impacts associated with the cartonboard production process and tested for takeaway cups ('Scenario 1') and a hamburger meal

('Restaurant Scenario'). These datasets were found to be important for the final results, as the cartonboard manufacturing process is a key contributor to the overall life cycle impacts of SU packaging products assessed in the present study. In particular, when considering life cycle datasets for cartonboard with low environmental impacts, the performance of single use packaging is clearly improved, especially for the Water Use impact category, and also to a lesser extent for the Climate Change impact category and the aggregated Single Score (see Section 3.1.2, Section 3.5.2 and Section 4.1 for further details).

It is important to note that the 'Benchmark dataset' (see Table 2 in Section 2.5.1) used for analysing the benchmark scenarios and conducting the sensitivity analysis, specifically concerning the life cycle impacts of cartonboard manufacturing, was derived from data provided by stakeholders. Additional datasets for the cartonboard manufacturing process ('Alternative 1' and 'Alternative 2' in Table 2, obtained from the EF database and from stakeholders, respectively) were employed to model alternative scenarios. Regarding 'Alternative 1', it was not possible to precisely identify all the background and foreground processes included due to the absence of detailed metadata. To prevent potential double-counting of the impacts of manufacturing carton products (cups and trays) in scenarios using this EF dataset, the impacts associated with cartonboard conversion were excluded. Conversely, cartonboard datasets obtained from stakeholders (for both the 'Benchmark dataset' and 'Alternative 2') were highly aggregated and lacking detailed supporting metadata. As a consequence, it was not possible to assess their level of consistency with the EF method and other EF datasets used in the model.

The present study also used as far as possible information from a recent ProCarton study on cartonboard and carton manufacturing and the associated industrial processes. It is also worth highlighting that the 'Benchmark dataset' for cartonboard used in this study had a carbon footprint value closely aligned with the value estimated in the ProCarton study (which pertains to the 'cradle-to-grave carbon footprint of cartons', with the exclusion of biogenic carbon flows and carbon removals).

The results for the 'Restaurant Scenario' focused on the environmental performance of a simple hamburger dine-in meal, modelled considering a set of SU packaging products (carton-based cup and trays) or MU alternatives (PP-based cup and plate). The 'Restaurant Scenario' generally resulted in lower impacts for the MU packaging in a majority of impact categories and simulations. This can be primarily attributed to the inherent nature of the dine-in option. Unlike takeaway meals, the dine-in option eliminates the need for transport to return the MU packaging. Furthermore, it allows a significantly higher number of reuses, as the MU packaging remains under the constant supervision of the restaurant staff, thereby minimising losses due to improper handling by users. In the 'Restaurant Scenario', the MU packaging had a lower impact in more than 60 % of the simulations in the sensitivity analysis for the Climate Change impact category and more than 90 % of the simulations for the aggregated Single Score. The assumptions about the recyclability of waste carton can change the benchmark results in favour of SU packaging, which had lower Climate Change impacts when the recycling of waste carton at the end-of-life stage was higher than 70–80 %. The assumptions about recycling at the end-of-life stage of materials in the MU packaging products were less relevant for the environmental performance. If the recyclability of PP is assumed to increase from 41 % to 85 % (for both the MU tray and cup for the dine-in meal of the 'Restaurant Scenario'), the BE point ([53]) for Climate Change is almost unchanged for all cartonboard datasets. This could be explained by the higher number of reuses expected in the case of the MU packaging products in the 'Restaurant Scenario', which makes the performance of this packaging less dependent on the assumptions about the recyclability of the materials. In the takeaway scenarios, transport via passenger car and the number of items transported back to the point of sale or the centralised washing facility had the most influence on the overall MU packaging impacts. By contrast, the MU packaging in the 'Restaurant Scenario' appeared to be mostly influenced by assumptions about the energy and water requirement for the washing step occurring within the restaurant. The performance of the MU meal packaging in the 'Restaurant Scenario' is also strongly influenced by the number of reuses if they fall in the range 5–20 reuses, as the BE point analysis for the benchmark scenario

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([53]) The BE point here is the value of the recyclability of the carton waste when the SU and the MU packaging had the same Climate Change impacts (considering all the other parameters fixed as in the benchmark scenario). For higher values of carton recyclability, the SU packaging then had then lower Climate Change impacts.

suggested that the BE point would be reached at around 20 reuses (around 18 reuses if the ‘Alternative 1’ dataset for cartonboard production is employed; around 40 if the ‘Alternative 2‘ dataset is used instead).

The study also highlighted the contribution of each impact category to the Single Score results derived from the benchmark scenarios. It was found that the Climate Change and ‘Resource Use, Fossil’ impact categories accounted for the majority of the Single Score across all scenarios. Conversely, the impact of Water Use was significantly less influential for the Single Score results. On the whole, the various impact categories made similar contributions to the Single Score for both SU and MU packaging across all scenarios, with Climate Change and ‘Resource Use, Fossil’ impacts having slightly more influence on the Single Score for MU packaging.

In addition, the present study also allowed aspects relevant for the life cycle impacts of MU packaging to be identified, for which few assessments exist in the literature. For instance, practices adopted during the washing of MU packaging including rinsing (with hot or cold water) and rewashing (after a first washing cycle in a dishwasher). The key parameters identified in the present study (e.g. the importance of the number of rotations, packaging mass, recycling at the end-of-life stage, consumer behaviour) were also recognised by most of the comparable literature studies in the packaging product field. It has also been acknowledged that the specific assumptions about some of these parameters could significantly affect the overall life cycle impacts of the packaging products analysed. However, employing different methodologies for the calculation of environmental life cycle impacts and different system boundaries could undermine the comparability of different study findings. Such variability in the approaches and assumptions made in the literature highlighted the need for a harmonised approach to the calculation of life cycle impacts. In addition, the metadata accompanying the available information in the literature (e.g. source of the data, source of the assumption) was frequently scarce or confidential, thereby further limiting a thorough analysis of the data and associated findings. Overall, this study revealed a number of insights and considerations regarding the impacts of MU and SU packaging. Particular attention was given to running a large number of simulations and scenarios in the sensitivity analysis. In line with the analysis of the limitations of the study, the report identifies crucial parameters and assumptions for the modelling of comparative LCA for SU and MU packaging products, on which future research should focus (including increasing the collection and quality of primary data on reuse operations, or the development of up-to-date and representative life cycle datasets for the manufacturing of cartonboard packaging products).

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List of abbreviations

BE	Break Even
BKV	Plastics Concepts Recovery (English translation)
EC	European Commission
EEA	European Environment Agency
EFTA	European Free Trade Association
EPPA	European Paper Packaging Alliance
EU	European Union
FEFCO	European Federation of Corrugated Board Manufacturers
HORECA	Hotels Restaurants and Catering
DG ENV	Directorate-General for Environment
LCA	Life Cycle Assessment
LDPE	Low-density polyethylene
MU	Multiple Use
SU	Single Use
JRC	Joint Research Centre
PEF	Product Environmental Footprint
PP	Polypropylene
PPWR	Packaging and Packaging Waste Regulation
PS	Polystyrene
UUID	Universal Unique Identifier
UK	United Kingdom

List of definitions

Cartonboard	In this study, the word “cartonboard” refers to a material that can be produced from primary wood fibres and/or from recovered fibres and is usually manufactured via pulping. This material needs to be further processed to arrive at the final packaging product. Thus “cartonboard” is used in this report to refer to a different packaging paper than the thick paper (usually brown) which is instead used especially for making boxes (i.e. secondary or tertiary packaging) and not used for the food and beverage packaging referenced in the study.
Carton	In this study, the word “carton” refers to a material that is produced by processing (in so-called “converters”) the cartonboard delivered from the mills plants into the final packaging product. As an example, folding and gluing are included in the converting of cartonboard into carton.

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6 Annexes

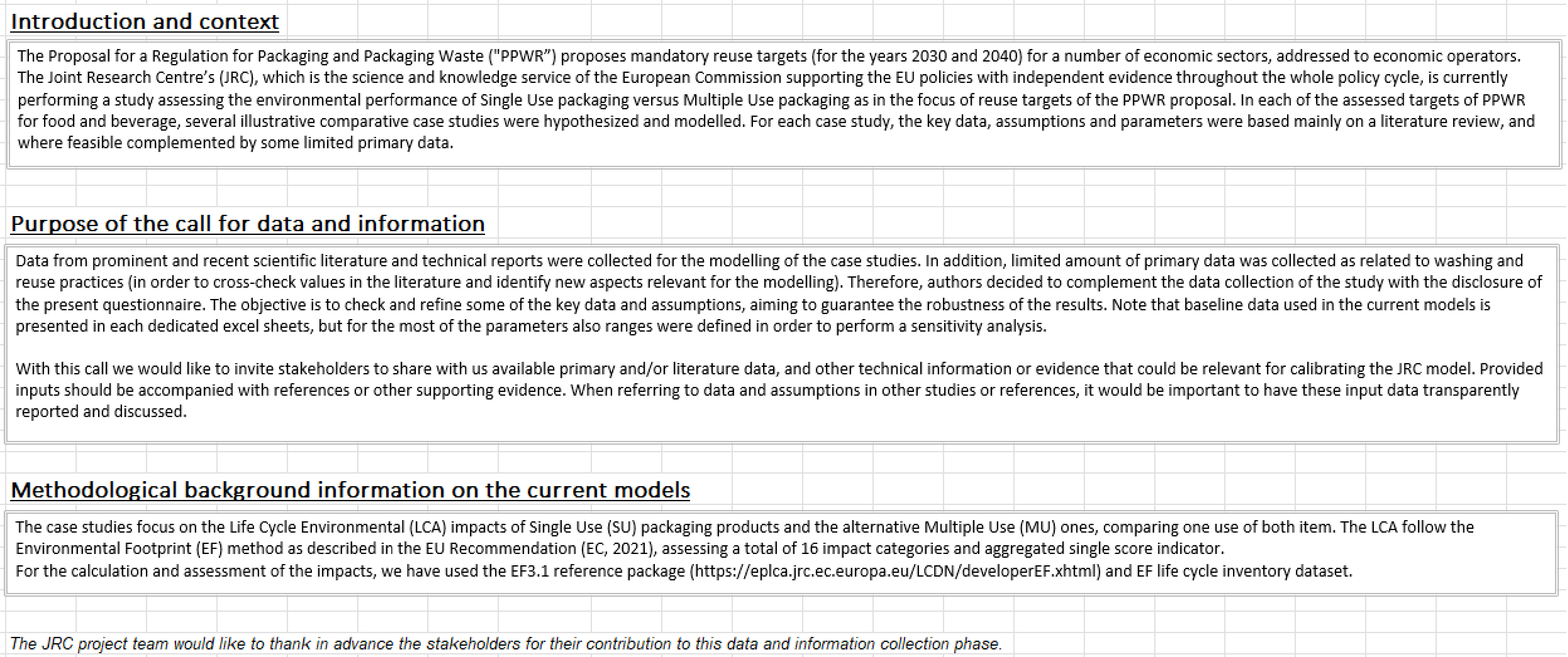
Annex 1. Details on the stakeholder consultation

This Annex aims at providing further details on the stakeholder consultation carried out by the JRC. As described in Section 2.3, the consultation aimed at collecting relevant data from stakeholders for all case studies under exam, towards improving their robustness and representativeness. The shared questionnaire took the form of a Microsoft Excel file, comprised of several sheet (e.g. Figure 33 and Figure 34). Hereafter the contents of the questionnaire are illustrated.

- In the sheet named “Introduction and context”, the purpose of the call for data and the relevant methodological information on the models were provided.
- In the sheet named “Data collection Instructions”, information on how to provide data and on the use of such information were provided.
- Other sheets were dedicated to specific data collections, in particular:
    - In the sheet “Beverage Cups (0.5L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use product Paper cup with LDPE plastic lining and PS lid (0.5 litre) vs multiple use product PP cup with PP Lid (0.5 litre)” [‘Scenario 1’].
    - In the sheet “General Food Trays 1 (1.1L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use product Carton tray with LDPE lining (1.1 litre) vs multiple use product PP tray (1.1 litre)” [‘Scenario 2 – CASE A’].
    - In the sheet “General Food Trays 2 (1.1L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use product Aluminium tray with carton cover and LDPE lining (1.1 litre) vs multiple use product PP tray (1.1 litre)” [‘Scenario 2 – CASE B’].
    - In the sheet “Glass Wine Bottles (0.75L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use product glass bottle (0.75 litre) vs multiple use product glass bottle thicker (0.75 litre)” [‘Scenario 4’].
    - In the sheet “Glass Beer Bottles (0.5L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use product glass bottle (0.5 litre) vs multiple use product glass bottle thicker (0.5 litre)” [‘Scenario 3 – CASE B’].
    - In the sheet “Alcoholic beverages (0.5L)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use Aluminium Can (0.5 litre) vs multiple use Plastic Bottle (0.5 litre)” [‘Scenario 3 – CASE A’].
    - In the sheet “Hamburger Meal (Restaurant)” general information on the case study were illustrated and stakeholders were invited to share data for SU and MU packaging products included in the sheet entitled “single use Hamburger Meal vs multiple use Hamburger Meal)” [‘Restaurant Scenario’].

For sake of completeness, screenshots taken from the file are provided hereafter for the “Introduction and context”, “Data collection Instructions” and “Beverage Cups (0.5L)” sheets.

Figure 33. Screenshot of the Microsoft Excel file shared during the stakeholder consultation, detailing the sheet “Introduction and context”.



Introduction and context

The Proposal for a Regulation for Packaging and Packaging Waste ("PPWR”) proposes mandatory reuse targets (for the years 2030 and 2040) for a number of economic sectors, addressed to economic operators. The Joint Research Centre’s (JRC), which is the science and knowledge service of the European Commission supporting the EU policies with independent evidence throughout the whole policy cycle, is currently performing a study assessing the environmental performance of Single Use packaging versus Multiple Use packaging as in the focus of reuse targets of the PPWR proposal. In each of the assessed targets of PPWR for food and beverage, several illustrative comparative case studies were hypothesized and modelled. For each case study, the key data, assumptions and parameters were based mainly on a literature review, and where feasible complemented by some limited primary data.

Purpose of the call for data and information

Data from prominent and recent scientific literature and technical reports were collected for the modelling of the case studies. In addition, limited amount of primary data was collected as related to washing and reuse practices (in order to cross-check values in the literature and identify new aspects relevant for the modelling). Therefore, authors decided to complement the data collection of the study with the disclosure of the present questionnaire. The objective is to check and refine some of the key data and assumptions, aiming to guarantee the robustness of the results. Note that baseline data used in the current models is presented in each dedicated excel sheets, but for the most of the parameters also ranges were defined in order to perform a sensitivity analysis.

With this call we would like to invite stakeholders to share with us available primary and/or literature data, and other technical information or evidence that could be relevant for calibrating the JRC model. Provided inputs should be accompanied with references or other supporting evidence. When referring to data and assumptions in other studies or references, it would be important to have these input data transparently reported and discussed.

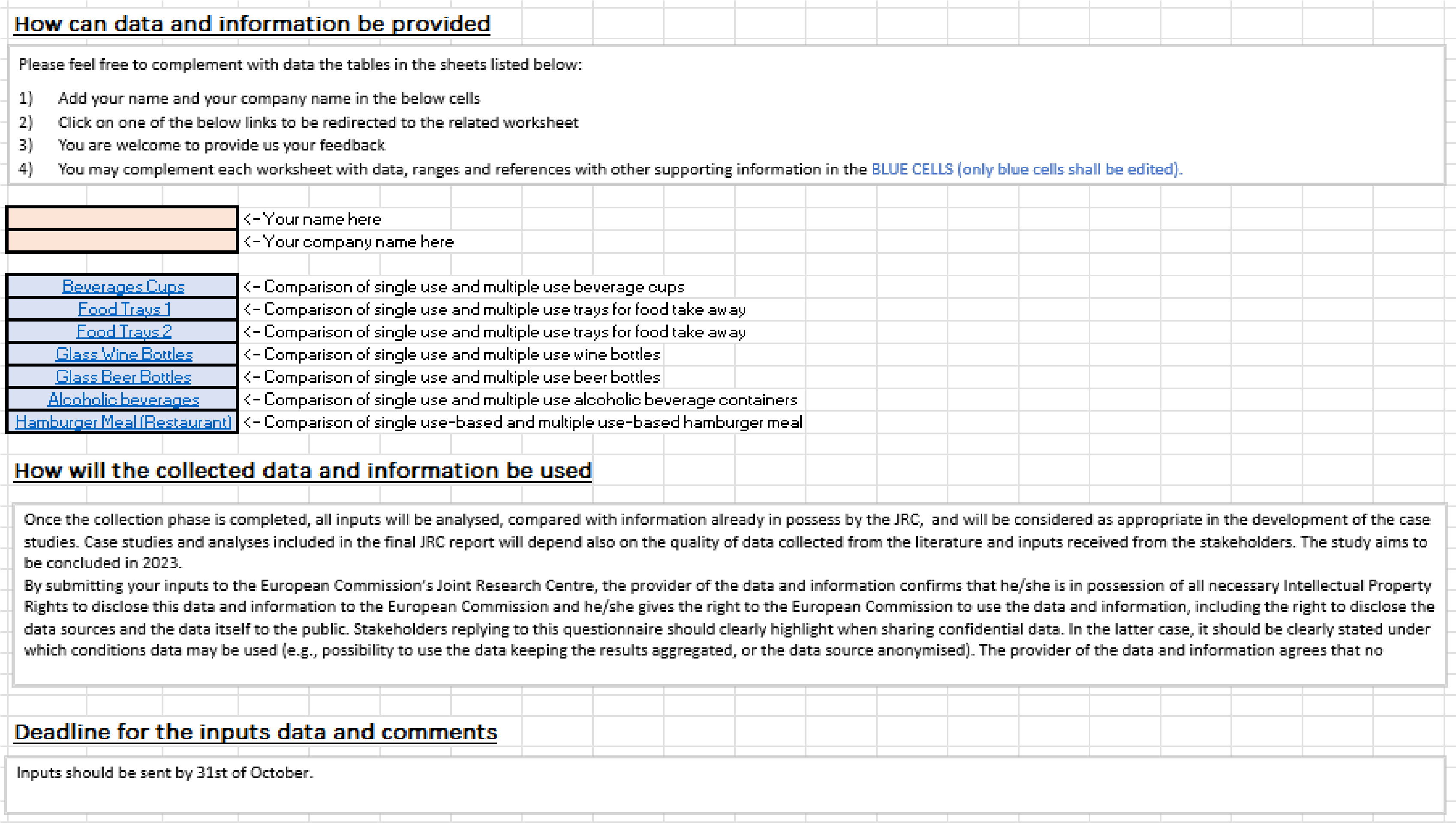
Methodological background information on the current models

The case studies focus on the Life Cycle Environmental (LCA) impacts of Single Use (SU) packaging products and the alternative Multiple Use (MU) ones, comparing one use of both item. The LCA follow the Environmental Footprint (EF) method as described in the EU Recommendation (EC, 2021), assessing a total of 16 impact categories and aggregated single score indicator.
For the calculation and assessment of the impacts, we have used the EF3.1 reference package (https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml) and EF life cycle inventory dataset.

The JRC project team would like to thank in advance the stakeholders for their contribution to this data and information collection phase.

Source: JRC analysis.

Figure 34. Screenshot of the Microsoft Excel file shared during the stakeholder consultation, detailing the sheet “Data collection Instructions”.



How can data and information be provided

Please feel free to complement with data the tables in the sheets listed below:

1) Add your name and your company name in the below cells
2) Click on one of the below links to be redirected to the related worksheet
3) You are welcome to provide us your feedback
4) You may complement each worksheet with data, ranges and references with other supporting information in the BLUE CELLS (only blue cells shall be edited).

	<- Your name here
	<- Your company name here

Beverages Cups	<- Comparison of single use and multiple use beverage cups
Food Trays 1	<- Comparison of single use and multiple use trays for food take aw ay
Food Trays 2	<- Comparison of single use and multiple use trays for food take aw ay
Glass Wine Bottles	<- Comparison of single use and multiple use wine bottles
Glass Beer Bottles	<- Comparison of single use and multiple use beer bottles
Alcoholic beverages	<- Comparison of single use and multiple use alcoholic beverage containers
Hamburger Meal (Restaurant)	<- Comparison of single use-based and multiple use-based hamburger meal

How will the collected data and information be used

Once the collection phase is completed, all inputs will be analysed, compared with information already in possess by the JRC, and will be considered as appropriate in the development of the case studies. Case studies and analyses included in the final JRC report will depend also on the quality of data collected from the literature and inputs received from the stakeholders. The study aims to be concluded in 2023.

By submitting your inputs to the European Commission’s Joint Research Centre, the provider of the data and information confirms that he/she is in possession of all necessary Intellectual Property Rights to disclose this data and information to the European Commission and he/she gives the right to the European Commission to use the data and information, including the right to disclose the data sources and the data itself to the public. Stakeholders replying to this questionnaire should clearly highlight when sharing confidential data. In the latter case, it should be clearly stated under which conditions data may be used (e.g., possibility to use the data keeping the results aggregated, or the data source anonymised). The provider of the data and information agrees that no

Deadline for the inputs data and comments

Inputs should be sent by 31st of October.

Source: JRC analysis.

Annex 2. List of the dataset included in the assessment

In Table 5 the full list of datasets employed for the analysis is reported.

Note that the dataset “Solid board, bleached; Kraft Pulping Process, pulp pressing, bleaching and drying; production mix, at plant; >220 g/m2” reported in Table 5 has been employed in the analysis of alternative cartonboard production impacts (named: ‘Alternative 1’, as described in Section 2.5.1), and was not employed in the benchmark analysis presented in the report with regard to carton-based packaging products. This dataset was included among the “cartonboard” manufacturing alternatives albeit it was considered that its impacts were covering cartonboard manufacturing and also conversion of cartonboard into carton (see main report in Section 2 for further details). The ‘Benchmark dataset’ (as well as the ‘Alternative 2’ dataset) was collected during the stakeholder consultation: further details are provided in Section 2.5.1. These two datasets covered cartonboard manufacturing production only, and when employed in the life cycle analysis additional energy was considered in the models to account for the converting needs to further process cartonboard into carton.

Table 5. Overview of the EF3.1 datasets employed for the study, coupled with the specific Universal Unique Identifier (UUID) of each dataset.

EF3.1 dataset name	UUID
Aluminium extrusion; primary production, aluminium extrusion; single route, at plant; 2.7 g/cm3	1739a600-8e46-4595-ba49-867b8d6f9a11
Aluminium ingot (manganese main solute); primary production, aluminium casting and alloying; single route, at plant; 2.7 g/cm3	5ad00e36-649c-471e-9b7c-a855b20e6f5f
Articulated lorry transport, Euro 4, Total weight <7.5 t; diesel driven, Euro 4, cargo; consumption mix, to consumer; up to 7,5t gross weight / 3,3t payload capacity	b551d8e9-91ea-4ee4-a3bb-a3437a45ec83
Articulated lorry transport, Euro 4, Total weight >32 t; diesel driven, Euro 4, cargo; consumption mix, to consumer; more than 32t gross weight / 24,7t payload capacity	e1ded83e-a02f-42cd-92f9-81cce21a3a98
Articulated lorry transport, Euro 4, Total weight 12-14 t; diesel driven, Euro 4, cargo; consumption mix, to consumer; 12-14t gross weight / 9,3t payload capacity	d231e082-c74c-4108-ae47-c7decd908094
Blow moulding; blow moulding; production mix, at plant; PET, HDPE and PP	215dd4d8-52ad-4eee-bd63-7a6193f2b8d5
Container glass, ER, Recycled Content 100%; Recycled container glass (all sizes) to be used for glass bottles and food jars; Production mix. Technology mix. EU-28 + EFTA; 1 kg of formed and finished recycled container glass	ab4e945f-9955-4414-b3fb-d42507cc4e2d
Container glass, green colour; Green colour container glass (all sizes) to be used for glass bottles and food jars; Production mix. Technology mix. EU-28 + EFTA; 1 kg of formed and finished container glass	cd904baf-b510-4e0a-958e-2a588a59e8f6
Container glass, virgin; Virgin container glass (all sizes) to be used for glass bottles and food jars; Production mix. Technology mix. EU-28 + EFTA; 1 kg of formed and finished container glass	5ccf94ab-173c-4688-bcc8-d434166be45e
Detergent proxy	Additional details provided in Table 6.
Detergent proxy bottles	Additional details provided in Table 7.
Energy Mix	Additional details provided in Table 8.
Film Extrusion (blowing); plastic extrusion; production mix, at plant; for PP, PE, PVC, PET and PS	34591654-1708-49f3-a12c-34180aae8290
Incineration PP; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; polypropylene	3e1c1433-a79f-47e7-bcd0-be45781f7ed7
Landfill of inert (aluminium); landfill including leachate treatment and with transport without collection and pre-treatment; production mix (region specific sites), at landfill site	3f7d5e8a-a112-4585-9e2f-dc8b667d66dc

EF3.1 dataset name	**UUID**
Landfill of inert (glass); landfill including leachate treatment and transport (no pre-treatment); production mix (region specific sites), at landfill site	01196227-0627-440c-9f2f-94b8f1e7d1ad
Landfill of paper and paperboard waste; landfill including leachate treatment and with transport without collection and pre-treatment; production mix (region specific sites), at landfill site; The carbon and water content are respectively of 30% C and 22% Water (in weight %)	86ff0001-4794-4df5-a1d4-083a9d986b62
Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment; production mix (region specific sites), at landfill site; The carbon and water content are respectively of 62%C and 0% Water (in weight %)	f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6
LDPE granulates; Polymerisation of ethylene; production mix, at plant; 0.91- 0.96 g/cm3, 28 g/mol per repeating unit	d327f4a5-93a1-4ead-856c-aeb8b2f25080
Passenger car, average; technology mix, gasoline and diesel driven, Euro 3-5, passenger car; consumption mix, to consumer; engine size from 1,4l up to >2l	1ead35dd-fc71-4b0c-9410-7e39da95c7dc
PET granulates, amorphous; Polymerisation of ethylene; production mix, at plant; 0.91- 0.96 g/cm3, 28 g/mol per repeating unit	52ecabcf-fb6a-4d58-895c-41078326bbcb
Polyethylene terephthalate (PET) granulate secondary ; no metal fraction; from post-consumer waste, via washing, granulation, palletisation; production mix, at plant; 90% recycling rate	49a42d24-84be-42d5-8fe4-48efad0f4487
Polypropylene, recycled, post-consumer; washing, drying, shredding, pelletizing; production mix, at plant; Erec/ErecEoL, efficiency 90%	637779a3-5c48-55b2-a42b-3e29f96325e1
Polystyrene production, high impact; polymerisation of styrene; production mix, at plant; 1.05 g/cm3	42affac5-a207-4ec5-bd7d-2dffd85ff50e
PP granulates {EU+EFTA+UK} | polymerisation of propene | production mix, at plant | 0.91 g/cm3, 42.08 g/mol per repeating unit | LCI result	eb6c15a5-abcd-4d1a-ab7f-fb1cc364a130
Recycling glass, waste management, technology mix, at plant; collection, sorting, transport, recycling; production mix, at plant; glass waste, efficiency 95%	25d927a6-022d-4797-aee5-c5918da38e91
Recycling of aluminium into aluminium ingot - from post-consumer; collection, transport, pretreatment, remelting; production mix, at plant; aluminium waste, efficiency 90%	c7f28f2a-f262-49ad-ba96-0cab313b186f
Recycling of post-consumer waste polypropylene (PP); collection, sorting, transport, washing, granulation, palletisation; production mix, at plant; 48,9% recycling rate	2ec1afd9-7d95-4b64-8120-c362bb0c8bee
Recycling of post-consumer waste polyethylene terephthalate (PET); collection, sorting, transport, washing, granulation, palletisation; production mix, at plant; 48,9% recycling rate	4a5df62a-5991-4862-a249-4eb07d2e943c
Recycling paper and cardboard, waste management, technology mix, at plant; collection, sorting, transport, recycling; production mix, at plant; paper waste, efficiency 90,9%	308685e7-15fe-417e-a016-1f6060a0ff10
Screw cap, PP; raw material production, plastic injection moulding; production mix, at plant; 0.91 g/cm3, 42.08 g/mol per repeating unit	05a26a08-1ab5-4523-b25f-41b9be0ffc76
Secondary aluminium ingot (manganese main solute); secondary production, aluminium casting and alloying; single route, at plant; 2.7 g/cm3	a44f2af0-f15b-4d46-89a6-5deb49e9f166
Solid board, bleached; Kraft Pulping Process, pulp pressing, bleaching and drying; production mix, at plant; >220 g/m2	0405501b-e12f-4d45-ab51-c5b1f5f12620
Tap water; average technology mix; consumption mix, at consumer; Technology mix for supply of drinking water to users	2195cfe0-a5cc-5be2-9102-c0a0cb656bcb
Thermal energy from natural gas; technology mix regarding firing and flue gas cleaning; production mix, at heat plant; MJ, 100% efficiency	6db46295-201a-47d1-af8f-c2a7bee43946
Treatment of residential wastewater, small plant; wastewater treatment including sludge treatment; production mix, at plant; 1m3 of wastewater treated	8126980a-29e9-416c-991d-2aa5fdad9062
Waste incineration of inert material; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; inert material waste	061572a7-989d-4104-8e39-85b46e3d249b

EF3.1 dataset name	**UUID**
Waste incineration of non-ferro metals, aluminium, more than 50µm; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; aluminium waste	0a1bc8da-ef57-4464-9065-b156cdf3a458
Waste incineration of paper and board; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; paper waste	08856e05-f2e1-47b1-832a-a429c989f665
Waste incineration of PE; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; polyethylene waste	010702b1-b39e-4d64-bcbc-dd826ee8654b
Waste incineration of PET; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; polyethylene terephthalate waste	03c6ca38-c023-41e2-9aca-8d86670bff2c
Waste incineration of PS; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment; production mix, at consumer; polystyrene waste	036307fb-9c35-4762-b6a7-322849ff73d9

Source: EF datasets. Note: Details on the Detergent and energy mixes models are reported in Table 6, Table 7 and in Table 8. All datasets were selected with the EU+EFTA+UK geography beside the dataset for recycled post-consumer polypropylene and the dataset for passenger car both having a Global geography (these two were selected due to lack of EU-specific EF3.1 datasets).

In the case of detergents used for the washing operations of the MU packaging products (excluding for bottles), a proxy dataset was calculated based on Campbell et al. (2020) and Ramboll (2022a). This proxy dataset (named "Detergent proxy" in Table 5) was modelled considering 71 % of chemicals distributed as follows: 43% of impacts associated to soda ash, 30 % of impacts associated with citric acid, 10 % of impacts associated with layered sodium silicates SKS6 powder, 7% of sodium percarbonate powder, 6 % of polycarboxylates active substance, 2 % of ethylenediamine and 2 % of fatty alcohol sulphate and 29 % of softened water. Details on the datasets employed for the modelling of the detergent is provided in Table 6. In the case of detergents used for the washing operations of MU bottles (i.e. wine and beer bottles), a proxy dataset was calculated considering the chemicals used in the washing of bottles as identified by Tua et al. (2020). This proxy dataset (named "Detergent proxy bottles" in Table 5) was modelled considering the need of 76 % disinfectant (peracetic acid), 0.03 % release agents for label removal, 8.6 % acidic products for the removal of the mineral residue and 15.8 % detergents based on caustic soda. Details on the datasets employed for the modelling of the detergent is provided in Table 6.

Table 6. Overview of the EF3.1 datasets employed for modelling the detergent considered in the study (excluding for bottles). The shares are based on Campbell et al. (2020) and Ramboll (2022a).

EF3.1 dataset name	**Total share**	**Specific share**	**UUID**
Ehtylenediamine production; technology mix; production mix, at plant; 100% active substance	71 %	2 %	12192840-df2f-498c-9ca5-a9d4401de922
Sodium silicate powder production; technology mix; production mix, at plant; 100% active substance		10 %	140b222f-7fe3-4efb-8692-2b387054960a
Soda production; technology mix; production mix, at plant; 100% active substance		43 %	546d4097-a453-4706-ac17-389325a04b6f
Citric acid production; technology mix; production mix, at plant; 100% active substance		30 %	d0becc20-49c4-4e8f-9ff8-8c392d5610ed
Polycarboxylate production; technology mix; production mix, at plant; 100% active substance		6 %	dbdbd19e-38e7-47e7-8894-f6c51ee1a90c
Fatty alcohols production; technology mix; production mix, at plant; 100% active substance		2 %	f0d6cd33-9022-4cd6-af15-9a88c1081685
Sodium percarbonate, powder production; technology mix; production mix, at plant; 100% active substance		7 %	55a8e0ee-2acd-4167-8d2e-95300f7dfeb7
Water, completely softened; average technology mix; production mix, at plant; Technology mix for supply of softened water to users	29 %	-	00e145fd-f5cb-5571-94f3-054ddbba312b

Source: EF datasets and literature review. Note: all datasets were selected with the EU+EFTA+UK geography beside the dataset for ethylenediamine production and the dataset for fatty alcohols production both having a Global geography (selected due to lack of EU-specific EF3.1 datasets).

Table 7. Overview of the EF3.1 datasets employed for modelling the detergent considered in the study for bottles' washing. The shares are based on Tua et al. (2020).

EF3.1 dataset name	Share	UUID
Acetic acid production; technology mix; production mix, at plant; 100% active substance	75.66 % (these two datasets were employed based on the molecular weight of the two chemicals for deriving the peracetic acid used as disinfectant)	09c336e4-436b-4be0-95bd-444d2295dc0d
Hydrogen peroxide, 100% production; technology mix; production mix, at plant; 100% active substance		edaebb9c-73a9-4e3a-a682-4fbb75b7a1d9
EDTA production; technology mix; production mix, at plant; 100% active substance	0.008 % (release agent)	f8eb9518-ab48-4476-a74e-56a28b6414da
Sodium cumenesulphonate production; technology mix; production mix, at plant; 100% active substance	0.016 % (release agent)	c4e9ca1c-f77c-4aef-a1e3-394f86dd44ae
Sulphuric acid production; technology mix; production mix, at plant; 100% active substance	4.28 % (mineral residue removal)	eb6abe54-7e5d-4ee4-b3f1-08c1e220ef94
Lactic acid production; technology mix; production mix, at plant; 100% active substance	4.28 % (mineral residue removal)	460f4294-2b1f-41d9-9596-d0168a51b10c
Sodium hydroxide production; technology mix; production mix, at plant; 100% active substance	15.79 % (release agent)	2ba49ead-4683-4671-bded-d52b80215e9e

Source: EF datasets and literature review. Note: all datasets were selected with the EU+EFTA+UK geography; rounding effect from the calculated share might be present.

The electricity consumption was modelled based on the EF3.1 "Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV" dataset. A set of different geographies was identified for a total of 5 Energy Mix (E-Mix) types. The dataset concerning the EU mix was selected as the reference benchmark for the models (named "E-Mix1"). The remaining four geographies represent extremes of the emissions intensities among Member States (as described in EEA, 2023). In particular, Poland, Germany, Sweden and Belgium were selected to represent a wide range of renewable shares in the country mixes. Each geography was therefore associated to a specific "E-Mix", as follows: "E-Mix1" (EU), "E-Mix2" (Germany), "E-Mix3" (Sweden), "E-Mix4" (Poland), "E-Mix5" (Belgium). In each sensitivity analysis simulation of each Scenario, the impacts associated to the energy mix were randomly extracted between these 5 mixes. A summary of the employed datasets included for the modelling of the energy mixes is provided in Table 8. All the datasets reported in Table 8 refer to the year 2012.

Table 8. Overview of the EF3.1 datasets employed for modelling the energy mixes considered in the study.

EF3.1 dataset name	Short name	Geography	Used in	UUID
Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV	E-Mix1	EU+EFTA+UK	- Benchmark calculations - Could be randomly extracted in sensitivity analysis simulations	34960d4d-af62-43a0-aa76-adc5fcf57246 (1)
Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV	E-Mix2	Germany	- Could be randomly extracted in the sensitivity analysis simulations	99fb7b5a-b681-40ea-9ccb-7b54b336d23c (2)
Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV	E-Mix3	Sweden	- Could be randomly extracted in the sensitivity analysis simulations	afa958d8-182c-4481-b81c-e2cbdb638930 (3)

EF3.1 dataset name	**Short name**	**Geography**	**Used in**	**UUID**
Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV	E-Mix4	Poland	- Could be randomly extracted in the sensitivity analysis simulations	646d61ac-1d33-4c2c-bc11-89dd1c829d1e (4)
Electricity grid mix 1kV-60kV; technology mix; consumption mix, to consumer; 1kV - 60kV	E-Mix5	Belgium	- Could be randomly extracted in the sensitivity analysis simulations	28290933-1fb0-42f4-a204-4e41169685a7 (5)

Source: EF datasets and own assumption. Note: (1) This dataset refers to an average EU mix share based on data from the International Energy Agency (IEA, 2024). The information available from the World Energy Outlook report (EIA, 2024) concerning the year 2012 did not provide a European energy mix breakdown by primary sources. Further, the level of aggregation of the dataset hindered a detailed overview of the sources mix employed in the dataset modelling. As a reference, the carbon footprint of this dataset amounted to 0.12 kg CO2 eq./MJ; (2) This dataset refers to electricity in Germany, considering the following mix composition (retrieved from the available dataset metadata): Nuclear 14.23 %, Lignite 23.95 %, Hard coal 18.25 %, Coal gases 1.78 %, Natural gas 9.77 %, Heavy fuel oil 0.96 %, Biomass 1.71 %, Biogas 5.20 %, Waste 1.99 %, Hydro 3.86 %, Wind 12.28 %, Photovoltaic 6.00 %, Geothermal 0.02 %. As a reference, the carbon footprint of this dataset amounted to 0.16 kg CO2 eq./MJ; (3) This dataset refers to electricity in Sweden, considering the following mix composition (retrieved from the available dataset metadata): Nuclear 38.45 %, Peat 0.24 %, Hard coal 0.29 %, Coal gases 0.25 %, Natural gas 0.54 %, Heavy fuel oil 0.39 %, Biomass 6.31 %, Biogas 0.02 %, Waste 1.75 %, Hydro 47.46 %, Wind 4.30 %, Photovoltaic 0.01 %. As a reference, the carbon footprint of this dataset amounted to 0.01 kg CO2 eq./MJ; (4) This dataset refers to electricity in Poland, considering the following mix composition (retrieved from the available dataset metadata): Lignite 33.34 %, Hard coal 49.71 %, Coal gases 1.12 %, Natural gas 3.86 %, Heavy fuel oil 1.26 %, Biomass 5.88 %, Biogas 0.35 %, Waste 0.04 %, Hydro 1.52 %, Wind 2.93 %. As a reference, the carbon footprint of this dataset amounted to 0.28 kg CO2 eq./MJ; (5) This dataset refers to electricity in Belgium, considering the following mix composition (retrieved from the available dataset metadata): Nuclear 48.64 %, Hard coal 4.09 %, Coal gases 2.51 %, Natural gas 28.42 %, Heavy fuel oil 0.39 %, Biomass 4.45 %, Biogas 0.98 %, Waste 2.61 %, Hydro 2.00 %, Wind 3.32 %, Photovoltaic 2.59 %. As a reference, the carbon footprint of this dataset amounted to 0.07 kg CO2 eq./MJ.

Annex 3. Factsheets of each examined Scenario

In this Annex, all Factsheets related to the various scenarios under examination are listed, summarizing the main methodological assumptions, system boundaries and results.

Factsheet – Scenario 1

PPWR reference: "cold or hot beverages filled into a container at the point of sale for takeaway by the final distributor"

Scenario 1 - SU Carton Cup with LDPE lining and PS lid vs MU PP Cup

-------------------- Scenario 1 - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 500 ml SU cup and a 500 ml MU cup are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of packaging, including the manufacturing step (including raw material sourcing, production of the components of the packaging and manufacturing of final packaging), the transport step (covering transports from manufacturing site to the selling point), the end-of-life steps (covering recycling, incineration and landfill) and the "Reuse" step for the MU packaging product.

In the case of the SU packaging, the following assumptions were employed (data on the masses retrieved during the stakeholder consultation):

- The impacts were calculated for a carton cup with a total mass of 17.58 g. The cup is composed of a carton body (11.22 g) with a LDPE lining (1.068 g) and a carton lid (4.79 g) with a LDPE lining (0.506 g).
- The SU packaging is manufactured, and then consumed. At the end-of-life, it was assumed that the SU packaging could be either recycled, incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from the selling point to home, as it was assumed to be the same for both SU and MU packaging.

In the case of the MU packaging, the following assumptions were employed:

- The impacts were calculated for a PP cup (including lid) with a mass of 48.3 g.
- The MU packaging is manufactured, and then consumed. The MU packaging was assumed to be washed (including rinsing of packaging) and consumed multiple times. At the end-of-life, it was assumed that the SU packaging could be either recycled, incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from restaurant to home, because it was assumed to be same for both SU and MU packaging.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging: the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.

- For the MU packaging: the recycled content of the PP; the number of reuses; the amount of energy required for the reuse step (i.e. washing, rinsing); the amount of water required in the rinsing; the transport distances in the reuse step and the amount of items transported to the washing; the amount of detergent used for washing.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) the benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges. Further sensitivity analyses have been performed in the context of 'Scenario 1' and are detailed in the main report.

-------------------- Scenario 1 – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 9.

Table 9. Overview of the life cycle stages considered for 'Scenario 1' for both Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	SU, MU	- SU: Production of cartonboard and LDPE sheet - MU: Production PP granulates	All the materials' transports are already included in the datasets related to this life cycle stage. The recycled content of all materials was assumed to be 0 % (note that the PP recycled content is allowed to reach values as high as 10 % in the sensitivity analysis simulations).
Cup manufacturing	SU, MU	- SU: Manufacturing of the carton cup and its lid - MU: Manufacturing of the PP cup	All materials' transports are already included in the datasets related to this life cycle stage. - SU: The electricity consumption to insert LDPE lining and to make a cup. - MU: The PP extrusion (blowing).
Transport	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t), Transport heavy duty lorry (<7.5 t)	Covering the transport of packaging from manufacturing to distribution centre and finally to use.
End-of-life - Recycling	SU, MU	- SU: carton recycling and avoided production (credits) - MU: PP recycling and PP avoided production (credits)	No recycling of LDPE in the SU packaging was considered. All the transports concerning recycling are already included in the datasets related to this life cycle stage.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
End-of-life - Incineration	SU, MU	- SU: Incineration of carton, LDPE, and PS - MU: incineration of PP	All the transports concerning incineration are already included in the datasets employed for this life cycle stage. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.
End-of-life - Landfill	SU, MU	- SU and MU: Transport articulated lorry (12-14t) - SU: Landfill of plastic waste (for LDPE) and landfill of carton and carton waste - MU: Landfill of plastic waste (PP)	-
Reuse	MU	- Transport passenger car - Water consumption from washing - Heat consumption - Electricity consumption - Detergents consumption from washing - Wastewater treatment	Includes inputs and outputs of the washing process, including rinsing with hot water before washing (prewashing) and passenger car for returning 10 % of the cups.

Source: JRC analysis.

-------------------- Scenario 1 – Inventory and Parameters (Benchmark values and related Ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 10 for the SU packaging product, and in Table 11 for the MU packaging product. The SU and MU cups masses and compositions have been estimated based on inputs received from stakeholder during the stakeholder consultation.

The transport from manufacturing to use was assumed to follow the EF method, considering that cups are first transported from the manufacturing site to the distribution centre and then to the selling points where they are sold to consumers. When available, distances were modelled according to the inputs received during the stakeholders' consultation. The consumption was assumed to happen close to the purchasing points (including on the streets). As a consequence, in case of the SU packaging, the cups are disposed to public rubbish bins, from where they end up to different end-of-life options. It was assumed that 15 % of carton cups are recycled, because of the lack of collection and recycling infrastructure of multilayer materials (Kearney, 2023). In the recycling facility, the LDPE layer is separated from carton, and only carton part is recycled, while LDPE layer is either landfilled or incinerated. In the case of MU packaging, cups have to be returned in the selling point from where they were bought. In that case it was assumed that 10 % of cups are transported back to the original place using passenger car without other purposes than returning the purchased packaging, whilst 90 % of the cups are returned by foot or bicycle (or by car, assuming the travel is done for other purposes such as shopping). As a consequence, no impacts were assigned for the 90 % of the returned cups. In case of 10 % of cups returned by passenger car, it was assumed that 5 cups are returned same time (i.e. the impacts are divided for 5 cups).

The reuse rate of MU PP cups vary largely between literature studies retrieved concerning this kind of packaging (e.g. KeepCup, 2018; CupClub, 2018). As an example, Ramboll (2022a) assumed 50 reuses with the assumption that only 50 % of cups are returned, thus each cup would have only 25 actual reuses. In the present study, a more cautious approach was employed, assuming 15 reuses and considering that not all cups are returned.

The Washing of MU cups was assumed to include rinsing and regular washing. Data of the washing cycle were received during the stakeholder consultation. Water consumption was based on stakeholder consultation input and is aligned with the value proposed by several literature sources (such as Pro.mo/Unionplast, 2015; CupClub, 2018; KeepCup, 2018; Foteinis, 2020). The rinsing water was estimated to be equal to the water consumption in the dishwasher. The heat consumption during rinsing was estimated considering the water specific heat capacity and that the rinsing water is heated to 30°C in the benchmark case or heated or used cold (50:50) in the sensitivity analysis (no impacts associated to heat consumption if used cold).

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders, and were introduced in the Annex 1. The parameters related to the CFF include: “R_1”, “A”, “Q_{sin}/Q_P”, “Q_{sout}/Q_P”, “R_2”, “R_3”; “$1 – R_2 – R_3$”. Notably, the R_2 parameter for MU cup was estimated from Ramboll et al. (2022a).

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named “Recycling Variability” allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 10. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging of ‘Scenario 1’.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Cup, total mass, g	17.58	-	-	-	Stakeholder consultation
Carton, g	16.01	-	-	Including weight of the lid	
Plastic lining LDPE, g	1.57	-	-	Including weight of the lid	
Electricity consumption in cup manufacturing, kWh	0.0085	-	-	-	Stakeholder consultation
Recycled content, % [R_1]	0	-	-	For all materials	EF method, Annex C (EC, 2021b)
A value (carton)	0.2	0.1	0.3	-	
A value (LDPE and PS)	0.5	0.25	0.75	-	
Q_{sin}/Q_p (carton)	0.85	0.43	1	-	
Q_{sin}/Q_p (LDPE)	0.75	0.38	1	-	
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	630	504	756	Distance, final amount considers mass	Stakeholder consultation
Transport heavy duty lorry (<7.5 t) from distribution centre to cafeteria/restaurant, km	150	75	225	Distance, final amount considers mass	
Recycling, % (carton) [R_2]	15	5	30	-	Kearney, 2023 (1)

Inventory values	Benchmark value	Min	Max	Remarks	Reference
Recycling, % (LDPE) [R_2]	0	-	-	-	EF method, annex C (EC, 2021b)
Recycling Variability	1	0.85	1.15	For all materials	Own estimation
Q_{Sout}/Q_p (carton)	0.85	0.17	1	-	EF method, annex C (EC, 2021b)
Q_{Sout}/Q_p (LDPE)	0.75	0.15	1	-	
Incineration, % (carton) [R_3]	39	32	44	Depends on R_2 min/max values	
Incineration, % (LDPE) [R_3]	46	37	55	Stakeholder consultation	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % (carton) [$1-R_2-R_3$]	46	38	51	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)
Landfill, % (LDPE) [$1-R_2-R_3$]	54	45	63	Calculated on R_3 values	
Landfill, % (PS) [$1-R_2-R_3$]	54	45	63	Calculated on R_3 values	

Source: JRC analysis. Note: (1) The benchmark value (15 %) was selected from the Kearney report (Kearney, 2023), in which it is indicated how such percentage could be driven by inadequate collection/sorting infrastructure, a multi-material mix lowering the recyclers' acceptance of these packaging, and the potentially high level of food contamination.

Table 11. Overview of the Inventory, parameters (benchmark values and ranges) for the Multiple Use (MU) packaging of 'Scenario 1'.

Process	Benchmark value	Min	Max	Remarks	Reference
Cup mass (PP), g	48.3	-	-	-	Calculated based on literature data provided during the stakeholder consultation
Recycled content, % [R_1]	0	0	10	-	Stakeholder consultation
A value	0.5	0.25	0.75	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	0.9	0.45	1	-	
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	454	363	544	Distance, final amount considers mass	Stakeholder consultation
Transport heavy duty lorry (<7.5 t) from distribution centre to cafeteria/restaurant, km	172	86	375	Distance, final amount considers mass	
Transport passenger car from home to cafeteria/restaurant, km	2.5	1.25	3.75	10 % of cups transported by car	Own estimation

Process	Benchmark value	Min	Max	Remarks	Reference
Items in passenger car from home to cafeteria/restaurant, pieces	5	2	8	-	
Water for rinsing, l	0.225	0.11	0.34	Equal to washing needs	Stakeholder consultation
Heat for rinsing, MJ	0.028	0	0.042	Linked to the amount of water used in rinsing	Own estimation (cold water or hot water 30 °C)
Electricity for washing, kWh	0.021	0.011	0.042	-	Stakeholder consultation
Water for washing, l	0.225	-	-	-	Stakeholder consultation
Detergents for washing, g	0.41	0.349	0.472	-	Stakeholder consultation
Wastewater from rinsing and washing, l	0.45	0.34	0.56	-	Derived from all water needs
Number of reuses	15	10	25	Considers that all cups are not returned for reuse	Own estimation
Recycling, % [R_2]	41	28	60	-	Ramboll, 2022a
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	0.9	0.8	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	27	18	33	Depends on R_2 min/max values	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	32	22	39	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)

Source: JRC analysis.

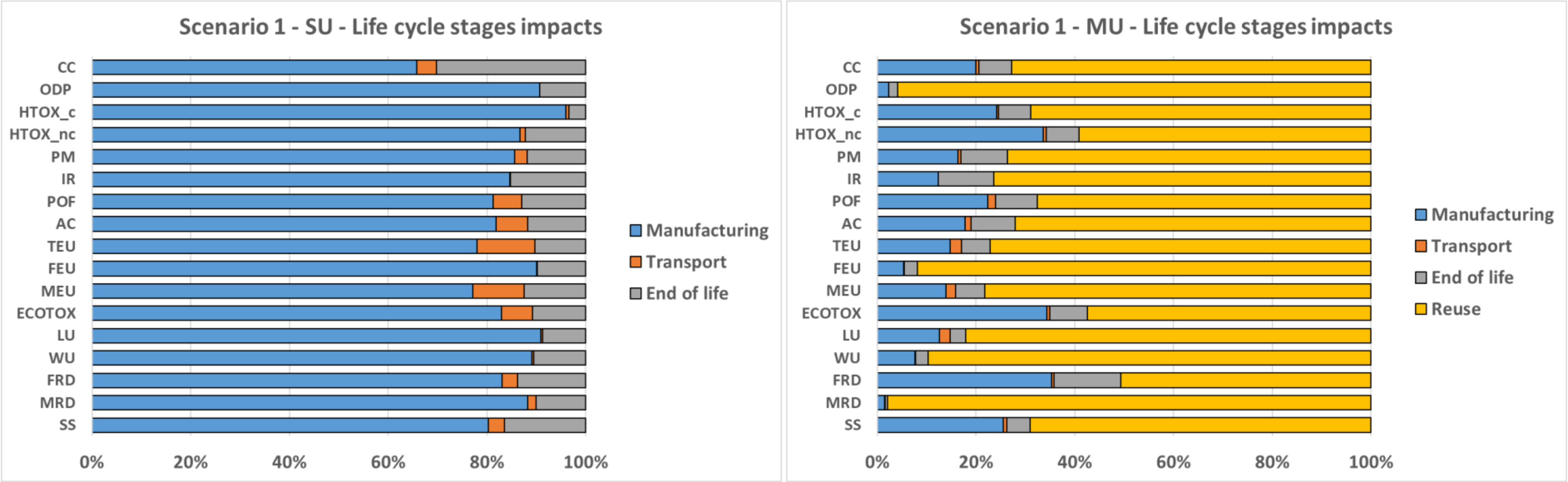
-------------------- Scenario 1 - Results --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- Scenario 1 - Benchmark results --------------------

Life cycle stages contribution for SU and MU are provided in Figure 35. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 85 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 76 % of the impacts in all impact categories). The reuse stage has almost 100 % contribution in the 'Resource Use, Minerals and Metals' and in the Ozone Depletion Potential impact categories.

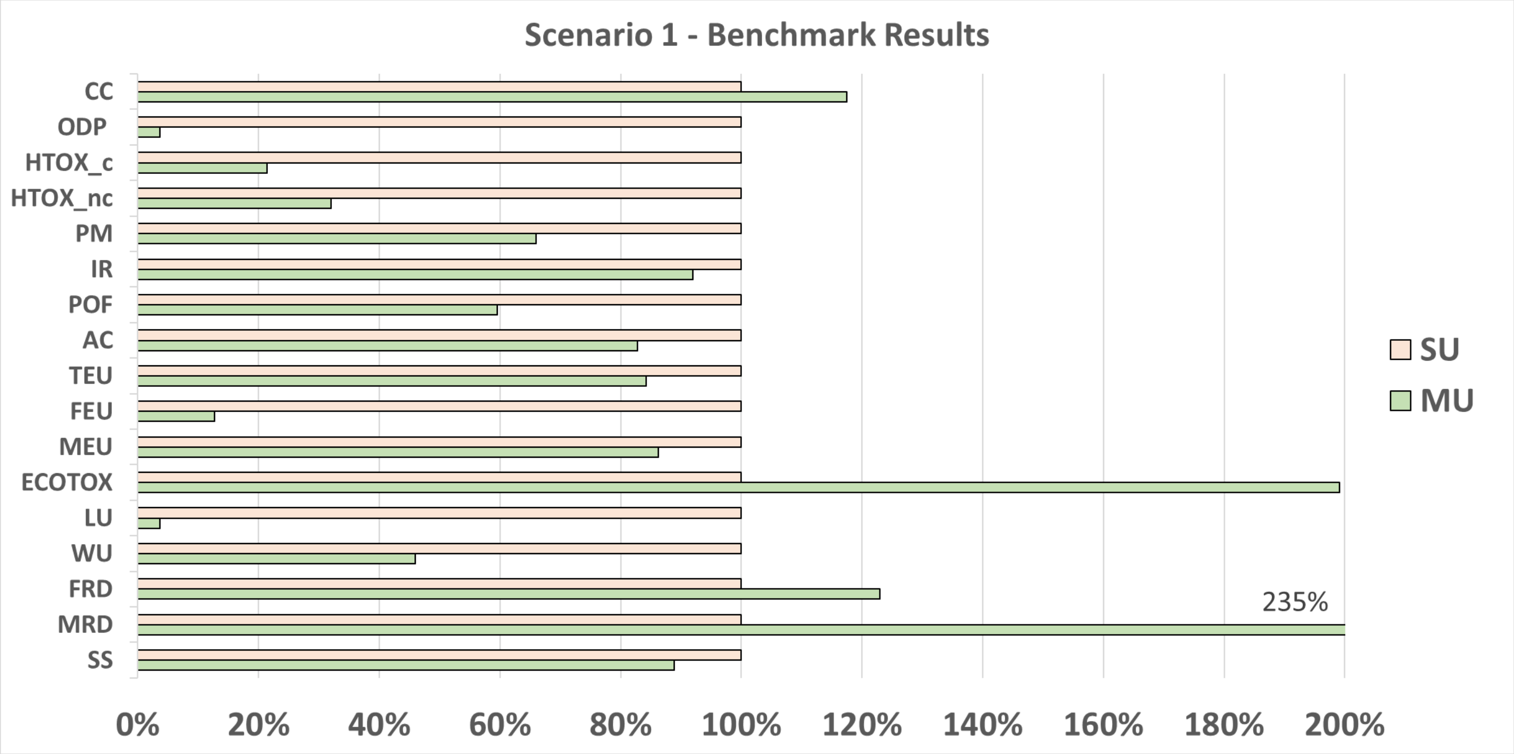
Figure 35. Overview of the contribution of the various lifecycle stages in the SU and MU packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 37*). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.*

The analysis of the benchmark impacts between SU and MU are provided in Figure 36 and commented in the main text of the report.

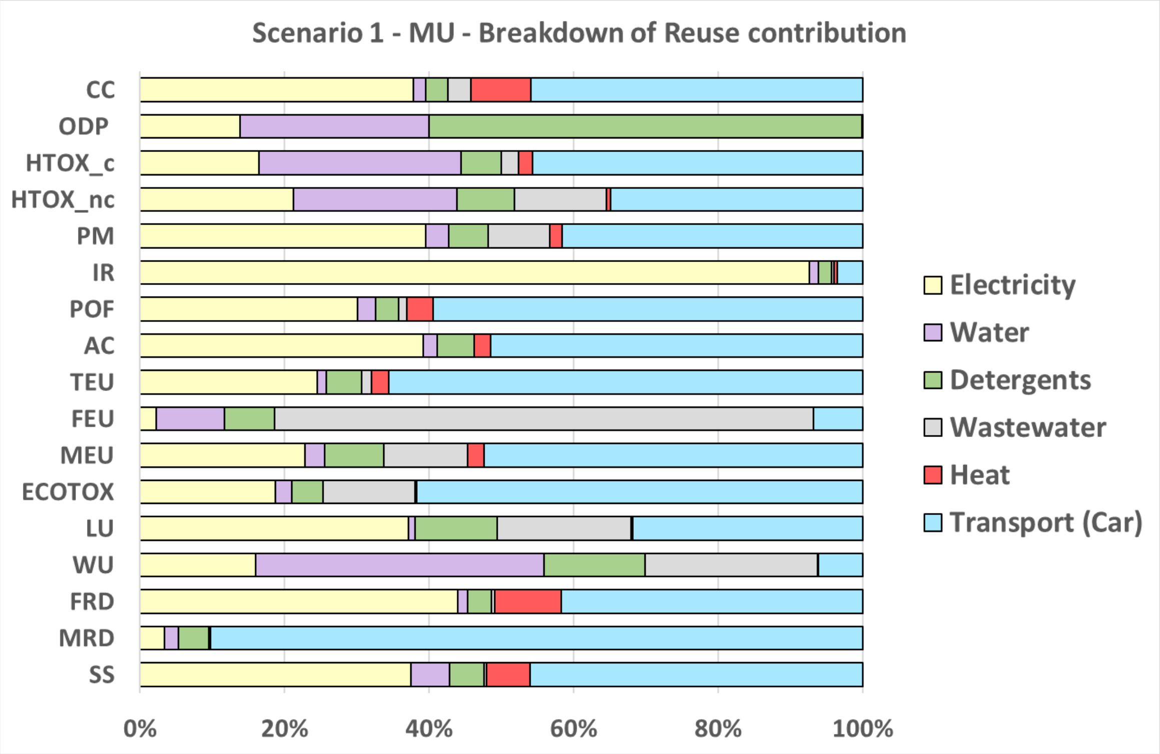
Figure 36. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 1'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Breakdown of the contribution of the benchmark impacts for the reuse phase of the MU are provided in Figure 37. In most of the impact categories, the transport via car has the highest impact. Water used in the washing has significant impact in the Water Use, 'Human Toxicity, cancer' and 'Human Toxicity, non-cancer' and in Ozone Depletion Potential impact categories, while wastewater from washing has the highest share of the impacts in the 'Eutrophication, Freshwater' impact category. In addition, the energy used in the washing has a significant share of the impacts in many impact categories, especially in Ionising Radiation. On the other hand, impacts associated to detergents has a significant impact in the Ozone Depletion Potential impact category.

Figure 37. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) packaging product (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

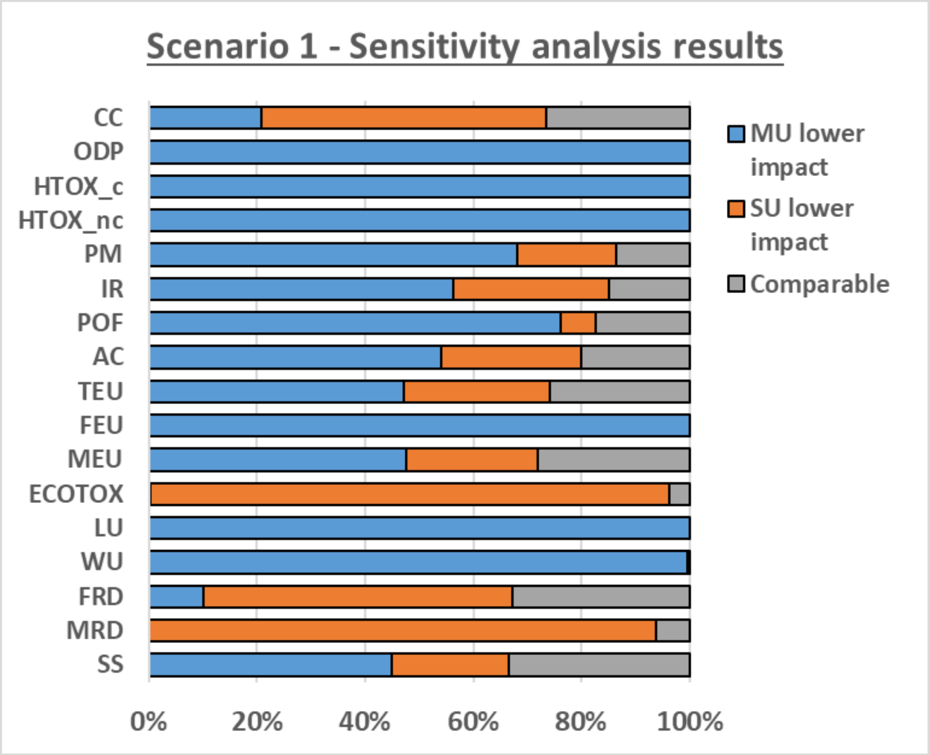


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **Scenario 1 –** Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for 'Scenario 1' are provided in Figure 38 and commented in the main text of the report.

Figure 38. Results of the sensitivity analysis of 'Scenario 1' for all impact categories of the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Scenario 2 – CASE A

PPWR reference: "takeaway ready-prepared food, intended for immediate consumption without the need of any further preparation, sold by the distributor"

Scenario 2 – CASE A - SU Carton tray with LDPE lining vs MU PP food tray

-------------------- Scenario 2 - CASE A - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 1.1 l SU and MU food trays are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of both packaging products, including the manufacturing step (including raw material sourcing, production of the components for the products and manufacturing of final product), the transport step (covering transports from manufacturing site to the selling point), the end-of-life steps (covering recycling, incineration and landfill) and the reuse step for the MU packaging product.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts were calculated for a carton container with a mass of 26.11 g, having a LDPE lining having a mass of 1.19 g (total mass of the packaging product under assessment: 27.3 g).
- The SU packaging product is manufactured and then consumed. At the end-of-life, it was assumed that the carton part of the SU packaging product could be recycled, incinerated or landfilled, whilst the LDPE part could be either incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from the selling point to home, as it was assumed to be the same for both SU and MU packaging products.

In the case of the MU packaging product, the following assumptions were employed:

- The impacts were calculated for a PP clamshell with a mass of 172 g.
- The MU packaging product is manufactured and then consumed. The MU packaging product was assumed to be washed (including rinsing and rewashing) and consumed multiple times. At the end-of-life, it was assumed that the packaging product could be recycled, incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from the selling point to home, as it was assumed to be the same for both SU and MU packaging products.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.
- For the MU packaging product: recycled content of the PP; the number of reuses; the amount of energy required for the reuse step (i.e. in rinsing and washing); the amount of water required in rinsing and washing; the rewashing rate; the transport distances in the reuse step and items transported un the car; the amount of detergent used for washing.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges. Further sensitivity analyses have been performed in the context of Scenario 2 – CASE A and are detailed in the main report.

-------------------- Scenario 2 – CASE A – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 12.

Table 12. Overview of the life cycle stages considered for 'Scenario 2 – CASE A' for the Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	SU, MU	- SU: Production of cartonboard and LDPE sheet - MU: Production PP granulates	All the materials' transport are already included in the datasets related to this life cycle stage. The recycled content of all materials was assumed to be 0 % (note that the PP recycled content is allowed to reach values as high as 10 % in the sensitivity analysis simulations).
Tray manufacturing	SU, MU	- SU: Manufacturing of the carton tray - MU: Manufacturing of PP tray	All materials' transports are already included in the datasets related to this life cycle stage. - SU: The LDPE lining is added to the cartonboard and tray is manufactured - MU: The PP granulates are extruded (blowing)
Transport	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t), Transport heavy duty lorry (<7.5 t)	Covering the transport of packaging products from manufacturing to distribution centre and finally to the selling point.
End-of-Life - Recycling	SU, MU	- SU: Carton recycling, Carton avoided production (credits) - MU: PP recycling, PP avoided production (credits)	All the transports concerning recycling are already included in the datasets related to this life cycle stage.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
End-of-life - Incineration	SU, MU	- SU: Incineration of carton and LDPE - MU: Incineration of PP	All the transports concerning incineration are already included in the datasets related to this life cycle stage. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.
End-of-life - Landfill	SU, MU	- Transport articulated lorry (12-14t) - SU: Landfill of plastic waste (LDPE) and landfill of carton and carton waste. - MU: Landfill of plastic waste (PP).	-
Reuse	MU	- Transport passenger car - Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process and transport related to reuse step, including rinsing with hot water before washing (prewashing) and transport of food trays from home to reuse.

Source: JRC analysis.

-------------------- <u>Scenario 2 – CASE A</u> – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 13 for the SU packaging product, and in Table 14 for the MU packaging product.

The SU tray manufacturing includes carton and LDPE sheet production, as well as actual tray manufacturing where LDPE lining is added to the cartonboard, and a tray is formed. In the MU packaging product, PP granulates are extruded to form a tray.

The transport from manufacturing to use was assumed to follow the EF method, considering that trays are first transported from the manufacturing site to the distribution centre and then to the selling point where they are sold to consumers. When available, distances were modelled according to the inputs received during the stakeholders' consultation. In the case of the MU packaging product, trays should be returned in the restaurant from where they were bought. It was assumed that 25 % of trays are transported back to the original place using same home delivery service that delivers the food (25 % of food sold as home delivery; Kearney, 2023). In this case, no impacts were allocated to the trays under exam. For the remaining 75 %, it was assumed that 90 % is returned by foot or bicycle (or by car, assuming the travel is done for other purposes, e.g. shopping) with zero impacts, and that 10 % is returned instead via passenger car without other purposes than returning the purchased packaging. In that case, it was assumed that 5 trays are returned same time (i.e. the impacts were divided for 5 trays).

It was assumed that 15 % of carton trays are recycled, as a consequence of the lack of collection and recycling infrastructure of multilayer materials (Kearney, 2023). In the recycling facility, LDPE layer is separated from carton, and only carton part is recycled, while LDPE layer is either landfilled or incinerated.

The washing of MU trays was assumed to include rinsing (with cold or hot water), rewashing and regular washing. Data of the washing cycle and were received during the stakeholder consultation. Heat consumption during rinsing was estimated considering the water specific heat capacity and that the rinsing water could be either heated to 30°C in the benchmark case. In the sensitivity analysis rinsing water was assumed to be heated or used cold (50:50) (no impacts associated to heat consumption if used cold). Also, additional washing was added in case that trays are not cleaned properly during the washing (1 % of the trays in the benchmark).

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders, and were introduced in the Annex 1. The parameters related to the CFF include: "R_1", "A", "Q_{sin}/Q_P", "Q_{sout}/Q_P", "R_2", "R_3"; "$1 - R_2 - R_3$". Notably, the R_2 parameter for MU trays was estimated from Ramboll et al. (2022a).

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named "Recycling Variability" allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 13. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging product of the 'Scenario 2 – CASE A'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Tray, total mass, g	27.3	-	-	-	Verburgt, 2021
Carton, g	26.11	-	-	-	
Plastic lining LDPE, g	1.19	-	-	-	
Electricity consumption in tray manufacturing, kWh	0.0547	-	-	-	Verburgt, 2021
Recycled content, % [R_1]	0	-	-	All materials	EF method, Annex C (EC, 2021b)
A value (carton)	0.2	0.1	0.3	-	
A value (LDPE)	0.5	0.25	0.75	-	
Q_{sin}/Q_p (carton)	0.85	0.43	1	-	
Q_{sin}/Q_p (LDPE)	0.75	0.38	1	-	
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	630	504	756	Distance, final amount considers mass	Stakeholder consultation
Transport heavy duty lorry (<7.5 t) from distribution centre to restaurant, km	150	75	225	Distance, final amount considers mass	
Recycling, % (carton) [R_2]	15	5	30	-	Kearney, 2023
Recycling, % (LDPE) [R_2]	0	-	-	-	EF method, Annex C (EC, 2021b)

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Recycling Variability	1	0.85	1.15	For all materials	Own estimation
Q_{Sout}/Q_p (carton)	0.85	0.17	1	-	EF method, Annex C (EC, 2021b)
Q_{Sout}/Q_p (LDPE)	0.75	0.15	1	-	
Incineration, % (carton) [R_3]	39	32	44	Depends on R_2 min/max values	
Incineration, % (LDPE) [R_3]	46	37	55	Depends on R_2 min/max values	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % (carton) [$1-R_2-R_3$]	46	38	51	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)
Landfill, % (LDPE) [$1-R_2-R_3$]	54	45	63	Calculated on R_3 values	

Source: JRC analysis.

Table 14. Overview of the Inventory, parameters (benchmark values and ranges) for the Multiple Use (MU) packaging product of the ‘Scenario 2 – CASE A’.

Process	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Tray mass (PP), g	172	-	-	-	Verburgt, 2021
Recycled content, % [R_1]	0	0	10	-	Stakeholder consultation
A value	0.5	0.25	0.75	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	0.9	0.45	1	-	
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	454	363	544	Distance, final amount considers mass	Stakeholder consultation
Transport heavy duty lorry (<7.5 t) from distribution centre to restaurant, km	172	86	258	Distance, final amount considers mass	
Transport passenger car from home to restaurant, km	5	2.5	7.5	Returning trays, 10 % of 75 % that is not home delivery in the reuse phase	Own estimation
Items in passenger car, pieces	5	2	8	-	
Water for rinsing, l	0.303	0.15	0.45	Equal to the washing needs	Stakeholder consultation
Heat for rinsing, MJ	0.038	0	0.057	Linked to the amount of water used in rinsing	Own estimation (cold water or hot water 30 °C)

Process	Benchmark value	Min	Max	Remarks	Reference
Electricity for washing, kWh	0.046	0.023	0.092	The additional energy need due to rewashing is added to these amounts in the model	Stakeholder consultation
Water for washing, l	0.303	-	-	The additional water need due to rewashing is added to this amount in the model	Stakeholder consultation
Detergents for washing, g	0.706	0.60	0.812	The additional detergents need due to rewashing is added to these amounts in the model	Stakeholder consultation
Wastewater from rinsing and washing, l	0.606	0.454	0.756	-	Derived from all water needs
Rewashing rate, %	1	0	2	Additional water (and wastewater), detergent and energy consumption to be considered additional to the related benchmark inventories	Stakeholder consultation
Number of reuses	20	15	25	Considers that all trays are not returned	Own estimation
Recycling, % [R_2]	41	28	53	-	Ramboll, 2022a
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	0.9	0.8	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	27	22	33	Depends on R_2 min/max values	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	32	26	39	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)

Source: JRC analysis.

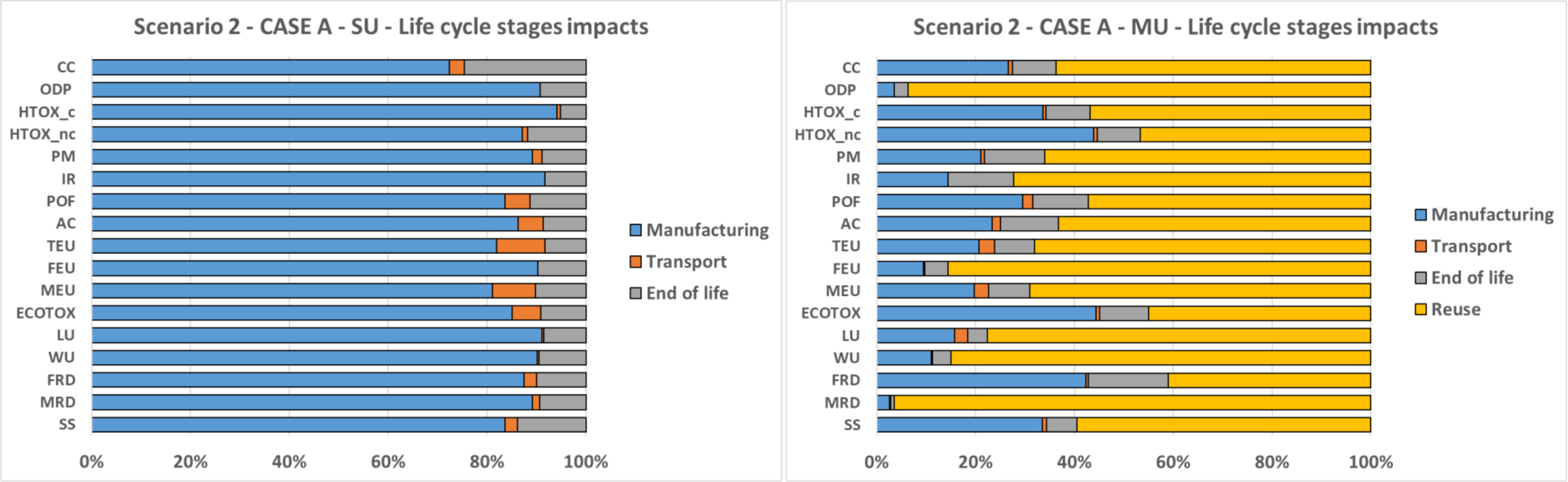
-------------------- Scenario 2 – CASE A – Results --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- Scenario 2 – CASE A - Benchmark results --------------------

Life cycle stages contribution for SU and MU are provided in Figure 39. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 87 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 68 % of the impacts in all impact categories). The reuse step has more than 90 % contribution in the Ozone Depletion, ‘Resource Use, Minerals and Metals’ impact categories, while in the Climate Change and Particulate Matter impact categories its contribution is lower than 70 %.

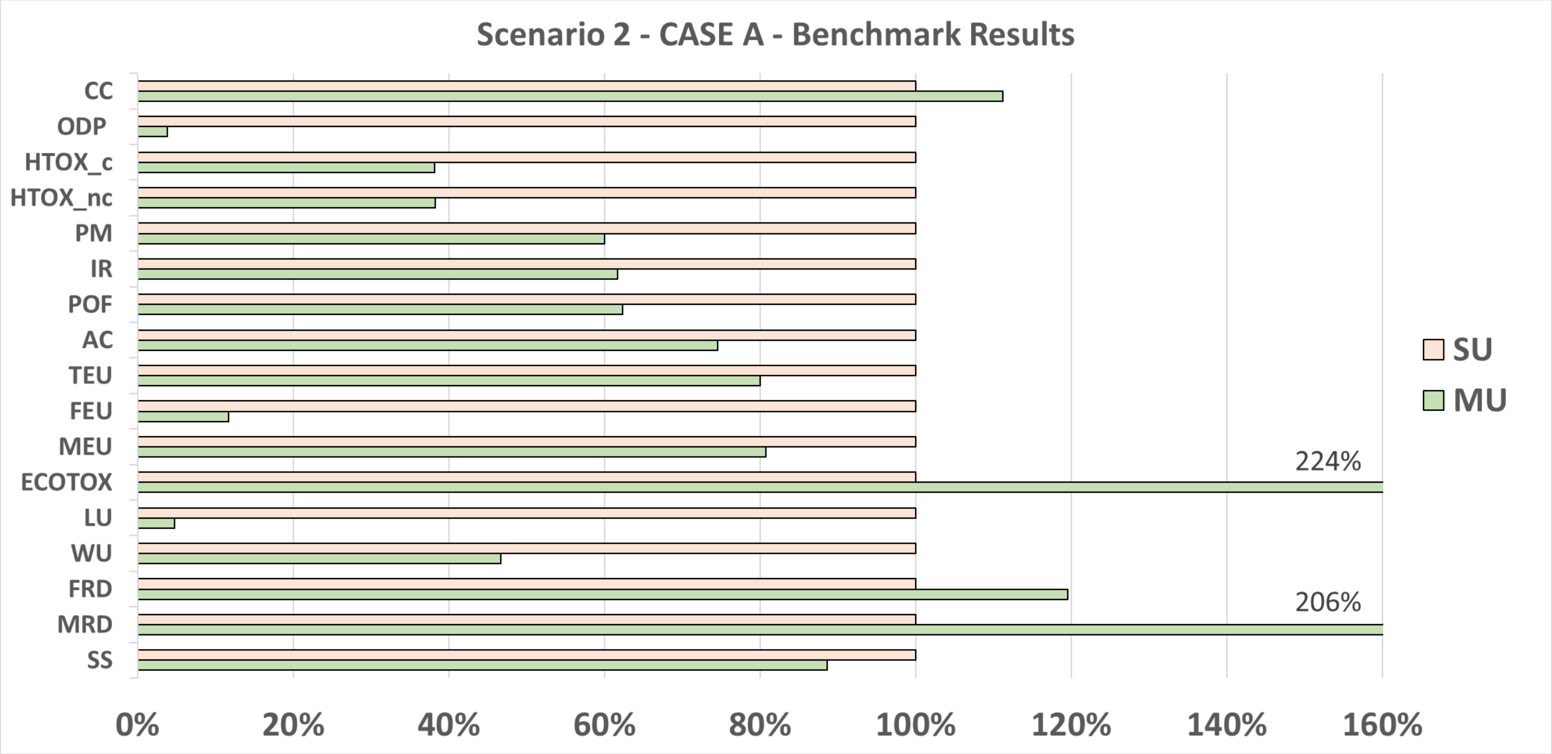
Figure 39. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label “Transport” in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the “Reuse” step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the “Reuse” label (for further details of the impacts of the reuse step see Figure 41). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

The analysis of the benchmark impacts between SU and MU are provided in Figure 40 and commented in the main text of the report.

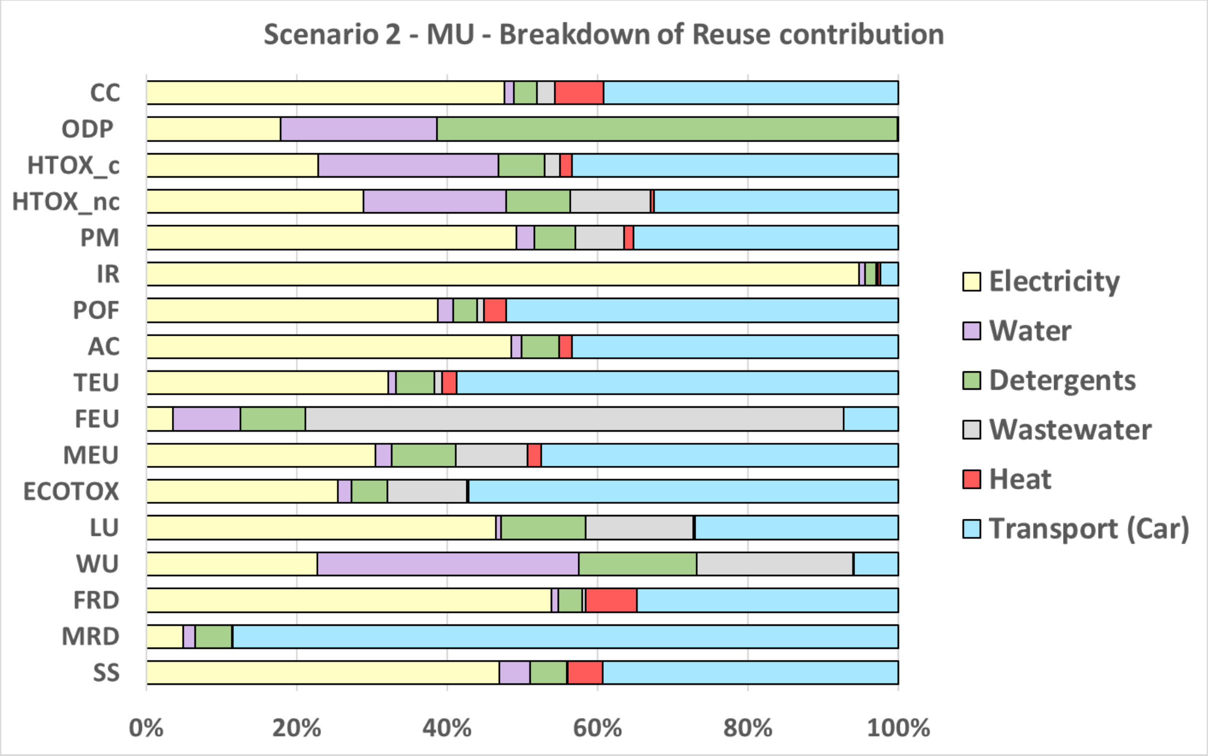
Figure 40. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 2 – CASE A'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Breakdown of the contribution of the impacts for the reuse phase of the MU are provided in Figure 41. In most of the impact categories, the transport car has the highest impact (returning used trays in the retail/selling point). Water used in the washing has significant impact in the Water Use, 'Human Toxicity, cancer' and 'Human Toxicity, non-cancer' and in Ozone Depletion Potential impact categories. Wastewater from washing has the highest share of the impacts in the 'Eutrophication, Freshwater' impact category. In addition, the energy used in the washing has a significant share of the impacts in many impact categories, especially in the Ionising Radiation impact category. Impacts associated to detergents have significant impact in the Ozone Depletion Potential impact category.

Figure 41. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) packaging product (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

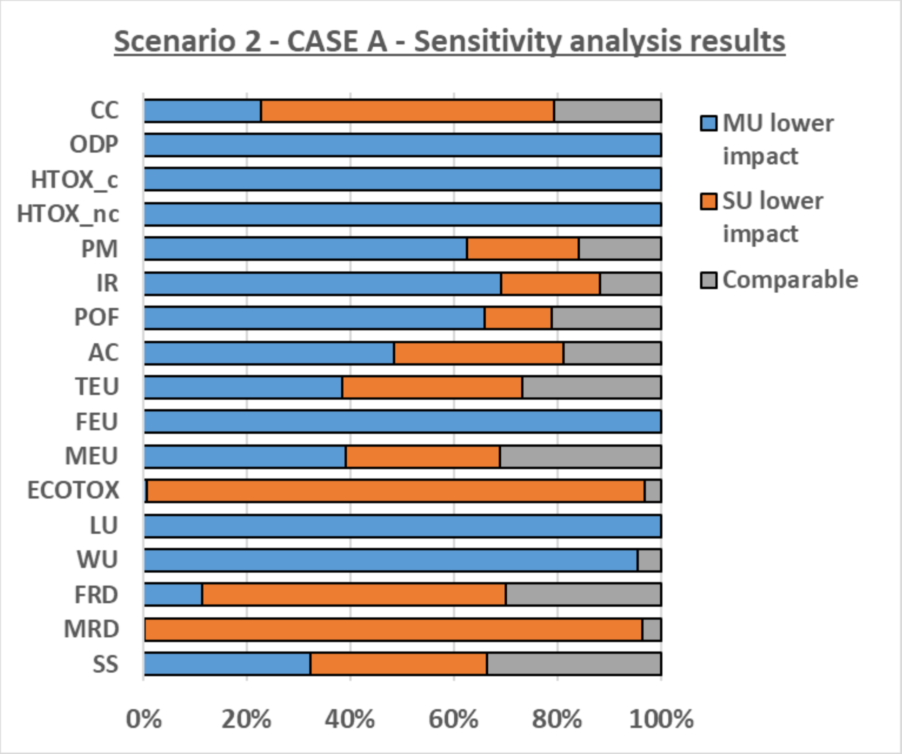


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **Scenario 2 – CASE A –** Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for 'Scenario 2 – CASE A' are provided in Figure 42 and commented in the main text of the report.

Figure 42. Results of the sensitivity analysis of 'Scenario 2 – CASE A' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Scenario 2 – CASE B

PPWR reference: "takeaway ready-prepared food, intended for immediate consumption without the need of any further preparation, sold by the distributor"

Scenario 2 – CASE B - SU Aluminium tray with carton cover vs MU PP food tray

-------------------- Scenario 2 – CASE B - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 1.1 l SU and MU food trays are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of both packaging products, including the manufacturing step (including raw material sourcing, production of the components for the products and manufacturing of final packaging product), the transport step (covering transports from manufacturing site to the selling point), the "End-of-life" step (covering recycling, incineration and landfill), and the reuse step for the MU packaging product.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts were calculated for an aluminium tray with a mass of 12.5 g, having a carton cover 10.8 g, coated with a LDPE lining having a mass of 0.5 g (total mass of the packaging product under assessment: 23.8 g).
- The SU packaging product is manufactured, and then consumed. At the end-of-life, a certain amount of the packaging products is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from the selling point to home, as it was assumed to be the same for both SU and MU packaging products.

In the case of the MU packaging product, the same assumptions as for the MU PP tray of 'Scenario 2 – CASE A' were employed.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.
- For the MU packaging product: recycled content of the PP; the number of reuses; the amount of energy required for the reuse step (i.e. in rinsing and washing); the amount of water required in rinsing and washing; the rewashing rate; the transport distances in the reuse step; the amount of detergent used for washing.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges.

-------------------- Scenario 2 – CASE B – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 15.

Table 15. Overview of the life cycle stages considered for 'Scenario 2 – CASE B' for the Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	SU, MU	- SU: Aluminium, cartonboard and LDPE sheet production - MU: Virgin and recycled PP granulates production	All the materials' transport are already included in the datasets related to this life cycle stage. The recycled content of all materials was assumed to be 0 % (note that the PP recycled content is allowed to reach values as high as 10 % in the sensitivity analysis simulations, whilst the Aluminium recycled content is allowed to reach values as high as 40 % in the sensitivity analysis simulations).
Tray manufacturing	SU, MU	- SU: Manufacturing of the tray and the lid. - MU: Manufacturing of PP tray	All the materials' transport are already included in the datasets related to this life cycle stage. - SU: Aluminium sheet is produced; LDPE lining is added in the carton lid. - MU: The PP granulates are extruded (blowing).
Transport	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t), Transport heavy duty lorry (<7.5 t).	Covering the transport of packaging products from manufacturing to distribution centre and finally to the selling point.
End-of-life - Recycling	SU, MU	- SU: Aluminium recycling, Aluminium avoided production (credits); Carton recycling, Carton avoided production (credits). - MU: PP recycling, PP avoided production (credits).	All the transports concerning recycling are already included in the datasets related to this life cycle stage.
End-of-life - Incineration	SU, MU	- SU: Incineration of aluminium, Carton, and LDPE - MU: Incineration of PP	All the transports concerning incineration are already included in the datasets related to this life cycle stages. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
End-of-life - Landfill	SU, MU	- SU and MU: Transport articulated lorry (12-14t). - SU: Landfill of aluminium), plastic waste (LDPE) and Carton waste - MU: Landfill of plastic waste (PP)	-
Reuse	MU	- Transport passenger car - Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process and transport related to reuse step, including rinsing with hot water before washing (prewashing).

Source: JRC analysis.

-------------------- Scenario 2 – CASE B – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 16 for the SU packaging product, whilst the values for the MU packaging product are the same as those presented in the Factsheet related to ‘Scenario 2 – CASE A’ (Table 14). In the aluminium tray manufacturing, the aluminium sheet is firstly produced, and then shaped into the final tray. The lid for the aluminium tray is made of carton and includes LDPE lining.

The transport from manufacturing to use was assumed to follow the EF method, considering that trays are first transported from the manufacturing site to the distribution centre and then to the selling point where they are sold to consumers as takeaway food or delivered home using home delivery service. When available, distances were modelled according to the inputs received during the stakeholders’ consultation. In the case of the MU packaging product, trays should be returned in the restaurant from where they were bought. It was assumed that 25 % of trays are transported back to the original place using same home delivery service that delivers the food (25 % of food sold as home delivery; Kearney, 2023). In this case, no impacts were allocated to the trays under exam. For the remaining 75 %, it was assumed that 90 % is returned by foot or bicycle (or by car, assuming the travel is done for other purposes, e.g. shopping) with zero impacts, and that 10 % is returned instead via passenger car without other purposes than returning the purchased packaging. In that case, it was assumed that 5 trays are returned same time (i.e. the impacts were divided for 5 trays).

It was assumed that 15 % of carton trays are recycled, because of the lack of collection and recycling infrastructure of multilayer materials (Kearney, 2023). In the recycling facility, LDPE layer is separated from carton, and only carton part is recycled, while LDPE layer is either landfilled or incinerated.

The washing of MU trays was modelled as described in Annex 3 for the Factsheet related to ‘Scenario 2 – CASE A’.

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders, and were introduced in the Annex 1. The parameters related to the CFF include: “R_1”, “A”, “Q_{sin}/Q_P”, “Q_{sout}/Q_P”, “R_2”, “R_3”; “$1 – R_2 – R_3$”. Notably, the R_2 parameter for MU trays was estimated from Ramboll et al. (2022a); whilst the maximum in the variability range associated to the R_1 parameter for aluminium was assumed to be equal to 40 %.

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named "Recycling Variability" allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 16. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging product of the 'Scenario 2 – CASE B'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Tray, total mass, g	23.8	-	-	-	Verburgt, 2021
Aluminium, g	12.5	-	-	-	
Carton, g	10.8	-	-	-	
Plastic lining LDPE, g	0.5	-	-	-	
Electricity consumption in tray manufacturing, MJ	0.007	-	-	Lid production	Verburgt, 2021
Recycled content, % (Carton, LDPE) [R_1]	0	-	-	-	EF method, Annex C (EC, 2021b)
Recycled content, % (Aluminium) [R_1]	0	0	0.4	Maximum, own assumption	
A value (Aluminium)	0.2	0.1	0.3	-	
A value (Carton)	0.2	0.1	0.3	-	
A value (LDPE)	0.5	0.25	0.75		
Q_{sin}/Q_p (Aluminium)	1	0.5	1	-	
Q_{sin}/Q_p (Carton)	0.85	0.43	1	-	
Q_{sin}/Q_p (LDPE)	0.75	0.38	1		
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	1200	960	1440	Distance, final amount considers mass	EF method (EC, 2021a)
Transport heavy duty lorry (<7.5 t) from distribution centre to restaurant, km	250	125	375	Distance, final amount considers mass	
Recycling, % (Aluminium) [R_2]	60	40	80	-	EF method, Annex C (EC, 2021b)
Recycling, % (Carton) [R_2]	15	5	30	-	Kearney, 2023
Recycling, % (LDPE) [R_2]	0	-	-	-	EF method, Annex C (EC, 2021b)
Recycling Variability	1	0.85	1.15	For all materials	Own estimation
Q_{Sout}/Q_p (Aluminium)	1	0.2	1	-	EF method, Annex C (EC, 2021b)
Q_{Sout}/Q_p (Carton)	0.85	0.17	1	-	

Inventory values	Benchmark value	Min	Max	Remarks	Reference
Q_{Sout}/Q_p (LDPE)	0.75	0.15	1	-	
Incineration, % (Aluminium) [R_3]	18	9	28	Depends on R_2 min/max values	
Incineration, % (Carton) [R_3]	39	32	44	Depends on R_2 min/max values	
Incineration, % (LDPE) [R_3]	46	37	55	Depends on R_2 min/max values	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % (Aluminium) [$1-R_2-R_3$]	22	11	32	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)
Landfill, % (Carton) [$1-R_2-R_3$]	46	38	51	Calculated on R_2 and R_3 values	
Landfill, % (LDPE) [$1-R_2-R_3$]	54	45	63	Calculated on R_3 values	

Source: JRC analysis.

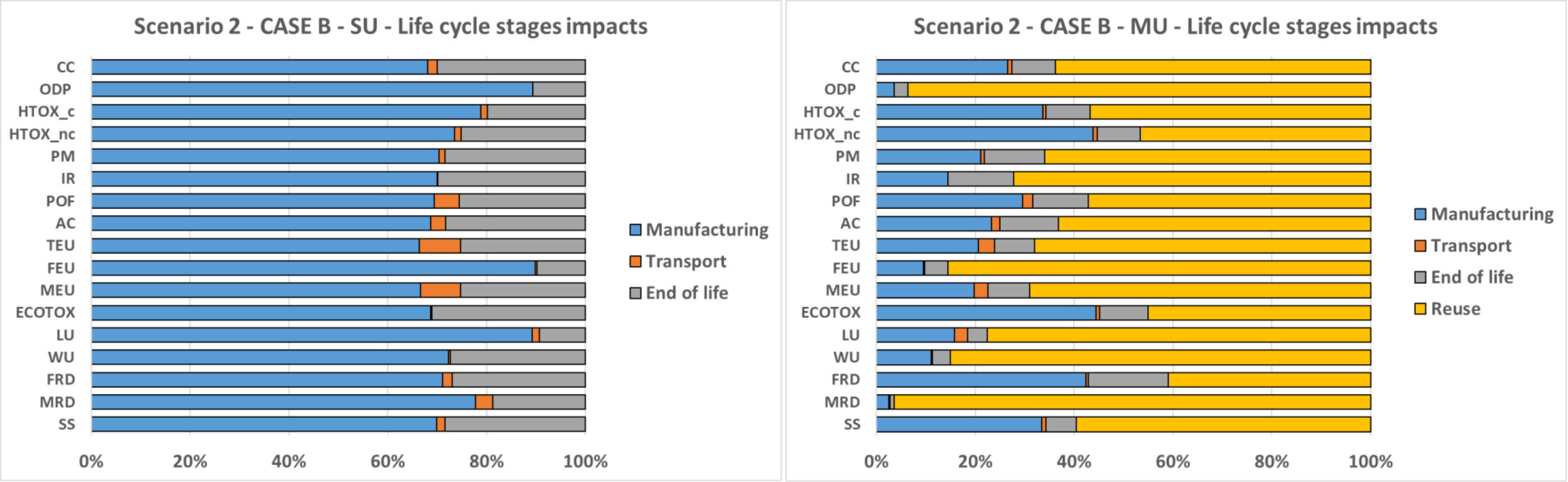
-------------------- **<u>Scenario 2 – CASE B</u> – Results** --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- **<u>Scenario 2 – CASE B</u> -** <u>Benchmark results</u> --------------------

Life cycle stages contribution for SU and MU are provided in Figure 43. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 74 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 68 % of the impacts in all impact categories). The reuse step has more than 90 % contribution in 'Resource Use, Minerals and Metals', and in Ozone Depletion Potential impact categories, while in Climate Change, Particulate Matter, Acidification and 'Eutrophication, Terrestrial' impact categories its contribution is lower than 70 %.

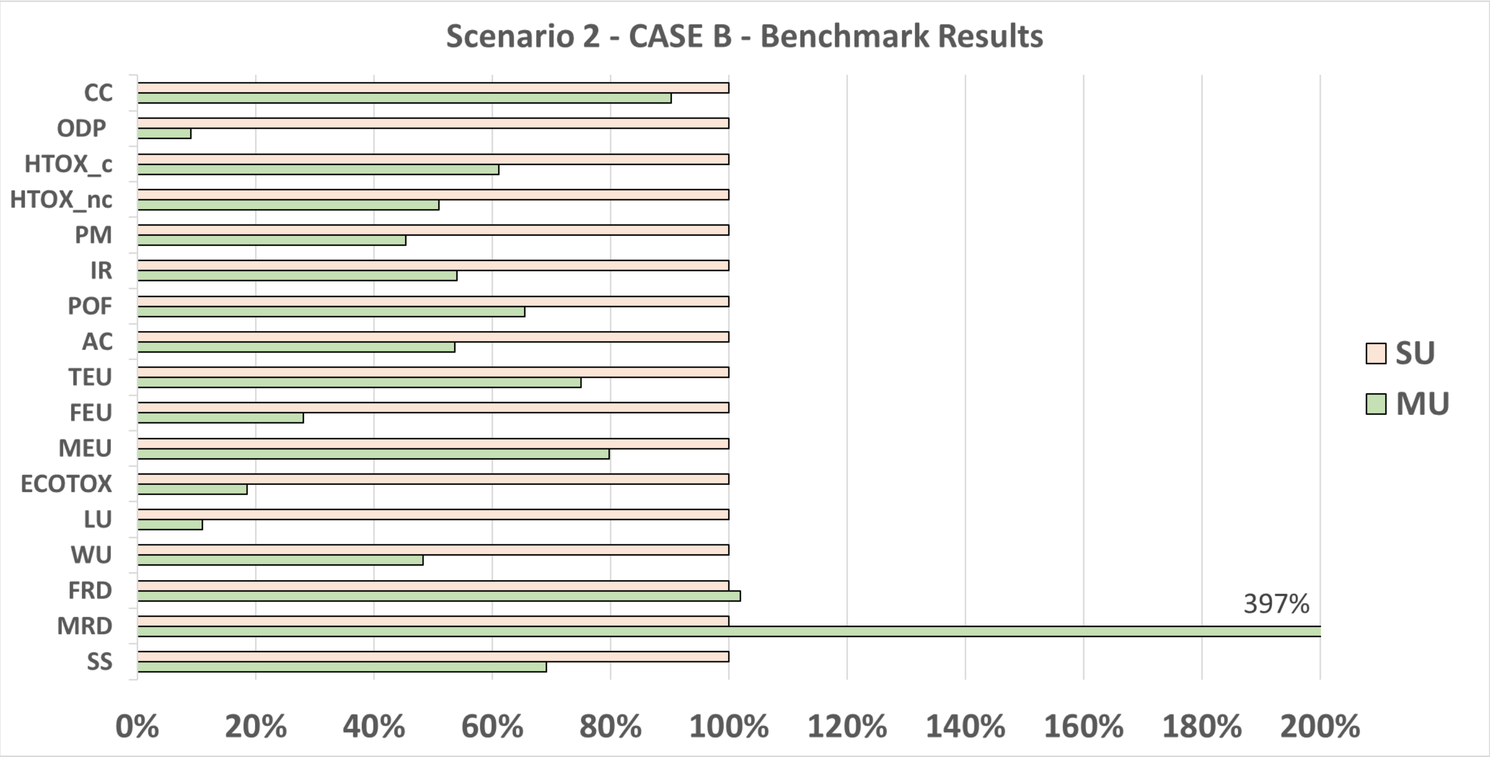
Figure 43. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 41). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

The analysis of the impacts between SU and MU are provided in Figure 44 and commented in the main text of the report.

Figure 44. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the ’Scenario 2 – CASE B’. SU impacts are set to 100 % for each impact category considered.



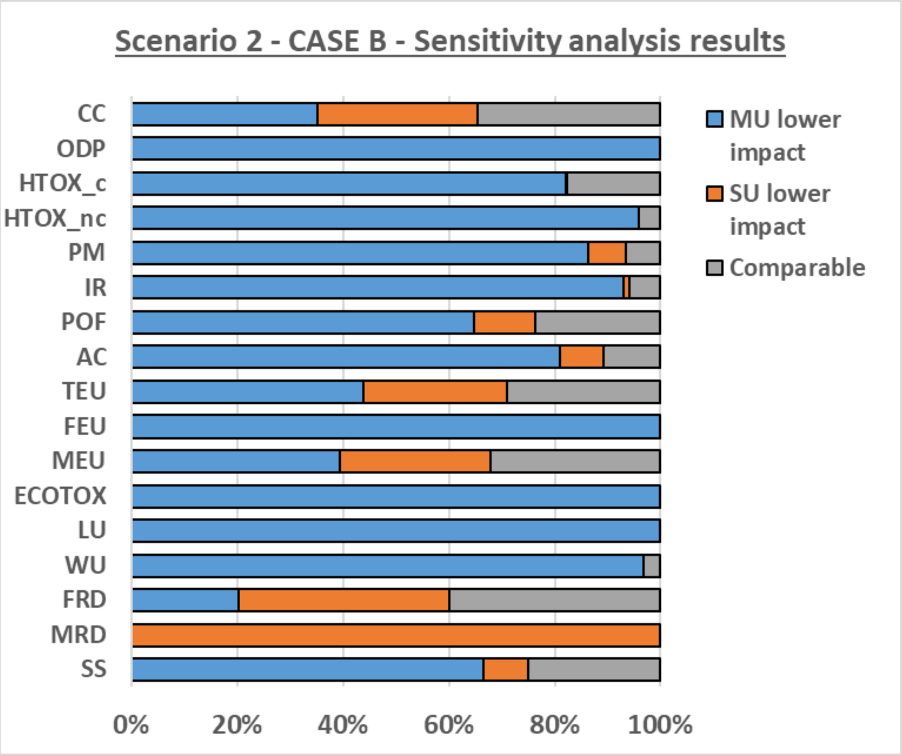
Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

The breakdown of the contribution of the impacts for the reuse phase provided in the Factsheet related to ‘Scenario 2 – CASE A’ (Figure 41).

-------------------- **Scenario 2 – CASE B –** Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for ‘Scenario 2 – CASE B’ are provided in Figure 45 and commented in the main text of the report.

Figure 45. Results of the sensitivity analysis of ‘Scenario 2 – CASE B’ for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Scenario 3 – CASE A

PPWR reference: "alcoholic beverages in the form of beer, carbonated alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, products based on spirit drinks, wine or other fermented beverages mixed with beverages, soda, cider or juice, non-alcoholic beverages in the form of water, water with added sugar, water with other sweetening matter, flavoured water, soft drinks, soda lemonade, iced tea and similar beverages which are immediately ready to drink, pure juice, juice or must of fruits or vegetables and smoothies without milk and non-alcoholic beverages containing milk fat, sold by the manufacturer and the final distributor"

Scenario 3 – CASE A – SU Aluminium can vs MU Plastic bottle

-------------------- Scenario 3 – CASE A - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 0.5 l beverage can (SU) and bottle (MU) are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of the packaging products, including the manufacturing step, the retail and use step (covering transports to retail and from retail to consumer), the end-of-life steps (covering recycling, incineration and landfill) and the reuse step for the MU packaging product. The impacts of certain life cycle stages, such as washing before first filling, bottle filling and transport from retail to home, were excluded from the analysis as being common in the two-life cycle under assessment. For the same reason, the energy needs in retail and the impacts associated to the use phase were also excluded.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts were calculated for an aluminium can with a mass of 15.9 g (considering a mass of 13.5 g for the can body, and a mass of 2.4 g for the can end).
- The SU packaging product is manufactured, and then consumed. At the end-of-life, a certain amount of the can is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, as it was assumed to be the same for both SU and MU packaging products.

In the case of the MU packaging product, the following assumptions were employed:

- The impacts were calculated for a PET bottle with a mass of 43 g, having a PP cap with a mass 2.15 g (total mass of the packaging product under assessment: 45.15 g).
- The MU packaging product is manufactured, and then consumed. The same bottle is then washed and cleaned and reused multiple times before reaching its end-of-life. At the end-of-life, a certain amount is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, as it was assumed to be same for both SU and MU packaging products.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycled content of raw material; the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.
- For the MU packaging product: the number of reuses; the amount of energy and detergents required for the reuse step (i.e. in washing); the transport distances in the reuse step; rewashing rate.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges.

-------------------- Scenario 3 – CASE A – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 17.

Table 17. Overview of the life cycle stages considered for 'Scenario – CASE A' for the Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	SU, MU	- SU: Virgin and recycled aluminium production - MU: Virgin and recycled PET granulate production	All the materials' transport are already included in the datasets related to this life cycle stage. All materials beside the PP cup were assumed to have a certain share of recycled content as later detailed in this Factsheet.
Manufacturing	SU, MU	- SU: Manufacturing of the aluminium can and energy needs for assembly - MU: PET bottle production, PP cap manufacturing (includes PP granulates and moulding)	All the materials' transport are already included in the datasets related to this life cycle stage. - SU: The can is manufactured combining the body and end parts - MU: blow moulding of PET granulated for bottle manufacturing
Transport	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t)	Covering the transport of packaging products from manufacturing to distribution centre and finally to the retail.
End-of-life - Recycling	SU, MU	- SU: Aluminium recycling, Aluminium avoided production (credits). - MU: PET recycling, PET avoided production (credits).	All the transports concerning recycling are already included in the datasets related to this life cycle stage.

Life cycle stages	**Included in model**	**Included in the life cycle stage**	**Comments**
End-of-life - Incineration	SU, MU	- SU: Incineration of aluminium. - MU: Incineration of PET and PP	All the transports concerning incineration are already included in the datasets related to this life cycle stages. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.
End-of-life - Landfill	SU, MU	- SU and MU: Transport articulated lorry (12-14t) - SU: Landfill of aluminium - MU: Landfill of plastic waste (PP and PET)	-
Reuse	MU (PET)	- Transport passenger car - Transport light duty - Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process, including rewashing, and the transport of bottles from home to the collection centre and further to the washing and back to the filling.

Source: JRC analysis.

-------------------- <u>Scenario 3 – CASE A</u> – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 18 for the SU packaging product, and in Table 19 for the MU packaging product.

The SU aluminium can is composed of a two parts, named aluminium "body" and aluminium "end". These two parts have different recycled content, both derived from the stakeholder consultation. Comparable recycled contents are also retrievable from EC (2021b). The MU bottles consist of PET bottle body and PP cap. In this study, only the PET bottle body was assumed to be reused. The manufactured and filled can or bottles are transported to the retail, and again at home for the consumption. However, transport from retail to home was assumed to be the same for both packaging products and was therefore excluded from the analysis. In case of the MU packaging, it was assumed that 90 % of bottles are transported without any impact to the collection centre by a transport performed primarily for other purposes (e.g. transport by car but occurring for other purposes, such as going shopping), or are transported by bicycle or by foot. Impacts associated to transport occurring via passenger car were allocated instead to the remaining 10 %, assuming such travel having no other purposes than returning the purchased packaging.

The washing of MU bottles was based on stakeholders' inputs collected during the stakeholder consultation. An additional washing (re-washing) was added in case that bottles are not cleaned properly during the washing (0.5 % of bottles in the benchmark).

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders. The parameters related to the CFF include: “R_1”, “A”, “Q_{sin}/Q_P”, “Q_{sout}/Q_P”, “R_2”, “R_3”; “$1 – R_2 – R_3$”.

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named “Recycling Variability” allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 18. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging product of the ‘Scenario 3 – CASE A’.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Can, total mass, g	15.9	-	-	-	Stakeholder consultation
Aluminium body, g	13.5	-	-	-	
Aluminium end, g	2.4	-	-	-	
Electricity consumption in manufacturing, kWh	0.0194	-	-	-	
Recycled content, % [R_1]	66	33	99	Aluminium body	Stakeholder consultation
Recycled content, % [R_1]	27	14	41	Aluminium end	
A value	0.2	0.1	0.3	Aluminium body & end	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	1	0.5	1	Aluminium body & end	
Transport heavy duty lorry (>32 t) from factory to retail, km	542	434	650	Distance, final amount considers mass	Stakeholder consultation
Recycling, % [R_2]	75	53	98	Aluminium body & end	EF method, Annex C (EC, 2021b)
Recycling Variability	1	0.85	1.15	For all materials	Own estimation
Q_{Sout}/Q_p	1	0.8	1	Aluminium body & end	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	12	1	22	Depends on R_2 min/max values, Aluminium body & end	EF method, Annex C (EC, 2021b)
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	13	1	26	Calculated on R_2 and R_3 values, Aluminium body & end	EF method, Annex C (EC, 2021b)

Source: JRC analysis.

Table 19. Overview of the Inventory, parameters (benchmark values and ranges) for the Multiple Use (MU) packaging product of the ’Scenario 3 – CASE A’.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Bottle, total mass, g	45.15	-	-	-	Stakeholder consultation
PET body, g	43	-	-	-	
PP cap, g	2.15	-	-	-	
Recycled content, % [R_1] (PET)	7	0	30	-	Stakeholder consultation
Recycled content, % [R_1] (PP)	0	-	-	-	Stakeholder consultation
A value (PET & PP)	0.5	0.25	0.75	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p (PET & PP)	0.9	0.45	1	-	
Transport heavy duty lorry (>32 t) from manufacturing to filling, km	250	50	450	Distance, final amount considers mass. This distance is covered once in the assumed total number of uses.	Stakeholder consultation
Transport heavy duty lorry (>32 t) from filling to retail, km	200	40	360	Distance, final amount considers mass. This distance is covered in each reuse.	
Transport passenger car from home to collection centre, km	5	2.5	7.5	Returning bottles, 10 % of the travels back to retail are allocated for empty bottles	Own estimation
Items in passenger car from home to collection centre, pieces	12	10	20	-	
Transport light duty lorry (<7.5 t), from collection centre to washing, km	100	20	180	Distance, final amount considers mass	Own estimation
Transport light duty lorry (<7.5 t) from washing to bottle filling, km	200	160	240	Distance, final amount considers mass	Stakeholder consultation
Electricity for washing, kWh	0.014	0.007	0.028	The additional electricity need due to rewashing is added to these amounts in the model	Stakeholder consultation
Water for washing, l	0.2	-	-	The additional detergents need due to rewashing is added to these amounts in the model	Stakeholder consultation

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Detergents for washing, g	0.0006	0.00051	0.00069	The additional water need due to rewashing is added to this amount in the model	Stakeholder consultation
Wastewater from washing, l	0.201	-	-	-	Derived from all water needs
Rewashing rate, %	0.5	0	2	Additional water (and wastewater), detergent and energy consumption to be considered additional to the related benchmark inventories	Stakeholder consultation
Number of reuses	9	5	15	Only PET bottle part	Stakeholder consultation
Recycling, % (PET) [R_2]	47	33	61	-	Calculated based on stakeholder consultation inputs
Recycling, % (PP) [R_2]	0	-	-	-	
Recycling Variability	1	0.85	1.15	For all materials	Own estimation
Q_{Sout}/Q_p	0.9	0.18	1		EF method, Annex C (EC, 2021b)
Incineration, % (PET) [R_3]	18	13	23	Depends on R_2 min/max values	Calculated based on stakeholder consultation inputs
Incineration, % (PP) [R_3]	35	28	42		
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % (PET) [$1-R_2-R_3$]	34	25	44	Calculated on R_2 and R_3 values	Calculated based on stakeholder consultation inputs
Landfill, % (PP) [$1-R_2-R_3$]	65	58	72		

Source: JRC analysis.

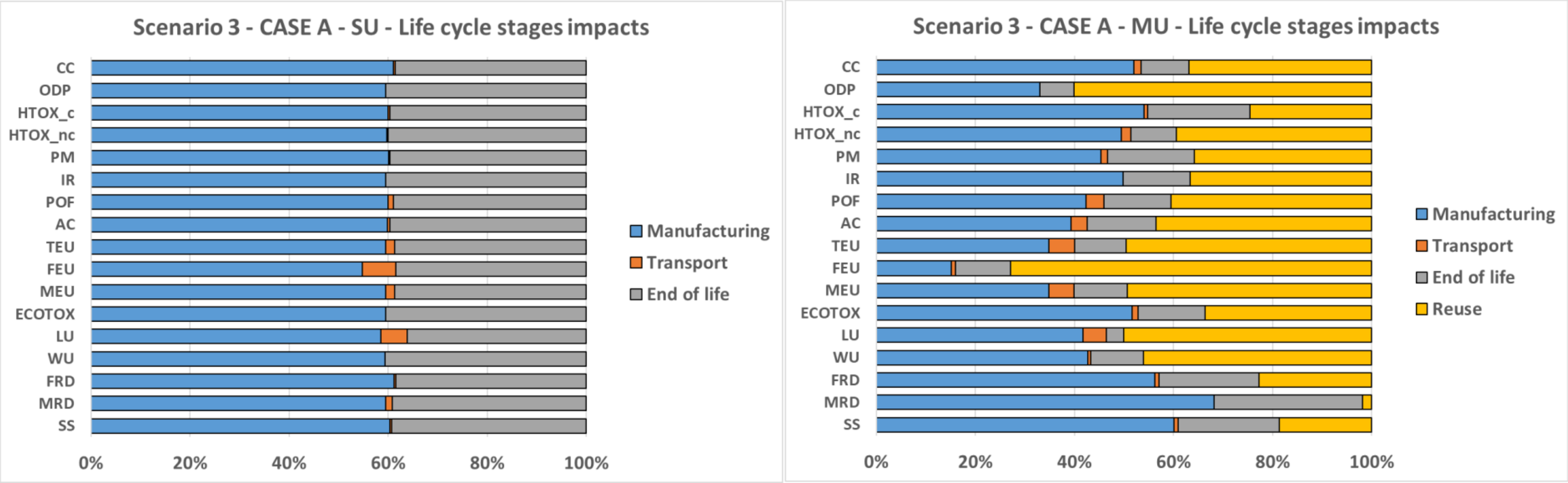
-------------------- **Scenario 3 – CASE A – Results** --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- **Scenario 3 – CASE A** - Benchmark results --------------------

Life cycle stages contribution for SU and MU are provided in Figure 46. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 59 % of the impacts in all impact categories), while in the MU case, the reuse step has a relevant contribution (average of 40 % of the impacts in all impact categories). The manufacturing of the MU packaging product contributes significantly to the overall life cycle performance of the packaging product averaging to a 44% contribution across impact categories. The reuse step has more than 60 % contribution in the 'Eutrophication, Freshwater' and Ozone Depletion Potential impact categories, while in the 'Human Toxicity, cancer', 'Resource Use, Fossil' impact categories and 'Resource Use, Minerals and Metals' its contribution is lower than 30 %.

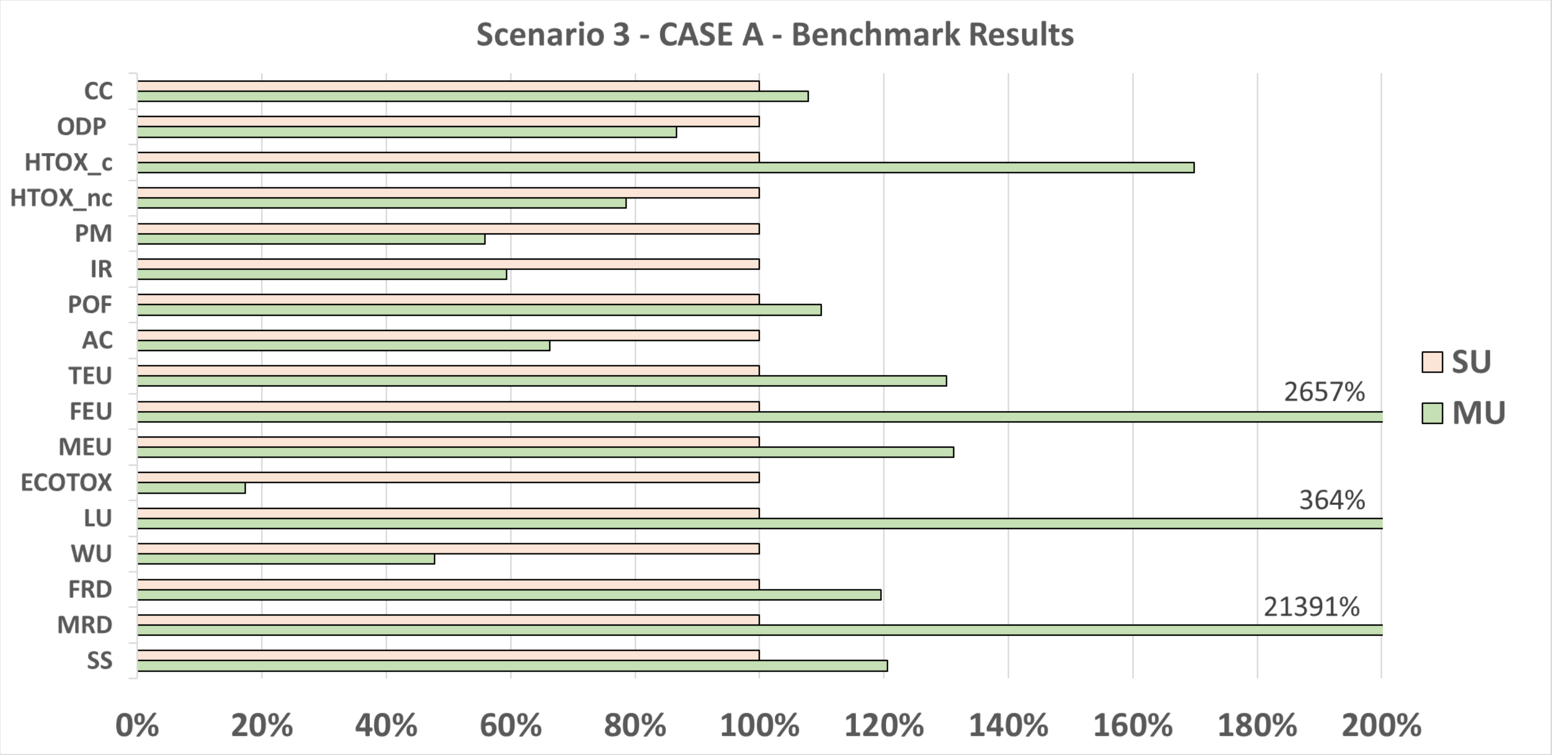
Figure 46. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 48). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score

The analysis of the impacts between SU and MU are provided in Figure 47 and commented in the main report.

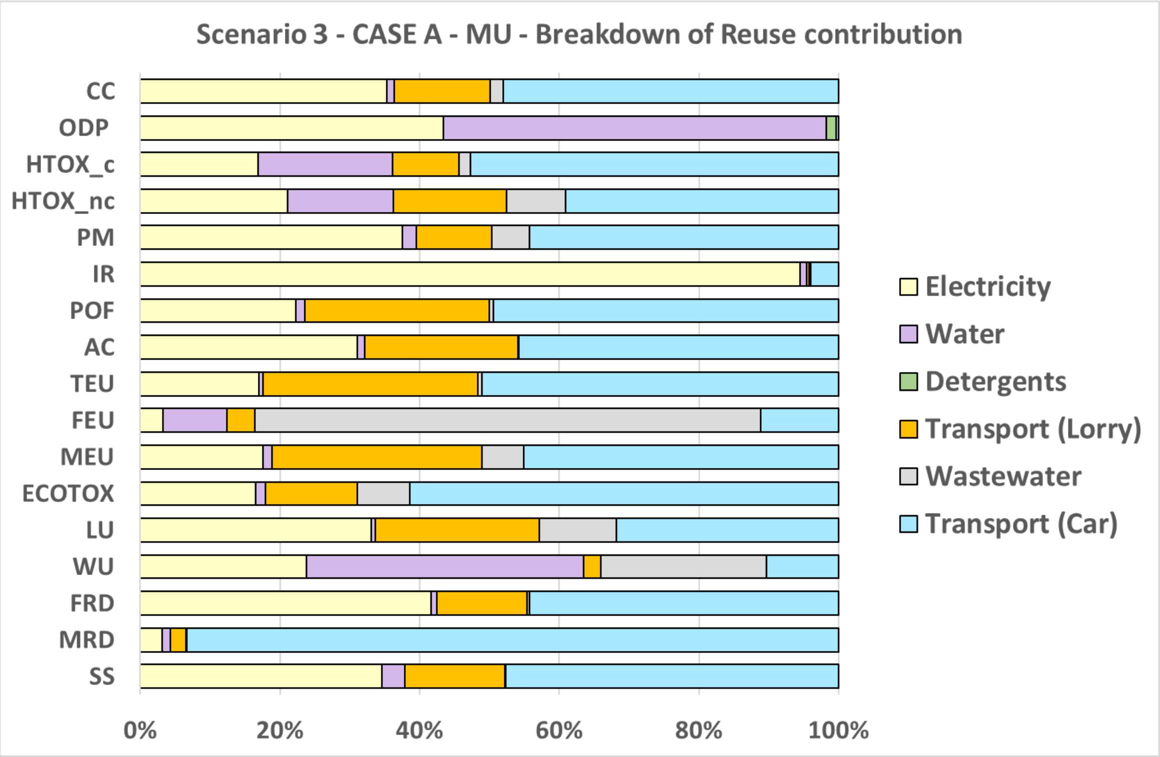
Figure 47. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 3 – CASE A'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Breakdown of the contribution of the impacts for the reuse phase of the MU are provided in Figure 48. In most of the impact categories, the transport car has the highest impact (returning used trays in the washing centre). Water used in the washing has significant impact in the Water Use, and in the Ozone Depletion Potential impact categories, while wastewater from washing has the highest share of the impacts in the 'Eutrophication, Freshwater' impact category. In addition, the energy used in the washing has a significant share of the impacts in many impact categories, especially in the Ionising Radiation impact category. Impacts associated to detergents

Figure 48. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

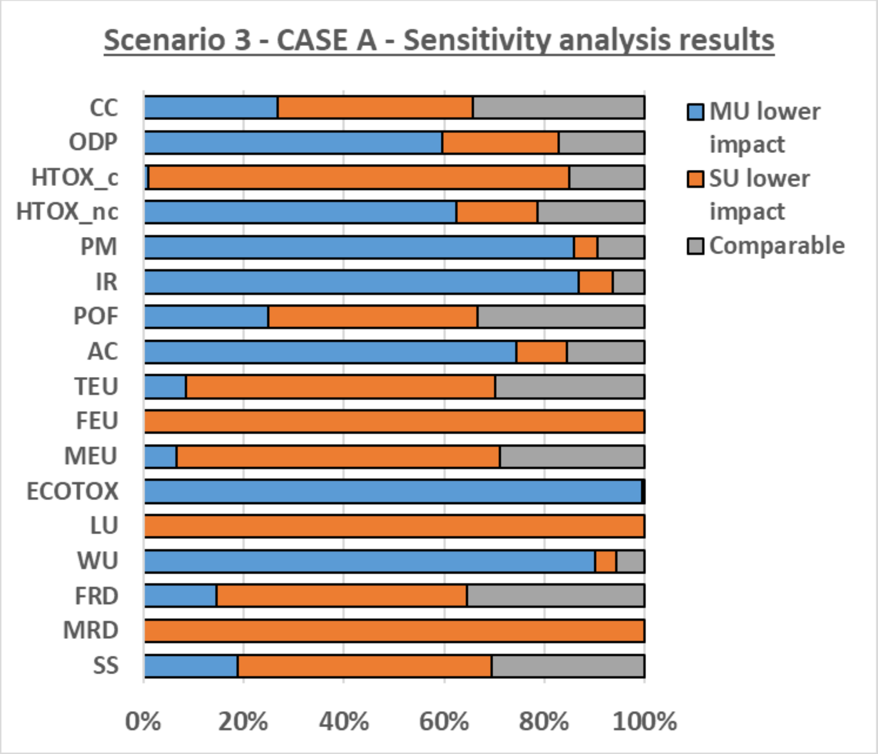


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **Scenario 3 – CASE A –** Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for 'Scenario 3 – CASE A' are provided in Figure 49 and commented in the main report.

Figure 49. Results of the sensitivity analysis of 'Scenario 3 – CASE A' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Scenario 3 – CASE B

PPWR reference: "alcoholic beverages in the form of beer, carbonated alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, products based on spirit drinks, wine or other fermented beverages mixed with beverages, soda, cider or juice, non-alcoholic beverages in the form of water, water with added sugar, water with other sweetening matter, flavoured water, soft drinks, soda lemonade, iced tea and similar beverages which are immediately ready to drink, pure juice, juice or must of fruits or vegetables and smoothies without milk and non-alcoholic beverages containing milk fat, sold by the manufacturer and the final distributor"

Scenario 3 – CASE B – SU Glass beer bottle vs MU Glass beer bottle

-------------------- Scenario 3 – CASE B - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 0.5 l SU and MU beer bottles are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of the packaging products, including the manufacturing step (excluding bottle closure), the retail and use step (covering transports to retail and from retail to consumer), the end-of-life steps (covering recycling, incineration and landfill) and the reuse step for the MU packaging product. The impacts of certain life cycle stages, such as washing before filling and filling of the bottles, were excluded from the analysis as being common in the two-life cycle under assessment. For the same reason, the energy needs in retail, the transport from retail to home, and the impacts associated to the use phase were also excluded.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts were calculated for a glass bottle with a mass of 280 g.
- The SU packaging product is manufactured, and then consumed. At the end-of-life, a certain amount of glass is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, as it was assumed to be the same for both SU and MU packaging products.

In the case of the MU packaging product, the following assumptions were employed:

- The impacts were calculated for a glass bottle with a mass of 343 g.
- The MU packaging product is manufactured, and then consumed. The same bottle is then washed and cleaned and reused a certain number of times before reaching its end-of-life. At the end-of-life, a certain amount of glass is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, as it was assumed to be the same for both SU and MU packaging products.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycled content of glass; the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.

- For the MU packaging product: the number of reuses; the amount of energy and detergents required for the reuse step (i.e. in washing); the transport distances in the reuse step; rewashing rate.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges.

-------------------- Scenario 3 – CASE B – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 20.

Table 20. Overview of the life cycle stages considered for 'Scenario 3 – CASE B' for the Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	SU, MU	- SU and MU: Virgin and recycled glass production	All the materials' transport are already included in the datasets related to this life cycle stage. Bottle closures were excluded.
Manufacturing	SU, MU	SU and MU: Bottle manufacturing	All the materials' transport are already included in the datasets related to this life cycle stage. Glass container manufacturing (finished and formed).
Retail and Use	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t)	Covering the transport of packaging products from manufacturing to filling and to retail.
End-of-life - Recycling	SU, MU	- SU and MU: Glass recycling, Glass avoided production (credits)	All the transports concerning recycling are already included in the datasets related to this life cycle stage.
End-of-life - Incineration	SU, MU	- SU and MU: Incineration of inert material	All the transports concerning incineration are already included in the datasets related to this life cycle stage. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
End-of-life - Landfill	SU, MU	- SU and MU: Transport articulated lorry (12-14t), Landfill of inert material	-
Reuse	MU	- Transport passenger car - Transport light duty - Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process, including rewashing, and the transport of bottles from home to the collection centre and further to the washing and to the filling.

Source: JRC analysis.

-------------------- <u>Scenario 3 – CASE B</u> – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 21 for the SU packaging product, and in Table 22 for the MU packaging product.

The mass of the SU and MU bottles were retrieved during the stakeholders' consultation. The manufactured and filled bottles are transported to the retail, and again at home for the consumption. However, the transport from retail to home was assumed to be the same for both packaging products and was therefore excluded from the analysis. In case of the MU packaging, it was assumed that 90 % of bottles are transported without any impact to the collection centre by a transport performed primarily for other purposes (e.g. transport by car but occurring for other purposes, such as going shopping), or are transported by bicycle or by foot. Impacts associated to transport occurring via passenger car were allocated instead to the remaining 10 %, assuming such travel having no other purposes than returning the purchased packaging.

The washing of MU bottles was based on stakeholders' inputs gathered during the stakeholder consultation. Additional washing was added in case that bottles are not cleaned properly during the washing (2 % of the bottles in the benchmark).

Certain parameters (e.g. quality factors, the "A" factor, etc.) related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b); whilst others such as "R_1", "R_2", "R_3"; "$1 - R_2 - R_3$" were collected via stakeholder consultation. The parameters related to the CFF include: "R_1", "A", "Q_{sin}/Q_P", "Q_{sout}/Q_P", "R_2", "R_3"; "$1 - R_2 - R_3$".

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named "Recycling Variability" allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 21. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging product of the 'Scenario 3 – CASE B'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Bottle, total mass (glass), g	280	-	-	-	Stakeholder consultation
Recycled content, % [R_1]	57	29	86	-	Stakeholder consultation
A value	0.2	0.1	0.3	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	1	0.5	1	-	
Transport heavy duty lorry (>32 t) from factory to retail, km	1306	1045	1567	Distance, final amount considers mass	Stakeholder consultation
Recycling, % [R_2]	75	52	97	-	Stakeholder consultation
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	1	0.5	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	4	0.4	7	Depends on R_2 min/max values	Calculated based on data gathered in the stakeholder consultation
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	21	2	41	Calculated on R_2 and R_3 values	Calculated based on data gathered in the stakeholder consultation

Source: JRC analysis.

Table 22. Overview of the Inventory, parameters (benchmark values and ranges) for the Multiple Use (MU) packaging product of the 'Scenario 3 – CASE B'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Bottle, total mass (glass), g	343	-	-	-	Stakeholder consultation
Recycled content, % [R_1]	52	26	78	-	Stakeholder consultation
A value	0.2	0.1	0.3	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	1	0.5	1	-	

Inventory values	Benchmark value	Min	Max	Remarks	Reference
Transport heavy duty lorry (>32 t) from factory to filling, km	764	153	1375	Distance, final amount considers mass. This distance is covered once in the assumed total number of uses.	Stakeholder consultation
Transport heavy duty lorry (>32 t) from filling to retail, km	542	434	650	Distance, final amount considers mass. This distance is covered in each reuse.	
Transport passenger car from home to collection centre, km	5	2.5	7.5	Returning bottles, 10 % the travels back to retail	Own estimation
Items in passenger car from home to collection centre, pieces	12	10	20	-	
Transport light duty lorry (<7.5 t), from collection centre to washing, km	100	20	180	-	Own estimation
Transport light duty lorry (<7.5 t) from washing to bottle filling, km	542	108	976	-	Stakeholder consultation
Electricity for washing, kWh	0.014	0.007	0.028	The additional energy need due to rewashing is added to these amounts in the model	Stakeholder consultation
Water for washing, l	0.2	-	-	The additional water due to rewashing is added to this amount in the model	Stakeholder consultation
Detergents for washing, g	0.075	0.064	0.086	The additional detergents need due to rewashing is added to these amounts in the model	Ramboll, 2022a
Wastewater from washing, l	0.204	-	-	-	Derived from all water needs
Rewashing rate, %	2	0	5	Additional water (and wastewater), detergent and energy consumption to be considered additional to the related benchmark inventories	Stakeholder consultation
Number of reuses	20	16	26	-	Stakeholder consultation
Recycling, % [R_2]	75	52	97	-	Stakeholder consultation
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	1	0.5	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	4	0.4	7	Depends on R_2 min/max values	Calculated based on data gathered in the stakeholder consultation

Inventory values	Benchmark value	Min	Max	Remarks	Reference
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [1-R_2-R_3]	21	2	41	Calculated on R_2 and R_3 values	Calculated based on data gathered in the stakeholder consultation

Source: JRC analysis.

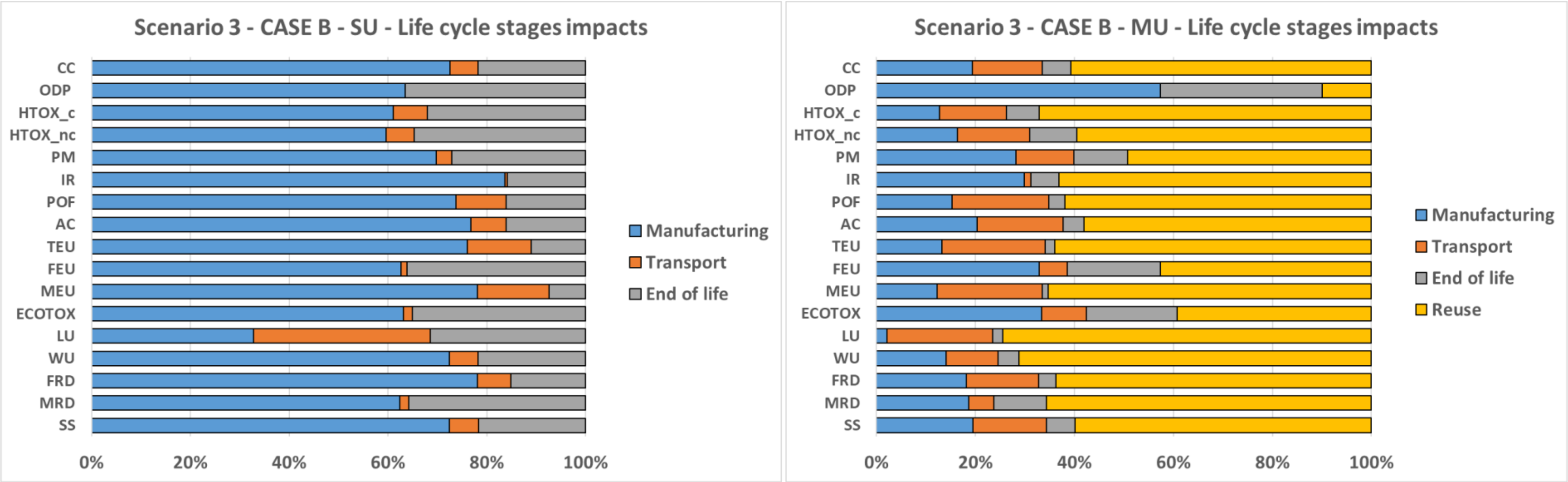
-------------------- Scenario 3 – CASE B – Results --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- Scenario 3 – CASE B - Benchmark results --------------------

Life cycle stages contribution for SU and MU are provided in Figure 50. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 68 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 57 % of the impacts in all impact categories). In the MU packaging product, the reuse stage contributes to lower share of the life cycle impacts in the Ozone Depletion, 'Eutrophication, Freshwater' and Ecotoxicity Freshwater impact categories, impacts compared to other impact categories. Such difference is mostly due to the relevance of the manufacturing and end-of-life stages for these impact categories.

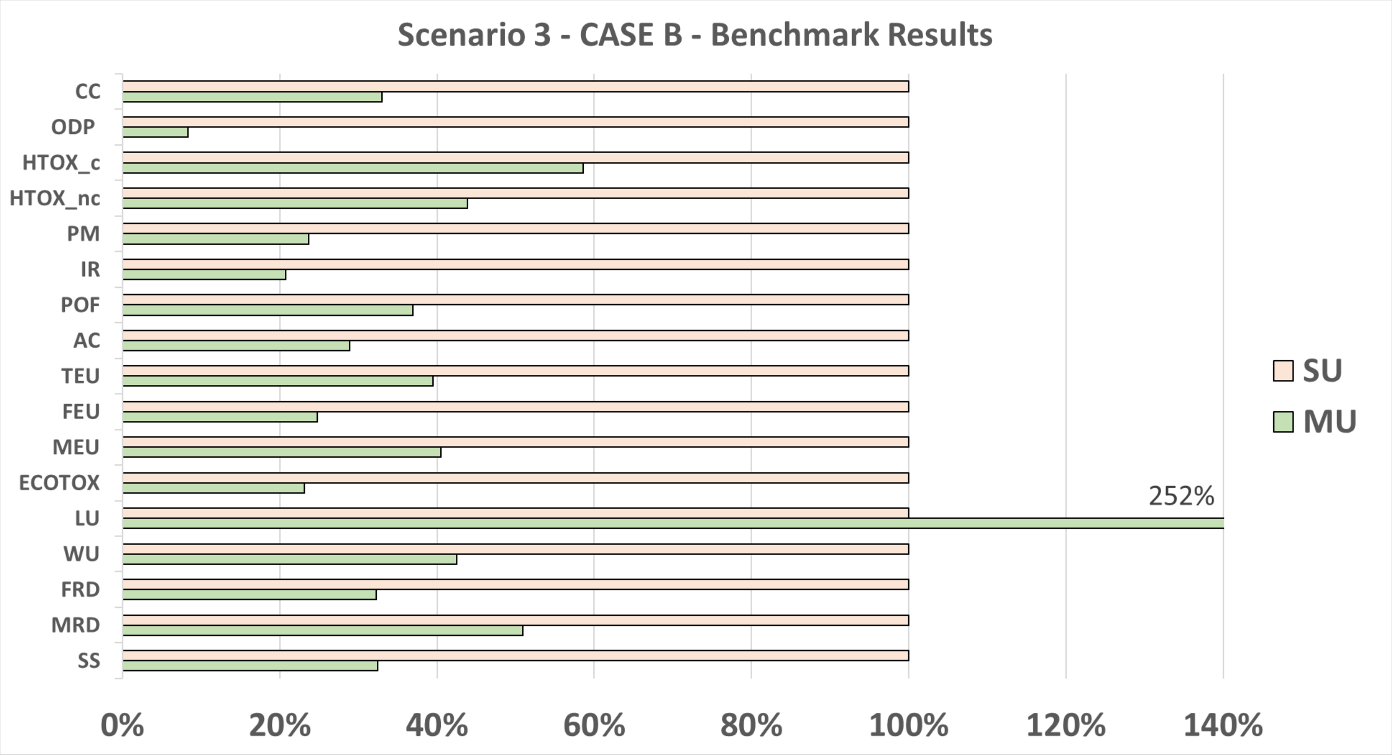
Figure 50. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 52*). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.*

The analysis of the impacts between SU and MU are provided in Figure 51 and commented in the main text of the report.

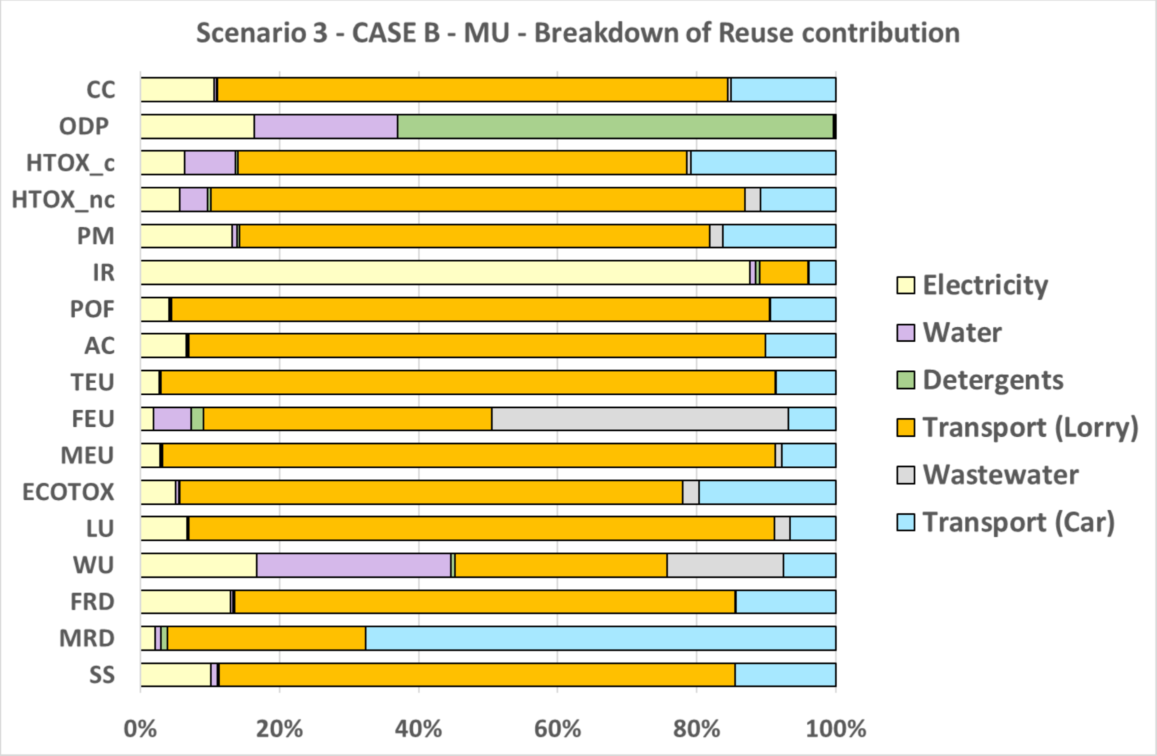
Figure 51. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 3 – CASE B'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

The breakdown of the contribution of the impacts for the reuse phase of the MU are provided in Figure 52. In most of the impact categories, transport lorry from bottle collection to the washing and again to bottle filling has the highest contribution for the reuse impacts. However, in case of the 'Resource Use, Minerals and Metals' impact category, passenger car to transport empty bottles from home to collection centre has the highest contribution. In case of the Ionising Radiation impact category, electricity in the washing has the highest contribution, and in case of the Ozone Depletion Potential impact category both detergents and water used in the washing have more than 80 % contribution together.

Figure 52. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) packaging product (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

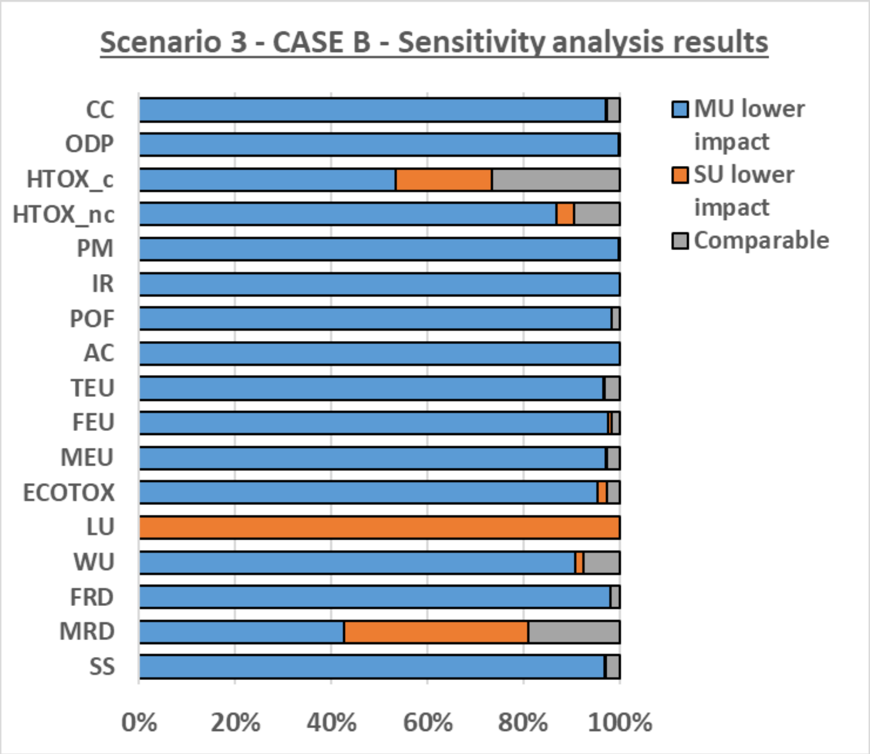


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **<u>Scenario 3 – CASE B</u> –** <u>Sensitivity analysis results</u> --------------------

Results of the sensitivity analysis simulations for 'Scenario 3 – CASE B' are provided in Figure 53 and commented in the main text of the report.

Figure 53. Results of the sensitivity analysis of 'Scenario 3 – CASE B' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Scenario 4

PPWR reference: "alcoholic beverages in the form of wine, with the exception of sparkling wine, old by the manufacturer and the final distributor"

Scenario 4 – SU Glass wine bottle vs MU Glass wine bottle

-------------------- Scenario 4 - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a 0.75 l SU and MU wine bottles are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The comparison covered the whole life cycle of the packaging products, including the manufacturing step (excluding bottle closure), the retail and use step (covering transports to retail and from retail to consumer), the end-of-life steps (covering recycling, incineration and landfill) and the reuse step for the MU packaging product. The impacts of certain life cycle stages, such as washing before filling and filling of the bottles, were excluded from the analysis as being common in the two life cycle under assessment. For the same reason, the energy needs in retail, the transport from retail to home, and the impacts associated to the use phases were also excluded.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts were calculated for a glass bottle with a mass of 542 g.
- The SU packaging product is manufactured, and then consumed. At the end-of-life, a certain amount of glass is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, as it was assumed to be the same for both SU and MU packaging products.

In the case of the MU packaging product, the following assumptions were employed:

- The impacts were calculated for a glass bottle with mass of 596 g.
- The MU packaging product is manufactured, and then consumed. The same bottle is then washed and cleaned and reused a certain number of times before reaching its end-of-life. At the end-of-life, a certain amount of glass is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis, except transport from retail to home, because it was assumed to be same for both SU and MU packaging products.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycled content of glass; the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.
- For the MU packaging product: the number of reuses; the amount of energy and detergents required for the reuse step (i.e. in washing); the transport distances in the reuse step; rewashing rate.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges.

-------------------- Scenario 4 – Life cycle stages --------------------

Details on the modelling of each life cycle stage are provided in Table 23.

Table 23. Overview of the life cycle stages considered for 'Scenario 4' for the Single Use (SU) and Multiple Use (MU) packaging products.

Life cycle stages	**Included in model**	**Included in the life cycle stage**	**Comments**
Raw materials	SU, MU	- SU and MU: Virgin and recycled glass production	All the materials' transport are already included in the datasets related to this life cycle stage. Bottle closures were excluded.
Manufacturing	SU, MU	SU and MU: Bottle manufacturing	All the materials' transport are already included in the datasets related to this life cycle stage. Glass container manufacturing (finished and formed).
Retail and Use	SU, MU	- SU and MU: Transport heavy duty lorry (>32 t)	Covering the transport of packaging products from manufacturing to filling and to retail.
End-of-life - Recycling	SU, MU	- SU and MU: Glass recycling, Glass avoided production (credits)	All the transports concerning recycling are already included in the datasets related to this life cycle stage.
End-of-life - Incineration	SU, MU	- SU and MU: Incineration of inert material	All the transports concerning incineration are already included in the datasets related to this life cycle stage. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.
End-of-life - Landfill	SU, MU	- SU and MU: Transport articulated lorry (12-14t), Landfill of inert material	-

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Reuse	MU	- Transport passenger car - Transport light duty - Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process, including rewashing, and the transport of bottles from home to the collection centre and further to the washing and to the filling.

Source: JRC analysis.

-------------------- Scenario 4 – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values, parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 24 for the SU packaging product, and in Table 25 for the MU packaging product.

The SU bottle mass was retrieved during the stakeholder consultation, whilst the MU bottle mass was estimated to be 10 % thicker compared to the SU bottle. The manufactured and filled bottle is transported to the retail, and again at home for the consumption. However, transport from retail to home was assumed to be the same for both packaging products and is not included in the assessment. In case of the MU packaging, it was assumed that 90 % of bottles are transported without any impact to the collection centre by a transport performed primarily for other purposes (e.g. transport by car but occurring for other purposes, such as going shopping), or are transported by bicycle or by foot. Impacts associated to transport occurring via passenger car were allocated instead to the remaining 10 %, assuming such travel having no other purposes than returning the purchased packaging.

Washing of MU bottles was based on the information retrieved during the stakeholder consultation. Additional washing was added in case that bottles are not cleaned properly during the washing (2 % of the bottles in the benchmark).

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders. The parameters related to the CFF include: “R_1”, “A”, “Q_{sin}/Q_P”, “Q_{sout}/Q_P”, “R_2”, “R_3”; “$1 – R_2 – R_3$”.

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named “Recycling Variability” allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 24. Overview of the Inventory, parameters (benchmark values and ranges) for the Single Use (SU) packaging product of the 'Scenario 4'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Bottle, total mass (glass), g	542	-	-	-	Stakeholder consultation
Recycled content, % [R_1]	34	17	51	-	Stakeholder consultation
A value	0.2	0.1	0.3	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	1	0.5	1	-	
Transport heavy duty lorry (>32 t) from factory to retail, km	1306	1045	1567	Distance, final amount considers mass	Stakeholder consultation
Recycling, % [R_2]	75	52	97	-	Stakeholder consultation
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	1	0.5	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	4	0.4	7	Depends on R_2 min/max values	Calculated based on data gathered in the stakeholder consultation
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	21	2	41	Calculated on R_2 and R_3 values	Calculated based on data gathered in the stakeholder consultation

Source: JRC analysis.

Table 25. Overview of the Inventory, parameters (benchmark values and ranges) for the Multiple Use (MU) packaging product of the 'Scenario 4'.

Inventory values	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Bottle, total mass (glass), g	596	-	-	-	Calculated from data gathered during stakeholder consultation
Recycled content, % [R_1]	34	17	51	-	Stakeholder consultation
A value	0.2	0.1	0.3	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	1	0.5	1	-	
Transport heavy duty lorry (>32 t) from factory to filling, km	764	153	1375	Distance, final amount considers mass. This distance is covered once in the assumed total number of uses.	Stakeholder consultation
Transport heavy duty lorry (>32 t) from filling to retail, km	542	434	650	Distance, final amount considers mass. This distance is covered in each reuse.	
Transport passenger car from home to collection centre, km	5	2.5	7.5	Returning bottles, 10 % the travels back to retail	Own estimation
Items in passenger car from home to collection centre, pieces	5	1	9	-	Own estimation
Transport light duty lorry (<7.5 t), from collection centre to washing, km	100	20	180	-	Own estimation
Transport light duty lorry (<7.5 t) from washing to bottle filling, km	542	108	976	-	Stakeholder consultation
Electricity for washing, kWh	0.014	0.007	0.028	The additional energy need due to rewashing is added to these amounts in the model	Stakeholder consultation
Water for washing, l	0.2	-	-	The additional water due to rewashing is added to this amount in the model	Stakeholder consultation
Detergents for washing, g	0.075	0.064	0.086	The additional detergents need due to rewashing is added to these amounts in the model	Ramboll, 2022a
Wastewater from washing, l	0.204	-	-	-	Derived from all water needs

Inventory values	Benchmark value	Min	Max	Remarks	Reference
Rewashing rate, %	2	0	5	Additional water (and wastewater), detergent and energy consumption to be considered additional to the related benchmark inventories	Own estimation
Number of reuses	20	16	26	-	Stakeholder consultation
Recycling, % [R_2]	75	52	97	-	Stakeholder consultation
Recycling Variability	1	0.85	1.15	-	Own estimation
Q_{Sout}/Q_p	1	0.5	1	-	EF method, Annex C (EC, 2021b)
Incineration, % [R_3]	4	0.4	7	Depends on R_2 min/max values	Calculated based on data gathered in the stakeholder consultation
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)
Landfill, % [$1-R_2-R_3$]	21	2	41	Calculated on R_2 and R_3 values	Calculated based on data gathered in the stakeholder consultation

Source: JRC analysis.

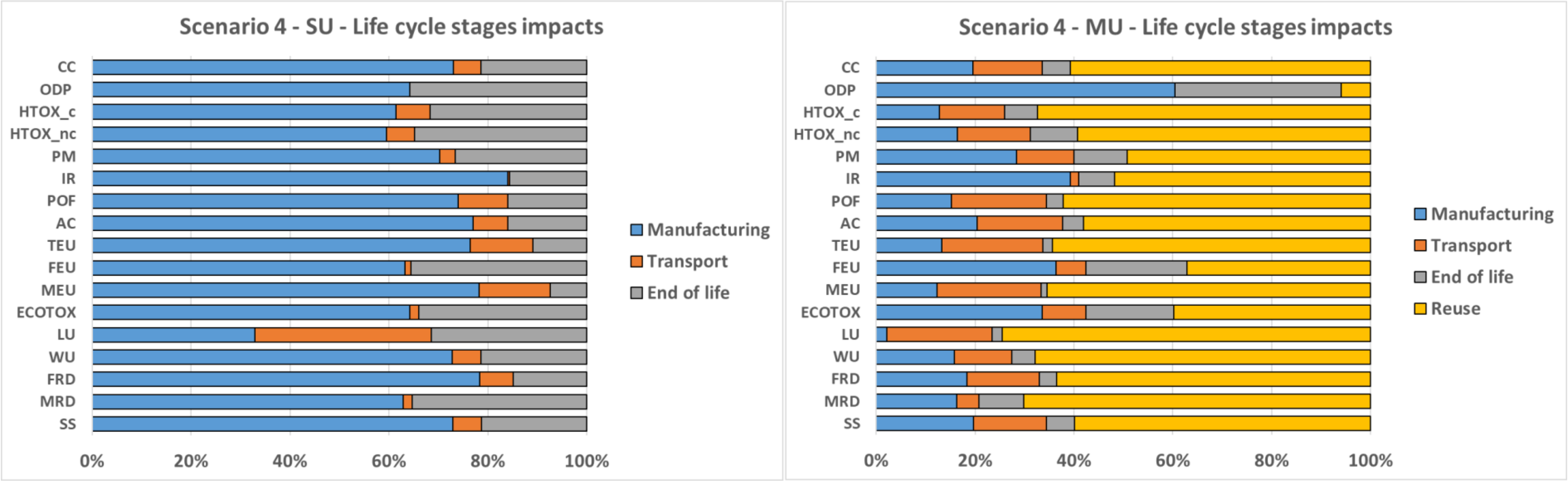
-------------------- **Scenario 4 – Results** --------------------

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Zampori and Pant, 2019). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- **Scenario 4** - Benchmark results --------------------

Life cycle stages contribution for SU and MU are provided in Figure 54. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 68 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 56 % of the impacts in all impact categories).

Figure 54. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) packaging products (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



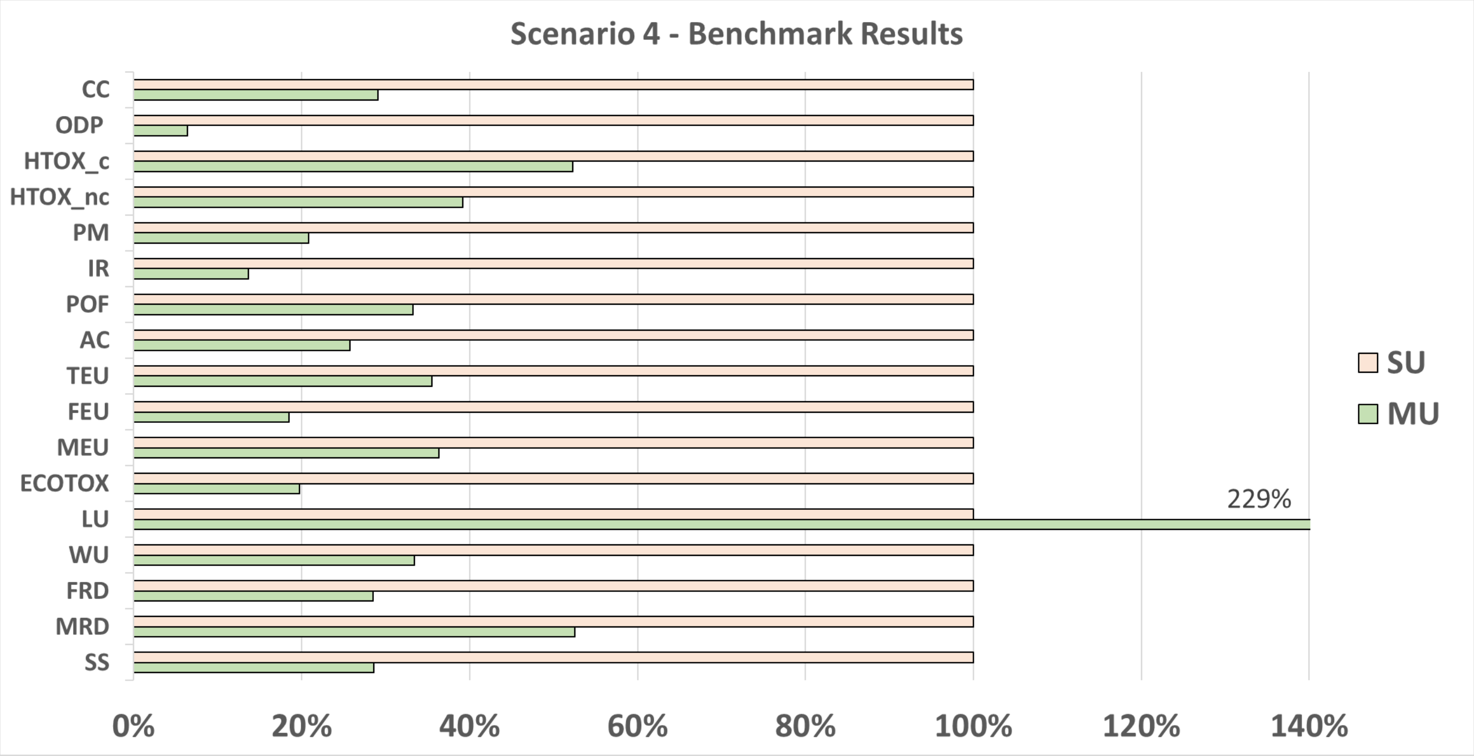
Scenario 4 - SU - Life cycle stages impacts

Scenario 4 - MU - Life cycle stages impacts

Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 56*). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.*

The analysis of the impacts between SU and MU are provided in Figure 55 and commented in the main report.

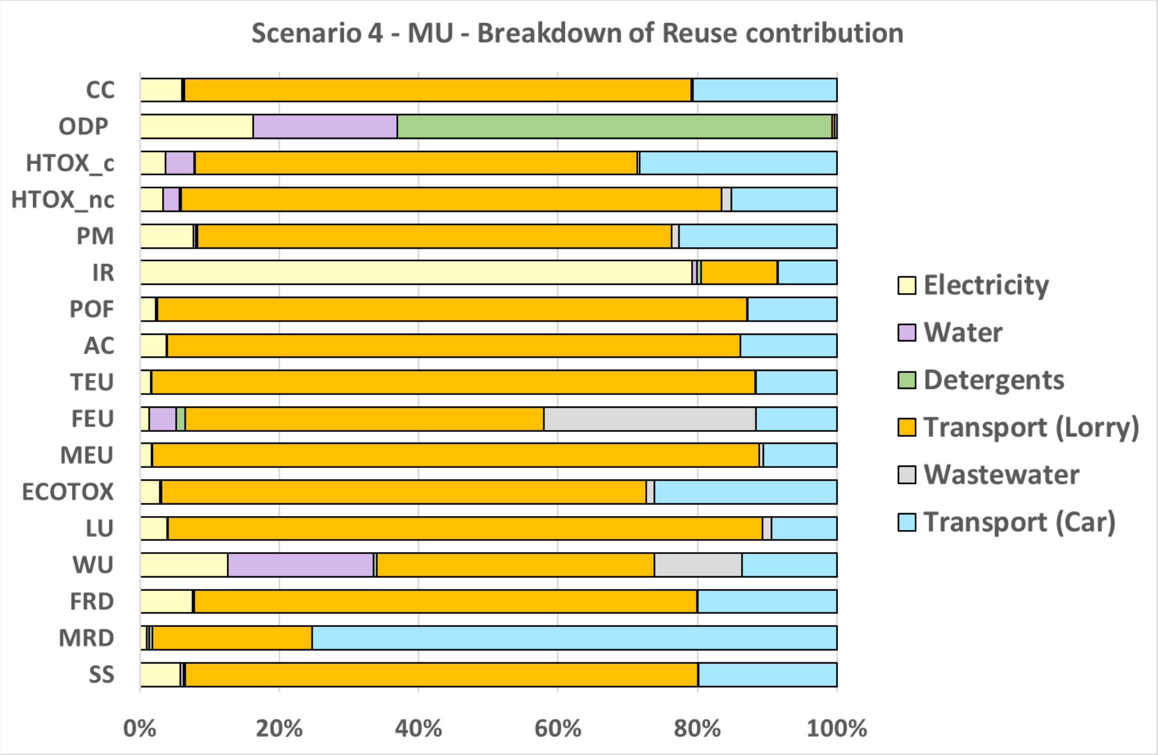
Figure 55. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) packaging products for the 'Scenario 4'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Breakdown of the contribution of the impacts for the reuse phase of the MU are provided in Figure 56. In most of the impact categories, transport lorry from bottle collection to the washing and again to bottle filling has the highest contribution for the reuse impacts. However, in case of the 'Resource Use, Minerals and Metals' impact category passenger car to transport empty bottles from home to collection centre has the highest contribution. In case of the Ionising Radiation impact category, electricity in the washing has the highest contribution, and in case of the Ozone Depletion Potential impact category both detergents and water used in the washing have more than 80 % contribution together.

Figure 56. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) packaging product (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

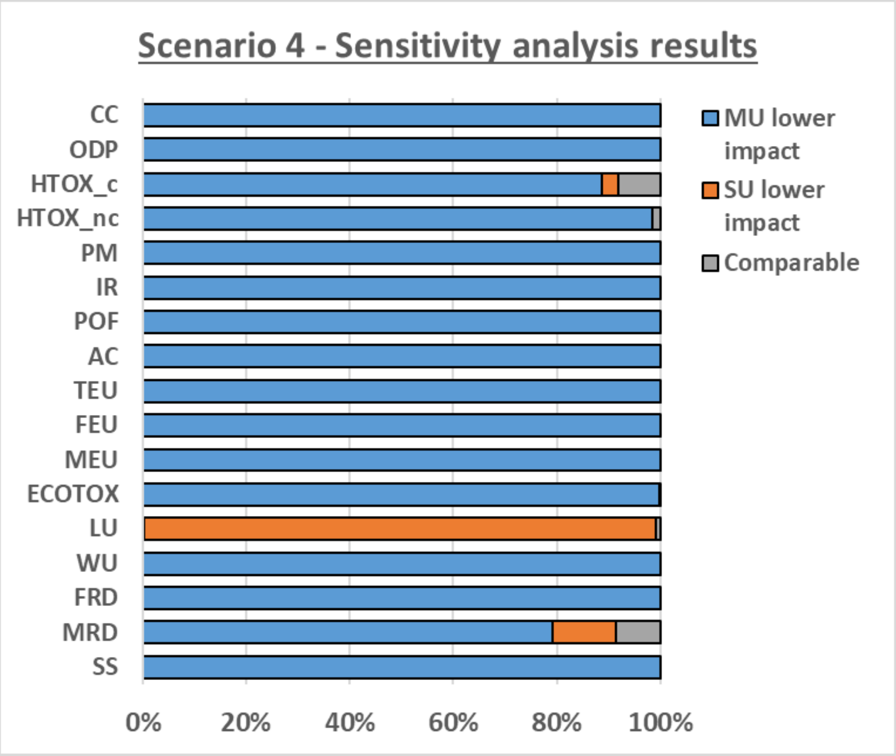


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **Scenario 4 –** Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for 'Scenario 4' are provided in Figure 57 and commented in the main text of the report.

Figure 57. Results of the sensitivity analysis of 'Scenario 4' for all impact categories for the Single Use (SU) and Multiple Use (MU) packaging products.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Factsheet – Restaurant Scenario

PPWR reference: "bans as of 2030 single use packaging for consumption in restaurants, which implies in practice a switch to 100 % reusable packaging. Moreover, Member States may exempt economic operators from point 3 of Annex V if they comply with the definition of micro-company"

Restaurant Scenario - SU Hamburger meal vs MU Hamburger meal

-------------------- Restaurant Scenario - Overview of the approach --------------------

In this Factsheet, the underpinning information and results related to the analysis of the environmental impacts of a dine-in SU "hamburger meal" and a dine-in MU "hamburger meal" are provided.

This annex is divided in subsections providing insights on: (i) the life cycle stages covered in the modelling, (ii) the inventory and the parameters employed in the calculations and the related benchmark values and ranges and (iii) the results of the analysis.

The analysis covered the whole life cycle of the packaging products, including the manufacturing step, the transport step covering transports from manufacturing site to distribution centre and finally to restaurant, the end-of-life step (covering recycling, incineration and landfill) and the reuse step for the MU packaging product.

In the case of the SU packaging product, the following assumptions were employed:

- The impacts for the SU meal were modelled as follows:
    1. A carton container assumed to contain the hamburger. The model for this packaging product is adapted from the SU 'Scenario 2 – CASE A' but including only carton with a different mass (modelled according to data retrieved during the stakeholder consultation). This carton has a total mass of 14.8 g, without a LDPE lining (also in this case, based stakeholders' inputs). This SU packaging product is manufactured (with a total electricity consumption equal to 0.003 kWh, according to stakeholder data) and then consumed. At the end-of-life, it was assumed that the carton part of the SU packaging product could be recycled, incinerated or landfilled. All transports between life cycle stages were included in the analysis.
    2. A smaller carton container used to contain the fries. The model for this packaging product is adapted from the SU 'Scenario 2 – CASE A' but including only carton with a different mass (modelled according to data retrieved during the stakeholder consultation). This carton has a total mass of 7.3 g, without a LDPE lining (also in this case, based stakeholders' inputs). This SU packaging product is manufactured (with a total electricity consumption equal to 0.0098 kWh, according to stakeholder data), and then consumed. At the end-of-life, it was assumed that it could be recycled, incinerated or landfilled.
    3. A 500 ml carton cup containing the drink was also included and the model for this packaging product is adapted from the SU 'Scenario 1'. Based on stakeholders' inputs (and direct real-life observations), the cups were modelled as for the SU 'Scenario 1' but without a lid. The carton used for the cups amounted to 11.2 g, with a LDPE lining having a mass of 1.07 g (also in this case, based stakeholders' inputs). This SU packaging product is manufactured and then consumed. At the end-of-life, it was assumed that the carton part could be recycled, incinerated or landfilled, whilst the LDPE part could be either incinerated or landfilled. All transports between life cycle stages were included in the analysis.

- The impacts for the MU meal were modelled as follows:
  1. A PP plate with own compartments for hamburger and fries, with a mass of 170 g (based on data retrieved during the stakeholder consultation). This MU packaging product is manufactured and then consumed. At the end-of-life, a certain amount is recycled, with the remaining parts being incinerated or landfilled. All transports between life cycle stages were included in the analysis. An ad-hoc model was prepared for this packaging product, which is described in the below sections of this Annex. Based on stakeholder data, it was assumed that the plate is reused 100 times in the benchmark simulation.
  2. A PP cup with a mass of 33 g (assuming that 15 g related to the lid weight should be removed from the total mass of the cup of 'Scenario 1 – CASE A'). This MU packaging product is manufactured and then consumed. At the end-of-life, it was assumed that the SU packaging product could be recycled, incinerated or landfilled. All transports between life cycle stages were included in the analysis. The model for this packaging product is the same as the one for the 'Scenario 1 – CASE A' multiple use packaging product, apart from the passenger car transport in the reuse step which has been excluded to model the dine-in Restaurant meal. As for the PP plate, also cups are reused 100 times.

An overview of the meal is proposed in Table 26.

Table 26. Overview of the Single Use (SU) and Multiple Use (MU) meal for the Hamburger meal.

Hamburger meal SU	**Hamburger meal MU**
• Carton box for the hamburger (adapted from 'Scenario 2 – CASE A' Single Use packaging product - Annex 1.4) • Carton folder for the fries (adapted from 'Scenario 2 – CASE A' Single Use packaging product). • Carton cup for the beverage (adapted from 'Scenario 1 – CASE A' Single Use packaging product).	• PP Plate for the hamburger and the fries (see details below) • PP Cup for the beverage (adapted from 'Scenario 1 – CASE A' multiple use packaging product)

Source: JRC analysis.

The analysis leveraged parametrized assumptions for key aspects of the value chain. In particular, the following key aspects were parametrized:

- For both the SU and MU packaging products: the recycling, incineration and landfill end-of-life shares; the quality factors for the recycled and recyclable material; the efficiency of the recycling process; the transport distances along the value chain.
- For the MU packaging product: the recycled content of the plate and cup; the number of reuses; the amount of energy required for the reuse step (i.e. in rinsing and washing); the amount of water required in rinsing and washing; the rewashing rate; the amount of detergent used for washing.

In the analysis, a set of energy mixes sets were derived and employed for the calculations as described in Annex 2.

The environmental impacts results of the two life cycles were analysed considering (i) the benchmark values for the parameters under exam and (ii) a sensitivity analysis carried out allowing random extractions of parameters' values in their associated ranges. Further sensitivity analyses have been performed in the context of the 'Restaurant Scenario' and are detailed in the main report.

-------------------- Restaurant Scenario – Life cycle stages --------------------

Details on the modelling of PP plate (MU meal) in each life cycle stage are provided in Table 27 whilst for SU and MU components of the meal, further details are provided in the Annexes described in Table 26.

Table 27. Overview of the life cycle stages considered for the PP plate of the Multiple Use (MU) hamburger meal.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
Raw materials	MU	- Production of virgin and recycled PP granulates	All the materials' transport are already included in the datasets related to this life cycle stage. The recycled content of all materials was assumed to be 0 % (note that the PP recycled content is allowed to reach values as high as 10 % in the sensitivity analysis simulations).
Plate manufacturing	MU	- Manufacturing of the PP plate	All the materials' transport are already included in the datasets related to this life cycle stage. The PP granulates are blow moulded.
Transport	MU	- Transport heavy duty lorry (>32 t) - Transport heavy duty lorry (<7.5 t)	Covering transport of packaging products from manufacturing site to distribution centre and from distribution centre to restaurant.
End-of-life - Recycling	MU	- PP recycling, PP avoided production (credits)	All the transports concerning recycling are already in the datasets related to this life cycle stage.
End-of-life - Incineration	MU	- Incineration of PP	All the transports concerning incineration are already included in the datasets related to this life cycle stage. Credits associated to the waste-to-energy treatment are already accounted in the dataset employed for the incineration process.

Life cycle stages	Included in model	Included in the life cycle stage	Comments
End-of-life - Landfill	MU	- Transport articulated lorry (12-14t) - Landfill of plastic waste (PP)	-
Reuse	MU	- Electricity consumption - Heat consumption - Water consumption - Detergents consumption - Wastewater treatment	Includes inputs and outputs of the washing process and relevant process, including rinsing with hot water before washing (prewashing). No transport is considered as the Restaurant meal is dine-in.

Source: JRC analysis. Note: for a description of the models of the other packaging products in the SU and MU hamburger meals, see Table 26.

-------------------- <u>Restaurant Scenario</u> – Inventory and parameters (benchmark values and related ranges) --------------------

The employed inventory values and parameters (benchmark values and the associated ranges employed for the sensitivity analysis) are presented in Table 28 for the PP plate in MU packaging product. Inventory values and parameters of other SU and MU meal components are presented in the dedicated Annexes and summarized in Table 26.

The MU plate for hamburger and fries was assumed to contain different compartments for different food items. It was estimated to have a mass of 170 grams based on data collected during the stakeholder consultation. The recycled content was set as 0 % based on stakeholders' inputs and allowed to range from 0 % to 10 % in the sensitivity analysis of the benchmark values.

Transport from manufacturing to use was assumed to follow the EF method, considering that plates are first transported from the manufacturing site to the distribution centre and then to the restaurant, and transport distances were based on data retrieved from the stakeholders. In this Scenario consumption and reuse (including washing operations) take place in the restaurant, thus additional transports were not included.

The washing of MU plates was assumed to include rinsing (with cold water or hot water), rewashing and regular washing. Data related to the washing step (e.g. including the energy consumption, the detergents need, the water consumption, etc.) were retrieved during the stakeholder consultation. Water consumption amount for rinsing was estimated to be equal to the water consumption on the regular washing. Rinsing water was estimated to be double of the water consumption in washing machine. Heat consumption during rinsing was estimated considering the water specific heat capacity and that the rinsing water could be either heated to 30°C in the benchmark case. In the sensitivity analysis rinsing water was assumed to be heated or used cold (50:50) (no impacts associated to heat consumption if used cold). Also, additional washing was added in case that plates are not cleaned properly during the washing (rewashing rate equal to 1 % of the plates in the benchmark, based on stakeholder consultation).

The parameters related to the CFF were selected based on the information available in the Annex C of the EF method (Zampori and Pant, 2019; EC, 2021b) or on the data collected from stakeholders. The parameters related to the CFF include: "R_1", "A", "Q_{sin}/Q_P", "Q_{sout}/Q_P", "R_2", "R_3"; "$1 - R_2 - R_3$".

The benchmark value for R_2 includes the collection and sorting efficiency, together with the recycling efficiency. The energy mix employed was modelled as described in the introduction of Annex 1. The parameter named "Recycling Variability" allows, during the sensitivity analysis, a further ± 15 % variation in the impacts of the recycling step at the end-of-life to allow for a better representativeness of potential case-specific recycling processes in the EU context (this parameter has no influence in the benchmark calculations).

Table 28. Overview of the Inventory and parameters (benchmark values and ranges) for the PP plate in Multiple Use (MU) meal of the 'Restaurant Scenario'.

Process	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Plate mass (PP), g	170	-	-	-	Stakeholder consultation
Recycled content, % [R_1]	0	0	10	-	Stakeholder consultation
A value	0.5	0.25	0.75	-	EF method, Annex C (EC, 2021b)
Q_{sin}/Q_p	0.9	0.45	1	-	
Transport heavy duty lorry (>32 t) from factory to distribution centre, km	454	363	544	Distance, final amount considers mass	Stakeholder consultation
Transport heavy duty lorry (<7.5 t) from distribution centre to restaurant, km	172	86	258	Distance, final amount considers mass	
Water for rinsing, l	0.22	0.11	0.33	Equal to the water needs for washing	Own estimation
Heat for rinsing, MJ	0.028	0	0.041	Linked to the amount of water used in rinsing	Own estimation (cold water or hot water 30 °C)
Electricity for washing, kWh	0.033	0.017	0.066	The additional energy need due to rewashing is added to these amounts in the model	Stakeholder consultation
Water for washing, l	0.22	-	-	The additional water due to rewashing is added to this amount in the model	Stakeholder consultation
Detergents for washing, g	0.510	0.434	0.587	The additional detergents need due to rewashing is added to these amounts in the model	Stakeholder consultation
Wastewater from rinsing and washing, l	0.44	0.33	0.55	-	Derived from all water needs
Rewashing rate, %	1	0	2	Additional water (and wastewater), detergent and energy consumption to be considered additional to the related benchmark inventories	Stakeholder consultation
Number of reuses	100	80	120	-	Own estimation based on stakeholder data
Recycling, % [R_2]	41	28	60	-	Ramboll, 2022a
Recycling Variability	1	0.85	1.15	-	EF method, Annex C (EC, 2021b)
Q_{Sout}/Q_p	0.9	0.8	1	-	
Incineration, % [R_3]	27	18	33	Depends on R_2 min/max values	
Transport articulated lorry (12-14t) to landfill, km	100	80	120	Distance, final amount considers mass	Adapted from EF method (EC, 2021a)

Process	**Benchmark value**	**Min**	**Max**	**Remarks**	**Reference**
Landfill, % [1-R_2-R_3]	32	22	39	Calculated on R_2 and R_3 values	EF method, Annex C (EC, 2021b)

Source: JRC analysis.

-------------------- Restaurant Scenario – Results --------------------

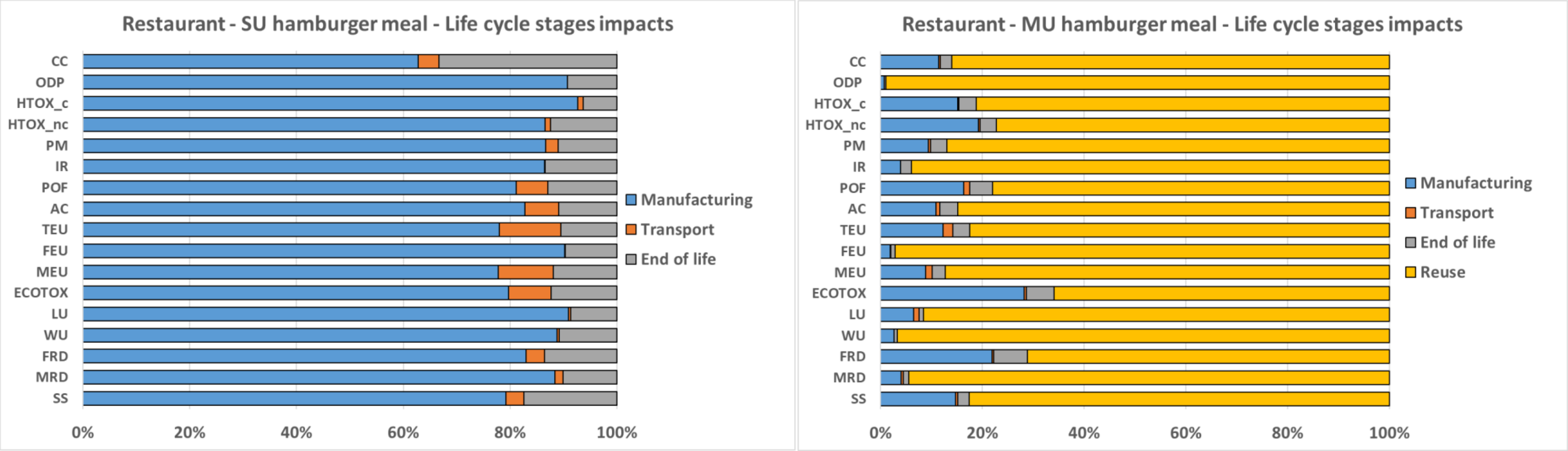
This section provides preliminary 'Restaurant Scenario' (Hamburger meal) results.

All values are calculated after Normalization and Weighting according to the EF3.1 Normalization Factors and Weighting Factors (Andreasi Bassi et al., 2023). Single Score (SS) results of a given life cycle stage have been derived by summing all Normalized and Weighted impacts for all impact categories.

-------------------- Restaurant Scenario – Benchmark results --------------------

Life cycle stages contribution for SU and MU packaging products are provided in Figure 58. In the SU case, the manufacturing step has the biggest contribution in the total impacts (average of 84 % of the impacts in all impact categories), while in the MU case, the reuse step has the highest contribution (average of 86 % of the impacts in all impact categories).

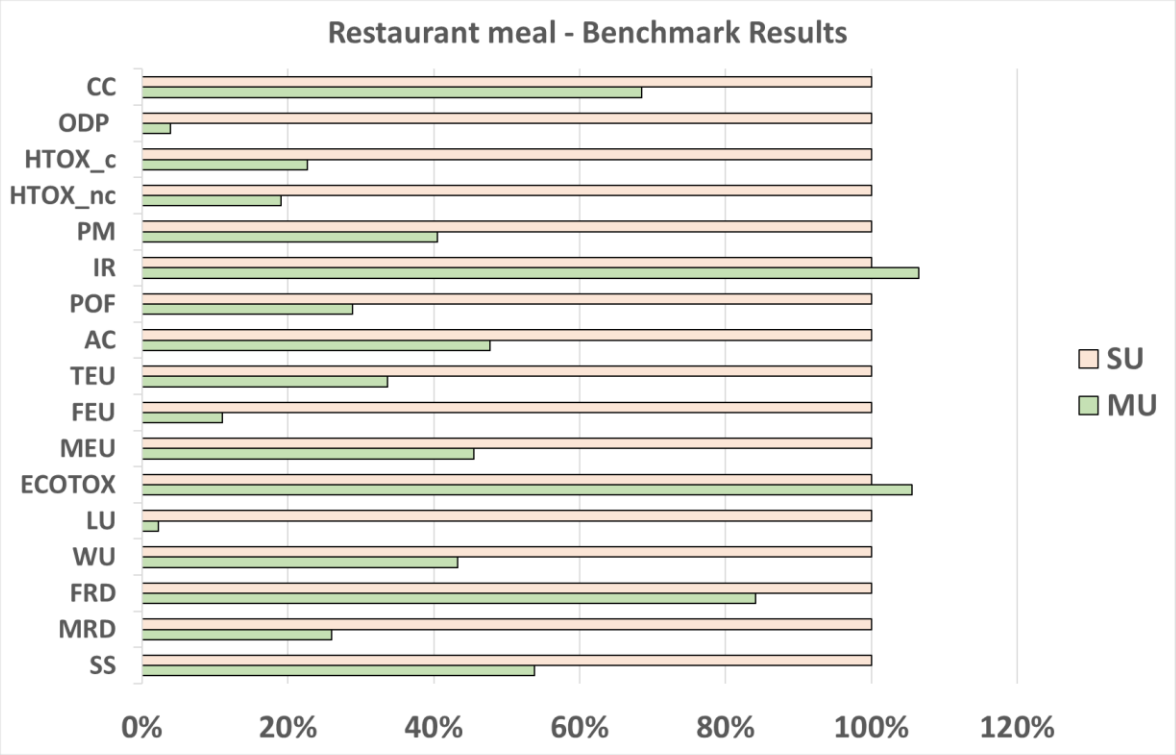
Figure 58. Overview of the contribution of the various lifecycle stages in the Single Use (SU) and Multiple Use (MU) meals (percentages calculated for the absolute values of the benchmark impacts, after Normalization and Weighting). Note: Raw materials and Production are included in the manufacturing step.



Source: JRC analysis. The label "Transport" in the legend of this figure refers to all transports occurring in the whole life cycles of the packaging except for the transports occurring in the "Reuse" step for the multiple use packaging (e.g. transport for bringing back the packaging), which are instead included within the "Reuse" label (for further details of the impacts of the reuse step see Figure 60*). Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.*

The analysis of the impacts between SU and MU are provided in Figure 59 and commented in the main report.

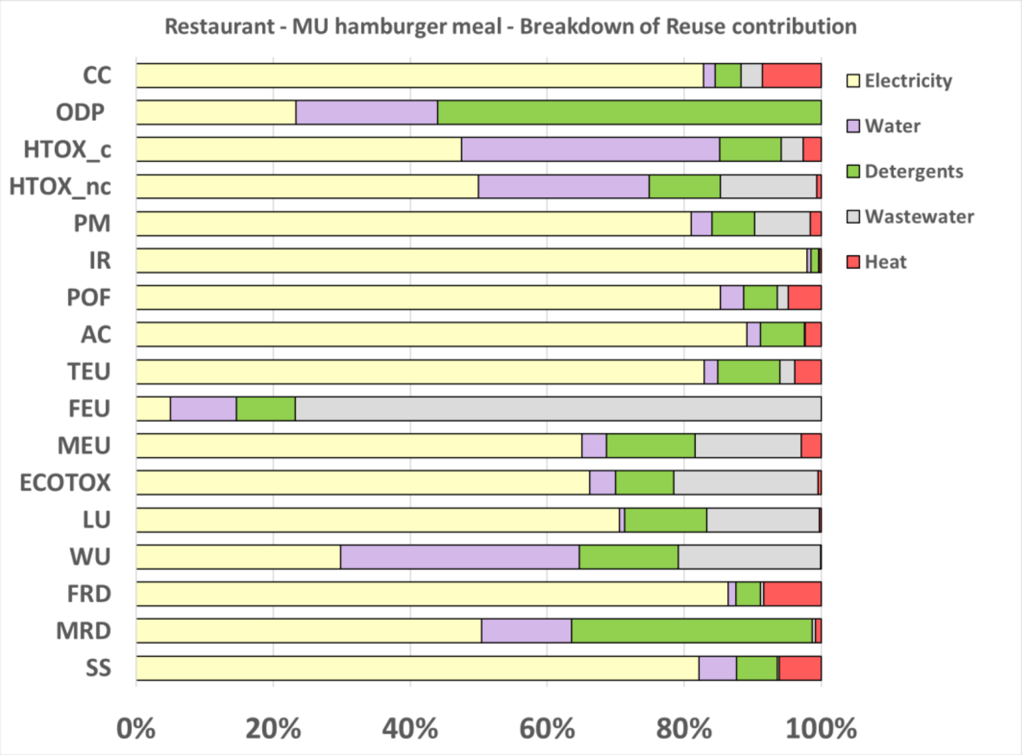
Figure 59. Analysis of the benchmark impacts of Single Use (SU) and Multiple Use (MU) meals for the 'Restaurant Scenario'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Breakdown of the contribution of the impacts for the reuse phase of the MU are provided in Figure 60. In most of the impact categories, the electricity used in the washing has the highest impact. Water used in the washing has significant impact in the Water Use, 'Human Toxicity, cancer' and 'Human Toxicity, non-cancer'), Ozone Depletion Potential and 'Resource Use, Minerals and Metals' impact categories. Wastewater from washing has the highest share of the impacts in the 'Eutrophication, Freshwater' impact category. In addition, impacts associated to detergents have a significant share in the Ozone Depletion Potential impact category.

Figure 60. Breakdown of the benchmark impacts for the reuse phase of the Multiple Use (MU) meal (percentages calculated for the absolute values of the impacts, after Normalization and Weighting).

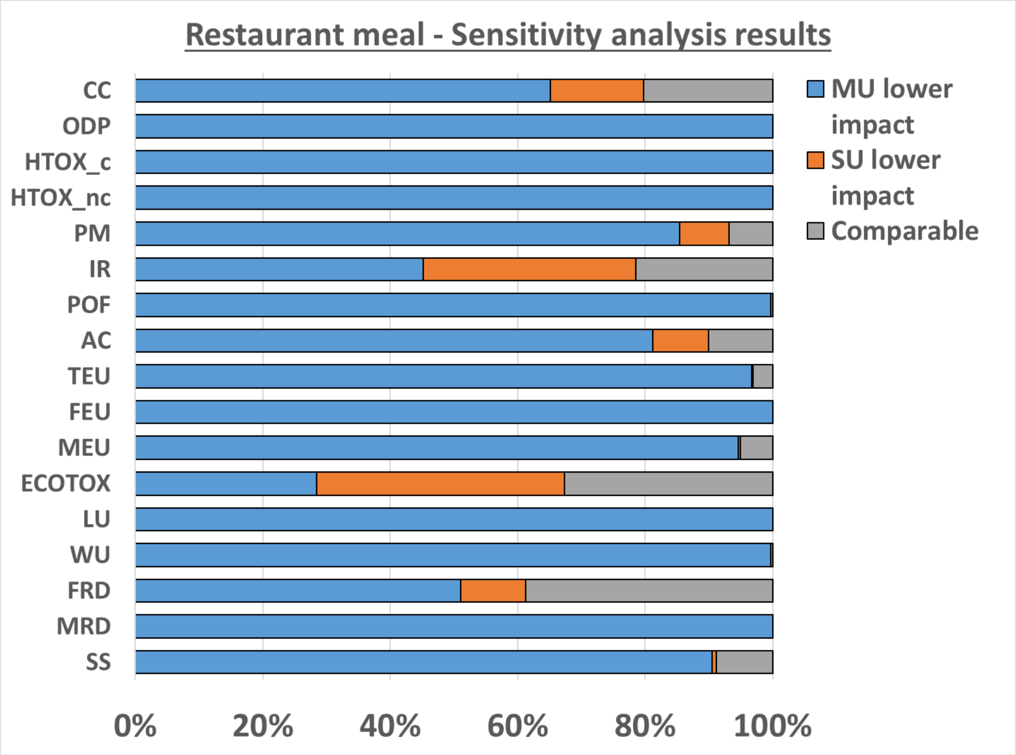


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

-------------------- **Restaurant Scenario** – Sensitivity analysis results --------------------

Results of the sensitivity analysis simulations for 'Restaurant Scenario' are provided in Figure 61 and commented in the main text of the report.

Figure 61. Results of the sensitivity analysis of the 'Restaurant Scenario' for all impact categories for the Single Use (SU) and Multiple Use (MU) meals.

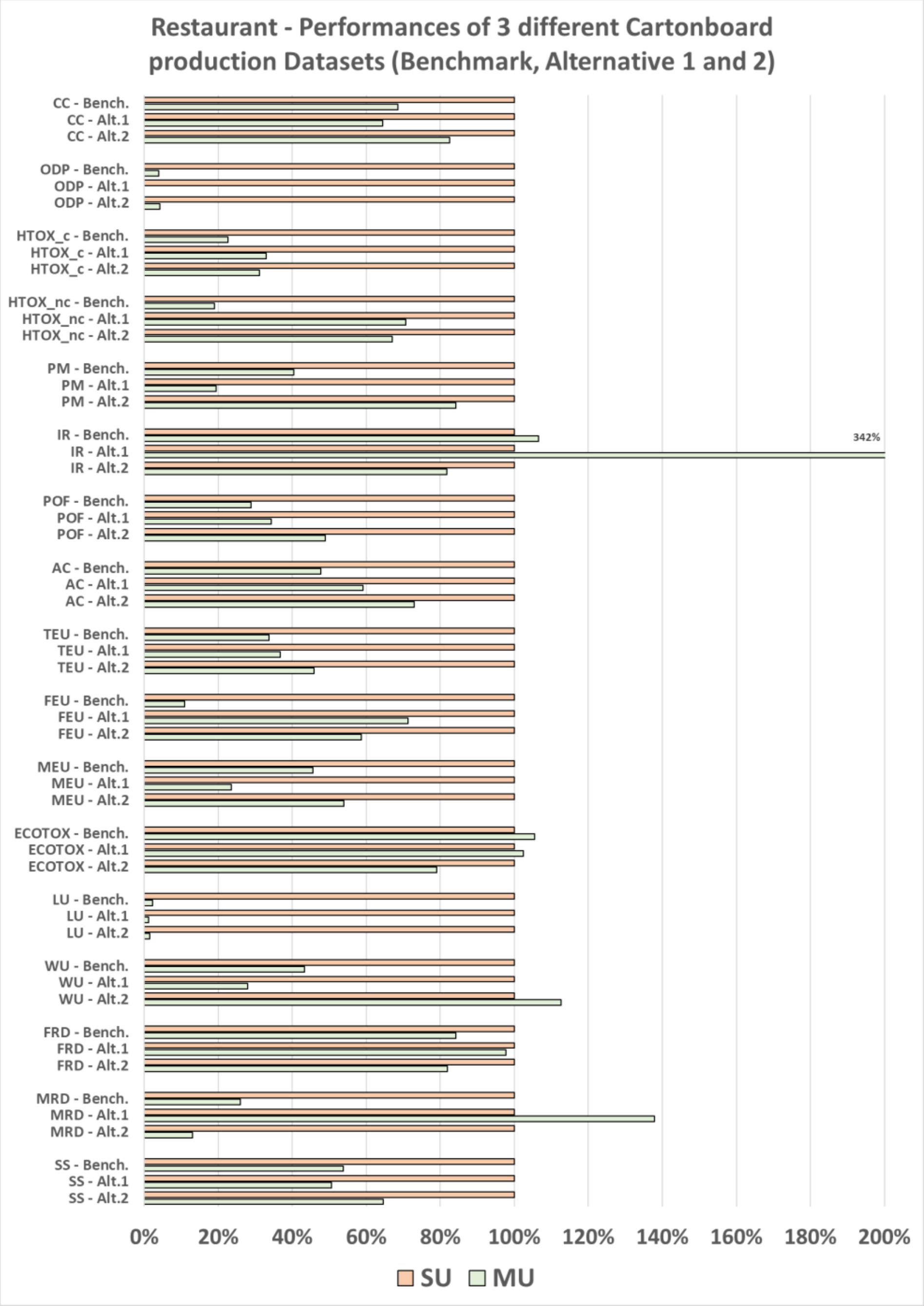


Source: JRC analysis. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Annex 4. Additional results on the cartonboard manufacturing impacts analysis

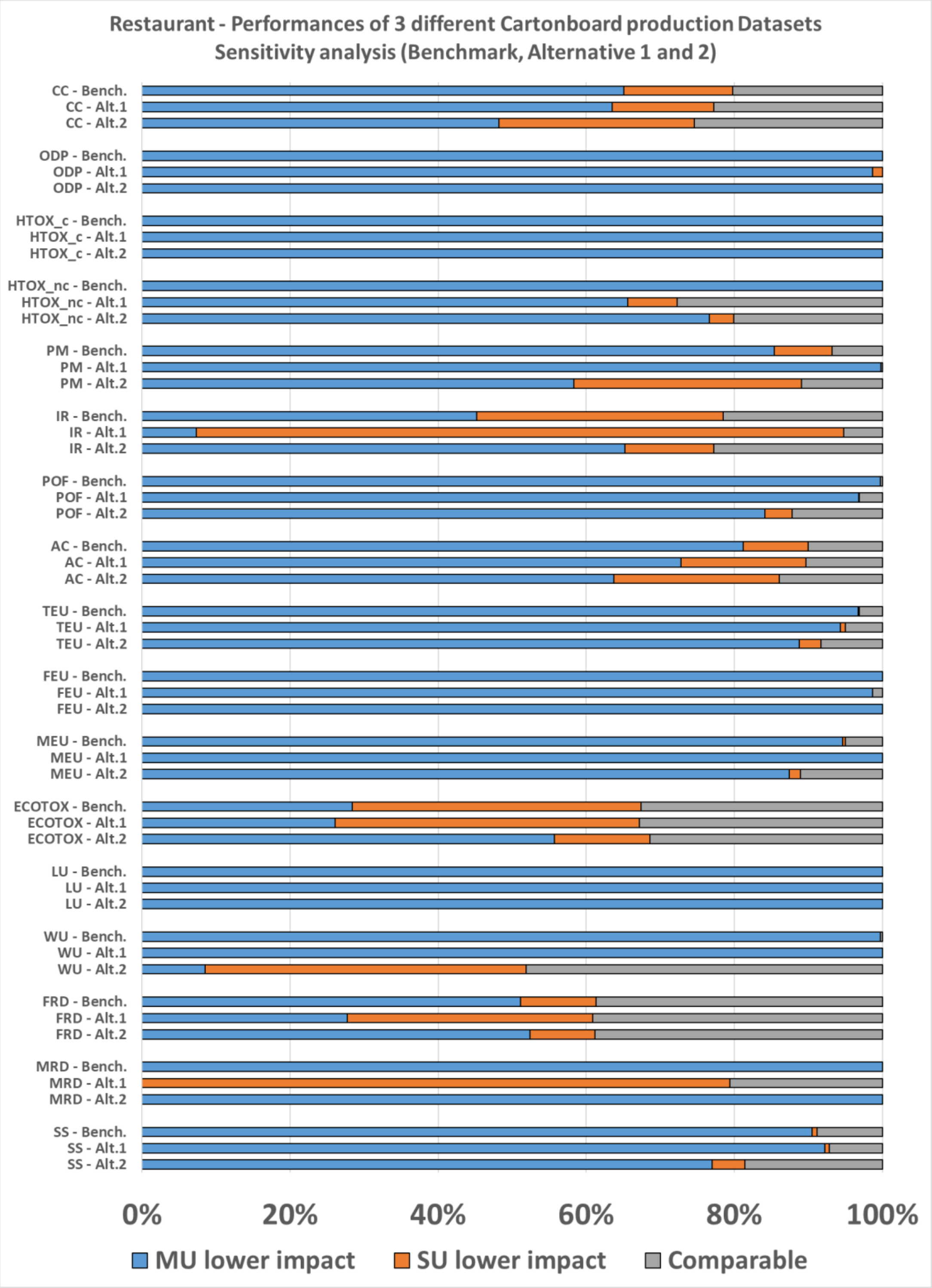
The effects of varying cartonboard production impacts are presented in Figure 62 (benchmark results) and in Figure 63 (sensitivity analysis results) for all impact categories with regard to 'Scenario 1'.

Figure 62. Results of the specific sensitivity analysis for cartonboard impacts for the Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 1'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. For further details see Section 2.5.1 and Annex 2. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

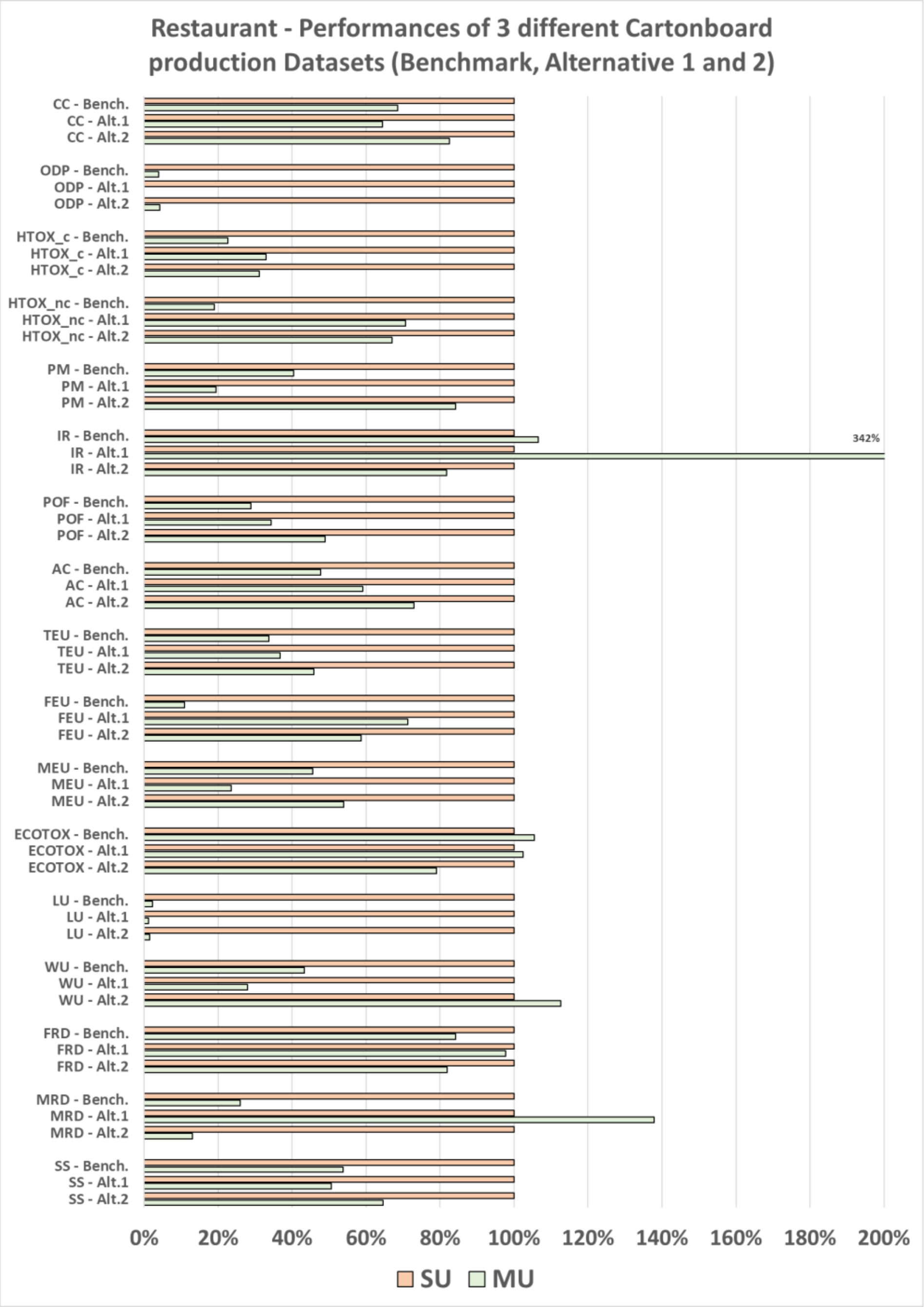
Figure 63. Results of the specific sensitivity analysis for cartonboard impacts, analysis the performances with regards of the sensitivity analysis results for the Single Use (SU) and Multiple Use (MU) packaging products for 'Scenario 1'.



Source: JRC analysis. For further details see Section 2.5.1 and Annex 2. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

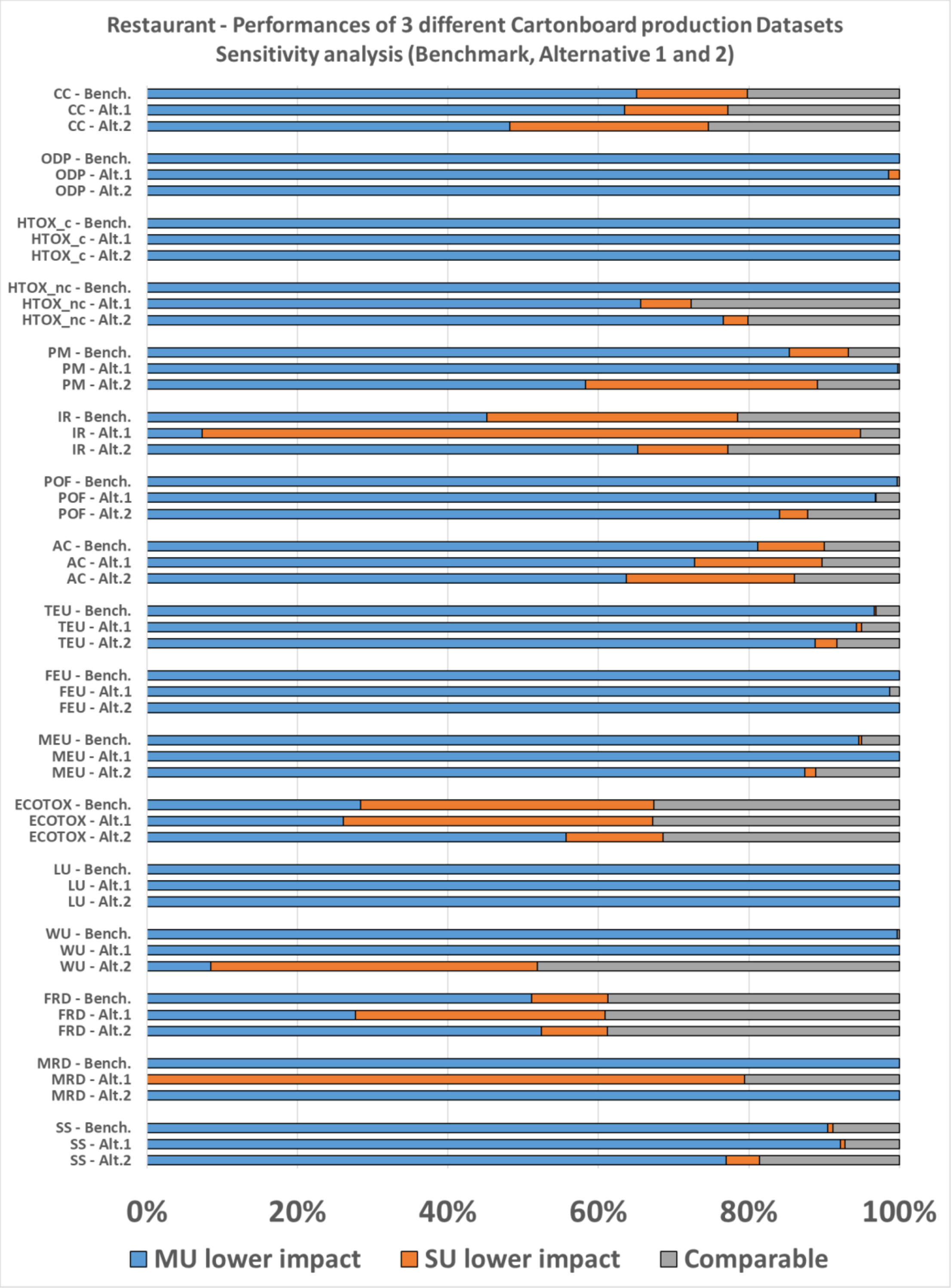
The effects of varying cartonboard production impacts are presented in Figure 64 (benchmark results) and in Figure 65 (sensitivity analysis results) for all impact categories with regard to the 'Restaurant Scenario'.

Figure 64. Results of the specific sensitivity analysis for cartonboard impacts for the Single Use (SU) and Multiple Use (MU) packaging products for the 'Restaurant Scenario'. SU impacts are set to 100 % for each impact category considered.



Source: JRC analysis. For further details see Section 2.5.1 and Annex 2. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

Figure 65. Results of the specific sensitivity analysis for cartonboard impacts, analysis the performances with regards of the sensitivity analysis results for the Single Use (SU) and Multiple Use (MU) packaging products for the 'Restaurant Scenario'.



Source: JRC analysis. For further details see Section 2.5.1 and Annex 2. Note: CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_nc = Human Toxicity, non-cancer; HTOX_c = Human Toxicity, cancer; PM = Particulate Matter; IR = Ionising Radiation; POF = Photochemical Ozone Formation; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity Freshwater; WU = Water Use; FRD = Resource Use, Fossil; MRD = Resource Use, Minerals and Metals; SS = Single Score.

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