HORIZON-CL6-2021-CIRCBIO-01
Innovative solutions to over-packaging and single-use plastics, and related microplastic pollution (IA)

BUDDIE-PACK

Business-driven systemic solutions for sustainable plastic packaging reuse schemes in mass market applications

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LCIA, LCCA and SIA screening studies, data gaps

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DISCLAIMER

Acronym description

ADEME	Agence de l'environnement et de la maîtrise de l'énergie - French Agency for Ecological Transition
BEP	Break-Even Point
BiB	Bag-in-Box
CFF	Circular Footprint Formula
CSR	Corporate Social Responsibility
EF	Environmental Footprint
EoL	End-of-Life
GA	Grant Agreement
GWP	Global Warming Potential
HDPE	High Density Polyethylene
ILO	International Labor Organisation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Center
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LCI	Life Cycle Inventory
PBT	Polybutylene terephthalate
PCR	Product Category Rules
PE	Polyethylene
PEFCR	Product Environmental Footprint Category Rules
PEF	Product Environmental Footprint
PET	Polyethylene terephtalate
PP	Polypropylene
RPP	Reusable Plastic Packaging
SDG	Sustainable Development Goals
SETAC	Society of Environmental Toxicology and Chemistry
SHDB	Social Hotspots DataBase
SIA	Social Impact Assessment
SLCA	Social Life Cycle Analysis
SUPP	Single Use Plastic Packaging
TRL	Technology Readiness Level
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations International Children's Emergency Fund
USA	United States of America
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organisation
WFF	Walk Free Foundation
WP	Work Package

Executive Summary

The aim of Deliverable 7.2 is to use screening studies for each use-case performed in the BUDDIE-PACK project to identify environmental, economic and social hotspots of reusable plastic packaging life cycles, and assess their potential benefits compared to single-use alternatives. This Deliverable enables the achievement of Milestone 7, which aims to reach a consensus on designs and materials choices made in WP1 and WP3 using LCA, LCCA and SIA screening, by communicating the screenings results with the partners throughout the screening tasks.

The first part of this deliverable underlines the methodological choices made in Deliverable 7.1 for LCA and LCCA screenings and the full assessment studies. Any deviations from these methodological choices that are used in the screening studies, due to data availability, feasibility or inputs from other Work Packages, are then described and justified. For LCCA, generic economic data used for every use-case is also indicated.

The screening studies include an LCA and an LCCA of the contributing factors, along with the assessment of Break-Even Points (BEP) of reusable systems, i.e. the number of times the reusable system must be used to be better than a single-use comparator. All use-cases were studied for this Deliverable and all available results are presented in this document. The Dawn Meats use-case (Meat secondary food packaging) is to be finalised after the Deliverable submission, as the data arrived later. The results are presented for all EF3.0 indicators for the contributor analysis and comparison to single-use, and are focused on Climate change and Water use for the sensitivity analyses of the Break-Even Point.

For the take-away food container in Vytal's use-case, a reusable PP container (used 20 times) is compared to a single-use laminated cardboard container, for service and on-site washing in a restaurant in Berlin. The baseline study gives a break-even point of 17 uses for Climate change and 32 uses for Water use. The LCCA break-even point is at 15 uses.

For the laundry detergent system in Asevi/SmurfitKappa's use-case, a reusable PP bottle (used 10 times) filled by a 10 l Bag-in-Box is compared to a single-use laundry detergent bottle. The baseline study gives a break-even point of 2 uses for Climate change and Water use. The LCCA break-even point has not been calculated as there is too big a discrepancy between the types of cost collected for the two systems.

For the catering tray in Ausolan's use-case, two systems are analysed:

- A multiportion tray, where the reusable CPET tray (used 50 times) is compared to a reusable steel tray (used 100 times). The baseline study shows a non-attainable break-even point on Climate change and Water use.
- A single-portion container, where the reusable PBT and PP container (used 50 times) is compared to a single-use PP container. The baseline study gives a break-even point of 8 uses for Climate change and 14 uses for Water use.

The systems are then combined to represent the proportional allocation of meals packaged in trays (80%) and those packed in containers (20%). The combined systems considered are:

- Steel trays and single-use single-portion plastic SUPP containers (the current system);
- Plastic RPP trays and reusable single-portion plastic RPP containers (the fully reusable plastic system);
- Steel trays and reusable single-portion plastic RPP containers (hybrid system).

The BEP analysis comparing them shows the hybrid system as the potentially best option.

For the on-the-spot food container in Uzaje's use-case, a reusable PP container (reused 20 times) is compared to a single-use PP container, for a usage in a supermarket and industrial washing both in Ile-

de-France. The baseline study gives a break-even point of 11 uses for Climate change and 12 uses for Water use. As the production of a single-use container is less expensive than the washing of a reusable container, the BEP is not reachable for the current system.

The following table sums up on which aspects the follow up work will focus for each use-case: the main contributors to the most significant impacts, and the data gaps to fill.

Use-case	Main contributors to Climate Change and Water Use	Data gaps
Take-away food container	Container production, Consumer transport	PBT production, Consumer transport
Refillable system for laundry detergent	BiB and reusable bottle production	Detergent distribution machine, recycled plastic content, BiB volume
Semi-rigid catering tray for schools and nursing homes	Tray production, Transport	PBT production, cost of RPP production, Industrial washing
On-the-spot food consumption container	Container production, Washing	PBT production, Industrial washing, Reverse Vending Machine

For all use-cases, the following data and prospective hypotheses should be collected and revised:

- Real reuse rate: return rate, decommissioning rate…;
- Final mass and material of the packaging developed in the project;
- Specific washing data;
- End-of-Life scenario of the reusable packaging: integration in existing recycling schemes, closed loop recycling;
- Integration of other single-use (cardboard…) and reusable options (steel, glass…) available on the market to get a comprehensive idea of the relevance of using a plastic reusable packaging.

The screening S-LCA is performed differently to the LCA and LCCA, as some methodological points needed to be addressed, as discussed in Deliverable 7.1. By doing screening studies of the plastic industry, with tools such as the Risk Mapping tool, this deliverable has successfully identified the relevant social topics for the full assessment of BUDDIE-PACK use-cases. These cover a range of stakeholder categories ranging from workers to local communities and consumers. These are largely aligned with the WBCSD, and UNEP and SETAC guidelines. However, a mandatory social topic (child labour) was removed due to lack of relevance for the project. Within this screening study generic data from literature and databases was used to assess representative sectors and countries of operation. Risk hot spots were subsequently identified, and the approach to impact characterisation within the full S-LCA was selected. Owing to several data related considerations, a reference scale approach is identified as the most appropriate. The developed reference scales, in conjunction with the partners co-operation and CSR documentation should enable a complete assessment of the use-cases with minimal need for assumptions of data imputations.

In conclusion, this deliverable shows the potential positive impact of the reusable solutions developed in the project. Many assumptions have been taken concerning decisive parameters of systems (packaging mass and End-of-Life, washing consumptions…), as data coming from the other Work packages was available at the end of the screening tasks or is still not available. These data gaps will be filled throughout the rest of the project, with input from large-scale demonstration of each use-case, and identification of methodological improvements from the screenings to the full assessment (real reuse rate calculation, transport allocation…).

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1 Introduction

The aim of Deliverable 7.2 is to use screening studies on each use-case performed in the BUDDIE-PACK project to identify environmental, economic and social hotspots of reusable plastic packaging life cycles, and assess their potential benefits compared to single-use alternatives. This Deliverable achieves Milestone 7, which aims to reach a consensus on designs and materials choices made in WP1 and 3, by communicating the screenings results with the partners throughout the screening tasks.

Section 2 gives an overview of the methodology chosen in Deliverable 7.1 for LCA and LCCA screening and full assessment studies. Any deviations from these methodological choices that are used in the screening studies, due to data availability, feasibility or inputs from other Work Packages, are then described and justified. For LCCA, generic economic data used for every use-case is also indicated.

As discussed in Deliverable 7.1, LCA and LCCA methodologies are available and sufficiently robust to perform studies on reusable plastic systems. Since SLCA is the least developed of the techniques, the screening work in this Deliverable does not resemble that performed for LCA and LCCA. Thus, the work performed on LCA and LCCA screening studies and the preparation of SLCA work for the full assessment studies are discussed separately in this Deliverable.

Section 3 is dedicated to the LCA and LCCA screening studies. For each use-case, the goal and scope of the study and Life Cycle Inventory (LCI) for reusable and single-use systems created for LCA are presented. LCCA data collection is performed using data from the LCI and price data from partners and generic databases. Results for comparative LCA and LCCA and Break-Even Point (BEP) analysis are then shown. Finally, a joint conclusion is given for LCA and LCCA discussing reusable system hotspots and corresponding guidelines and data gaps.

Section 4 presents the work carried out on SLCA. There is a need to develop the methodology, based on guidance documents studied in Deliverable 7.1. Hotspot identification of the plastics industry in a range of countries and the Corporate Social Responsibilities (CSR) policies of the project partners are analysed to select the indicators to be studied in the full assessment. Finally, the process for data collection during the full assessment is discussed and transformed into the selected performance indicators.

2 Methodology used for the screening studies

The aim of the first part of Work Package 7 was to identify the methodologies and data available for the screening LCAs, LCCAs and SLCAs, and to plan how the screening studies will answer the remaining methodological uncertainties for the full assessment phase.
In deliverable D7.1, methodological references were chosen for the LCA and LCCA screening studies and full assessment, knowing that the methodology for screening studies would vary depending on available data, and thus differ from the full assessment methodology. Here, the LCA and LCCA screening methodology chosen in deliverable D7.1 is presented and any deviations from this to adapt to the data available from the project partners are discussed.

2.1 LCA

2.1.1 Methodology chosen

The following section give a summary of the choices made in deliverable D7.1 for the LCA screening studies:

2.1.1.1 Standards and methodology chosen

The Grant Agreement of the BUDDIE-PACK project states that the Product Environmental Footprint (PEF)(1) will be applied for LCA studies. However, as discussed in Deliverable 7.1, the PEF methodology does not fully apply ISO 14044 (2) standards and does not have a packaging category rule, meaning that comparative assessments between packaging solutions made with the PEF should not be published.
On the other hand, the ADEME methodology for comparative LCAs of packaging (3) is specific to packaging environmental assessments. It follows the ISO 14044 standard, with methodological choices applying the PEF recommendations (e.g. transport allocation, CFF). However, the reference data developed by this methodology are only applicable for a French case study.
To conform to the Grant Agreement, the project will apply the PEF methodology, adding as many elements of specific packaging data and modelling rules as possible from the ADEME methodology. The aim of the screening studies is then to create a method similar to the PEFCRs (4) for packaging analyses, including methods to model reusable packaging. The screening phase will aim to identify the most relevant life cycle stages, processes and environmental impacts, as well as the data quality requirements.

2.1.1.2 Impact categories and indicators chosen

At first, all impact indicators and corresponding characterisation methods recommended by the PEF shown in Table 1 are assessed during the screening phase. The screening studies will enable a choice of most relevant indicators for packaging LCAs to see if it is aligned with the restricted choice of indicators suggested by the ADEME methodology.

Table 1: Chosen impact indicators and methods recommended by PEF (1) for the screening studies

Impact category	Indicator	Unit	Characterisation methods	Robustness
Climate change	Global Warming Potential	kg CO2 eq	Global Warming Potentials (GWP) over a 100 year time horizon (based on IPCC 2013)	I
Particulate matter	Impact on human health	disease inc.	PM model (Fantke et al., 2016 in UNEP 2016)	I

Ozone depletion	Ozone Depletion Potential	kg CFC11 eq	EDIP model based on the ODPs of the World Meteorological Organisation (WMO) over an infinite time horizon (WMO 2014 + integrations)	I
Ionizing radiations	Human exposure efficiency relative to U^{235}	kBq U^{235} eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	II
Acidification	Accumulated Exceedance (AE)	mol H+ eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Photochemical ozone formation	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as applied in ReCiPe 2008	II
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	van Oers et al., 2002 as in CML 2002 method	III
Resource use, minerals & metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	van Oers et al., 2002 as in CML 2002 method	III
Human toxicity, cancer	Comparative Toxic Unit for humans	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Human toxicity, non-cancer	Comparative Toxic Unit for humans	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems	CTUe	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Water use	User deprivation potential (deprivation weighted	m^3 deprived	Available WAter REmaining (AWARE) model (Boulay et al., 2018; UNEP 2016)	III

	water consumption)			
Land use	Soil quality index	Pt	Soil quality index based on LANCA model (De Laurentiis et al. 2019) and on the LANCA CF version 2.5 (Horn and Maier, 2018)	III

The guidelines to design the most environmentally friendly reusable packaging will be based on the results and interpretation of climate change and water use indicators as recommended by the ADEME methodology.

2.1.1.3 Interpretation of LCA results and Sensitivity analyses

The aim of the screening studies is to identify the main contributors to the environmental impacts, to feed the eco-design guidelines of WP1 and improve the performance of reusable packaging. To confirm the main contributors to the environmental impacts, sensitivity analyses may be performed using best-case/worst-case scenarios for some of the following parameters, after discussion with the use-case leaders:

- Packaging: packaging mass and content capacity;
- Freight transports: type (thermic or electric truck), distance multiplication factor from 1 to 5;
- Consumer transport, if there is one: type (thermic or electric vehicle), distance, type of allocation (volume allocation from 0% to 100%);
- Washing: consumptions, with or without a first wash by the consumer;
- Energy mix: country specific or renewable;
- End-of-life (country specific municipal scenario for plastic packaging, 100% recycled, 100% incineration, 100% landfill).

2.1.1.4 Tools and software

To conduct the LCAs, a set of documents have been created using Excel:

- Global document aiming to harmonize methodology between partners for all the LCA studies, for example End-of-Life modelling with CFF parameters, secondary data to use for materials/processes/transports/end-of-life or the impact categories chosen;
- One work document per use-case, with different tabs:
    - Iteration history;
    - Scope of the study (Functional unit, reference flows, perimeters);
    - Data collection for the single-use packaging and reusable packaging;
    - Calculations used for the single-use packaging and reusable packaging;
    - Life Cycle Inventory for the single-use packaging and reusable packaging;
    - LCA results (Comparison, Contributors, Sensitivity analyses)

The software used by all partners to perform the LCAs is Simapro v9.5 using the ecoinvent v3.9.1 database.

2.1.2 Methodological adjustments for screening studies

2.1.2.1 Secondary and tertiary packaging

In deliverable 7.1, the scope of screening studies excluded secondary and tertiary packaging production. However, one of the use-cases revealed a big contribution of this packaging, therefore it was decided to include secondary and tertiary packaging when data is already available from use-case leaders.

2.1.2.2 Freight transport allocation

As specified in deliverable 7.1, generic data with t.km allocation will be used to see the potential impact of all elementary flows. The aim of the screenings was then to develop the fuel consumption allocation formula from the PEF to add other elementary flows. Because the amount of packaging per truck was not known by use-case leaders, it was preferable to keep generic data from ecoinvent with a t.km allocation.

2.1.2.3 Consumer transport allocation

It was first indicated that the allocation formula from the PEF methodology would be used to calculate consumer transport by car to get and return the reusable packaging for B2C use-cases. However, it has been decided to change for a best case/worst case scenario comparison, the best case being a trip by foot and the worst case by car with a 100% allocation. The allocation formula is then unnecessary for screening studies.

2.1.2.4 Packaging number of rotations

The calculation formulas given by the PEF and ADEME methodologies are too elaborate to be used when the packaging is at such an immature design stage. If the use-cases' large scale demonstrations had begun during the screening phase, the first tasks performed would have focused on finding the right indicators to assess the performance of large-scale reuse cycles, e.g return rate. But no large-scale test has been performed yet so the indicators, which are needed for the formula, are not available. Therefore, the target number of uses given by the use-case leaders will be used at first and subject to a sensitivity analysis in the screening studies with the break-even point analysis.

2.1.2.5 Reuse infrastructure

Databases do not have data on relevant types of infrastructure for the reverse logistics needed to collect and treat packaging in a reuse loop, and the screening phase is not long enough to gather all necessary information at this stage. Thus, the reverse logistics infrastructure needed for reuse will not be included in the screening studies.

2.1.2.6 End-of-life (EoL) model

According to the PEF, the Circular Footprint Formula (CFF) is applied to calculate the End-of-Life benefits and burdens (Figure 1).

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

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

Figure 1: Circular Footprint Formula

where:

A: allocation factor of burdens and credits between supplier and user of recycled materials.
B: allocation factor of burdens and credits for energy recovery processes.
Q_{Sin}/Q_P and Q_{Sout}/Q_P: quality ratios between the secondary material and the primary material at the point of substitution.

R_1: proportion of material in the input to the production that has been recycled from a previous system.
R_2: proportion of the material in the product that will be recycled in a subsequent system.
R_3: proportion of the material in the product that is used for energy recovery at EoL.
$E_{recycled}$ and $E_{recyclingEoL}$: specific emissions and resources consumed arising from the recycling process of the input recycled material, and of the material at EoL.
E_V: specific emissions and resources consumed arising from virgin material production.
E^*_V: specific emissions and resources consumed arising from the production of virgin material assumed to be substituted by recyclable material.
E_{ER}: specific emissions and resources consumed arising from the energy recovery process.
$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed that would have arisen from the specific substituted energy source, heat and electricity respectively.
E_D: specific emissions and resources consumed arising from disposal of waste material.
$X_{ER,heat}$ and $X_{ER,elec}$: the efficiency of the energy recovery process for both heat and electricity.
LHV: Lower Heating Value of the material in the product that is used for energy recovery.

Q_{Sin}/Q_P and Q_{Sout}/Q_P have in reality the same value and will be further simplified by Q_S/Q_P. Same observation for $E_{recycled}$ and $E_{recyclingEoL}$ that will be simplified by $E_{recycling}$ and E_V and E^*_V simplified by E_V.
The CFF also provides default values for A, R_1, R_2, R_3 and Q_S/Q_P, where R_1, R_2, R_3 are country specific.
The screening studies used default values for A, R_1 and Q_S/Q_P, but it has been decided to base R_2 and R_3 on a best case/worst case scenario comparison, the best case being a 100% recycled packaging and the worst case a 100% incinerated packaging with a 100% allocation to the supplier. This choice aims to present the potential result variation associated with end-of-life, but it must be kept in mind that these 100% scenarios are not realistic for any type of packaging.

For a material that is 100% recycled, the CFF becomes:

$$(1-R_1)E_V + R_1 \times \left(AE_{recycling} + (1-A)E_V \times \frac{Q_S}{Q_P}\right) + (1-A) \times \left(E_{recycling} - E_V \times \frac{Q_S}{Q_P}\right)$$

For a material that is 100% incinerated, the CFF becomes:

$$(1-R_1)E_V + R_1 \times \left(AE_{recycling} + (1-A)E_V \times \frac{Q_S}{Q_P}\right) + E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}$$

All the parameters concerning process specific emissions and resources are datasets in ecoinvent, except $E_{recycling}$ that comes from literature. $X_{ER,heat}$ and $X_{ER,elec}$ values are those of the ADEME methodology. For the screenings, $E_{SE,heat}$ has been simplified from a country mix dataset to a country specific heat generated from natural gas dataset.

2.1.2.7 Calculation method

The Product Environmental Footprint (PEF) is the life cycle assessment-based methodology recommended by the European Commission to quantify the environmental impacts of products. The Environmental Footprint (EF) method provides detailed requirements on the modelling method, EF compliant data, characterisation and normalisation methods.
The calculation presented in Deliverable 7.1, was based on the EF 3.0 reference package. Since the beginning of the screening phase, the updated EF3.1 reference package, including the new IPCC characterisation factors published in 2021, has been implemented in Simapro. An analysis of changes caused by updating EF3.0 to EF3.1 characterisation factors on LCA results has been performed on a first screening to assess the criticality of changing or keeping the same method.

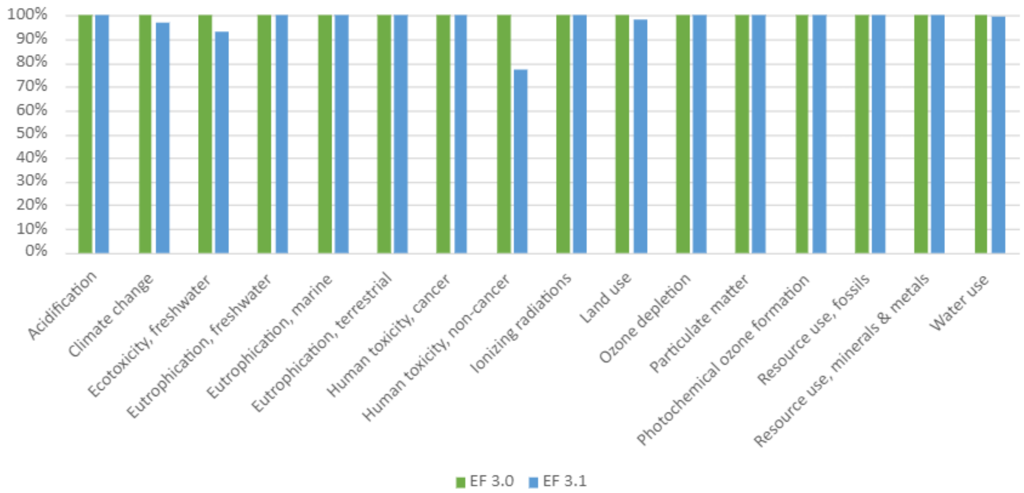


Figure 2: EF 3.0/EF 3.1 comparison on reusable packaging LCA

Figure 2 compares EF3.0 and EF3.1 results for a reusable packaging, showing a 3% decrease for Climate change, a 7% decrease for Freshwater ecotoxicity, a 22% decrease for non-carcinogenic Human toxicity and a 1% decrease for Land use. Concerning the comparison with the single-use packaging, the method change doesn't modify the conclusion, with a relative impact of the single-use packaging increasing between 1% and 5%.

The conclusions have also been compared with the ones drawn from the JRC technical report (5). Table 2 shows the impact categories for which the characterisation method has been changed in EF3.1 and how. For the six categories changed, Table 3 shows the impact of those changes on datasets LCA results.

Table 2: Updated characterisation methods in EF3.1

Impact categories	Changes brought to characterisation methods
Climate change	Updated underlying method (IPCC AR6); Bug fixing ; Missing subcompartments
Particulate matter	No change
Ozone depletion	No change
Ionizing radiations	No change
Acidification	Bug fixing; Missing subcompartments
Eutrophication, terrestrial	No change
Eutrophication, freshwater	No change
Eutrophication, marine	No change
Photochemical ozone formation	Bug fixing
Resource use, fossils	No change
Resource use, minerals & metals	No change
Human toxicity, cancer	Reduction of the number of sub-impact categories; Bug fixing
Human toxicity, non-cancer	Revision of the derivation rules; Revision of inorganic substances; Reduction of the number of sub-impact categories; Bug fixing
Ecotoxicity, freshwater	Harmonization of the calculation principles and data sources; Revision of the derivation rules; Revision of inorganic substances; Reduction of the number of sub-impact categories; Bug fixing
Water use	No change
Land use	No change

Table 3: Impact of updated characterisation methods on datasets in EF3.1

Impact categories	Datasets relative difference
Climate change	Average: 2.9% lower. 94% of datasets decrease <10%. Changes due to the lower characterisation factor of methane.
Acidification	Only increase for 6 container glass datasets (+ 8%)
Photochemical ozone formation	No difference
Human toxicity, cancer	Only increase for 13 datasets (100 <1.5%, 2 = 12%, 1 =33%)
Human toxicity, non-cancer	Average: 20% lower. 94% of datasets decrease. Changes due to chlorine and carbon monoxide CF changes.
Ecotoxicity, freshwater	Average: 10% lower. 70% of the datasets increase or decrease between 0 and 50% and 98% between 0 and 100%. Sub-categories mostly affected: "Waste incineration", "Electricity production", "Energetic raw materials", "Agricultural production means", "inorganic and organic chemicals", "Metals and semimetals", "Paper and cardboard" and "Wood production"

The report corroborates the LCA results calculated, the average change on Climate change, non-carcinogenic Human toxicity and Freshwater ecotoxicity corresponding approximately to the decrease in the comparative LCA. For the three other indicators, the report said that no changes should be visible or on a few datasets, that may not be used in the reusable packaging LCI.

The average changes given in the JRC technical report are to be expected in the screening studies presented in this report and a method change should not modify their conclusions. The decision was therefore made to keep EF3.0 for the screening studies, as one of the partners still does not have the update.

Since the full assessment finishes in 2026, it is however necessary to use the latest version of EF for that phase, otherwise results will be considered outdated.

2.1.2.8 Water consumption indicator

A discussion between partners on whether to use water consumption or water use indicators was held at the beginning of the screenings. Indeed, the Grant Agreement states that the PEF would be applied in the screening LCA task, and that a focus would be made on climate change and water consumption indicators. Yet the PEF does not use the water consumption indicator, used for example in the ReCiPe method, but the water use indicator. Water consumption is an inventory indicator, giving the total cubic metre consumed per functional unit, whereas the water use includes a notion of resource scarcity per region which is stated in cubic metre deprived. The difference between the two indicators in the results for reusable and single-use packaging are shown in Figure 3.

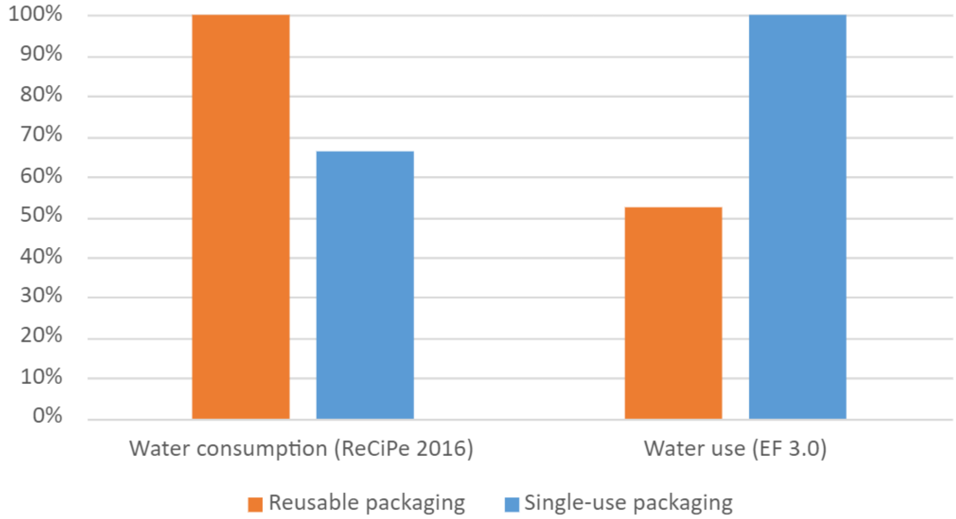


Figure 3: Water indicator impact comparative analysis between reusable and single-use packaging

The graph shows a reversal of results caused depending on the indicator considered. The conclusion is that the reusable packaging requires a bigger volume of water during its life cycle, but in countries where it is a less precious resource. It should be noted that, because of scarcity evaluation, the water use indicator has a robustness of III, meaning that it is the indicator recommended by the EF but to be applied with precaution. It is very important for this characterisation method to provide country specific water data. Water consumption does not have a robustness note from EF, because it is an inventory indicator. As the main goal is to apply the PEF, water use will be kept for the LCA screenings and in the full assessment, but water consumption may be used for one of the other tasks of the full assessment: the creation of circularity indicators as proxy for environmental impact evaluation of reusable packaging.

2.1.2.9 Impact categories chosen

As discussed in Deliverable 7.1, all the impact categories are evaluated to ascertain the contributions of process steps for each indicator. This allows for identification of hotspots. Design guidelines are given from the break-even point analyses which are performed for climate change and water consumption according to the Grant Agreement. The break-even point for fossil resource use was considered in Deliverable 7.1, but the first screenings showed a result correlation with climate change indicator, therefore this was not taken further.

2.2 LCCA

2.2.1 Methodology chosen

As described in section 3.2.2 of Deliverable 7.1, the methodology used to perform the screening is based on a collection of specific cost items that will prepare the financial analysis work. For the screening studies, the following costs are included:

- Direct costs:
  - Material procurement;
  - Energy and water consumption;
  - Ultimate waste (production loss);
  - End-of-life management (cost of landfilling or recycling).
- Indirect costs:
  - Workforce;
  - Capital expenditure;
  - Maintenance.

The idea is first to collect all direct costs related to the product production and transformation along the value chain. This is aligned with the LCA methodology and allows collection of an important part of the cost items. Then, indirect costs only related to the LCCA methodology will be collected in a second step when the perimeter will be finalized for the project (e.g., CAPEX, workforce…).

After collecting all relevant costs, the cost price per product is calculated (€/item), including all direct and indirect costs. For the CAPEX per product, the calculation is the same; the total CAPEX is divided by the annual production during the depreciation period. This gives a CAPEX distributed linearly for each product produced over the depreciation period. The cost price is given by the following equation:

$$COST\ PRICE\ = DIRECT\ COST\ + \frac{INDIRECT\ COST}{annual\ production} + \frac{CAPEX}{DP\ .\ annual\ production}$$

DP: Depreciation period

For each use-case, the cost related to the two different scenarios (SUPP/RPP) follows the steps described in Figure 4. In this methodology, the SUPP is considered as a baseline and is commercially available. We considered that the TRL of the SUPP is TRL9. For the RPP value chain, depending on the use-cases, commercial or products under development will be used. Hence, the TRL level of the RPP solutions will vary and has to be considered case by case.

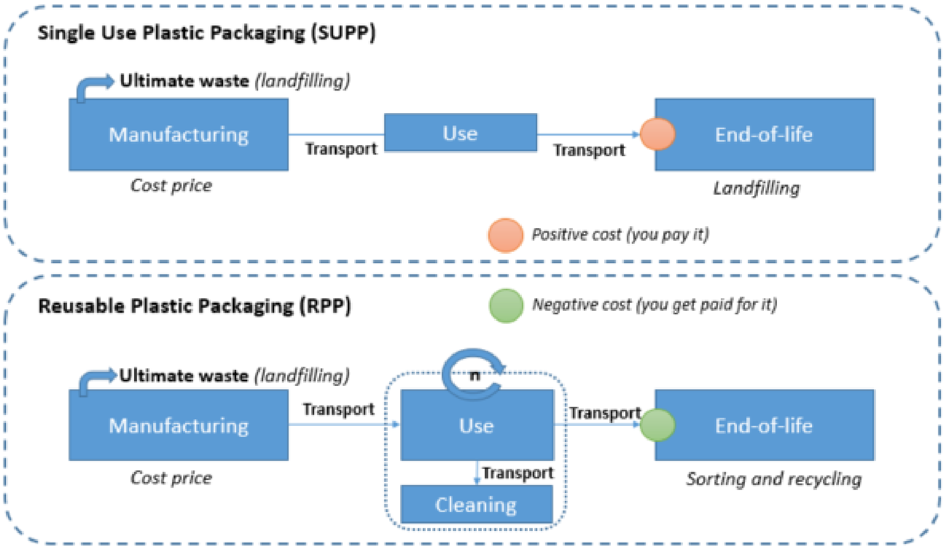


Figure 4: Schematic description of the different steps for the cost calculation of the SUPP/RPP scenarios

For each step, inventory items were collected from the LCA. For the RPP, the product waste will be recycled within regular waste streams such as PE, PP, steel, etc. The EoL step is therefore a negative cost as the recycling step will create value to the global value chain. The value of the main EoL streams are given in Table 4. Energy and water consumption together with waste generated from material loss and material consumption were considered with their market prices. Transportation costs were calculated using the distance identified in the LCI and converted into cost using Table 5.
Concerning raw material, in this study, most of the products are purchased at market prices. Then, the cost of the raw material is included in the purchase price. In the case that the packaging is manufactured by the partners, the average cost for the virgin material was given by the partners (to limit the risk of giving up sensitive information).

Table 4: Average selling prices for plastic and steel waste. Source: Recyclage Récupération (7)

Material	Market price of the recycled material (January 2024)
PP	680€/t
PE	920€/t
Paper & Cardboard	310€/t
Steel	950€/t

It is important to note that, for several scenarios, the cost price is not accessible, mainly because the partners are not plastic converters but rather retailers. The use of market purchase price is then used (the price at which the partners buy the products). This cost integrates all costs from prior steps (transformation and material procurement) as well as commercial margin. Hence, we can only compare use-cases that use similar metrics (cost price or purchase cost).

2.2.1.1 Calculation of the break-even point

The break-even point is given by the number of use cycles (n) when the cost of RPP products is equal to the cost of SUPP products. This point is calculated by solving the following equation:

$$a \,.\, n = a' \,.\, n + b'$$

Where *a* is equal to the cost of SUPP product, *a'* is the variable cost of RPP product that correspond to the cost of cleaning and *b'* the fixed cost of RPP that corresponds to the cost of the reusable product itself, n being the number of cleaning/use iterations.

2.2.2 Methodological adjustments for screening studies

For the screening, the direct and indirect costs considered as generic are presented in Table 5 and are used for all LCCA work. This allows comparison of each use-case on the same cost basis. For simplicity and homogeneity reasons, the costs are taken as French market prices. Other national markets could be studied within the task of WP4 if need be. Considering EoL, when not specified otherwise, French average landfilling cost is considered for landfill cost.

Table 5: Description of the generic cost items for the LCC studies

Item	Value	Unit	Source
Electricity	0.18	€/kW.h	EDF, 2023, https://www.edf.fr/sites/entreprise/files/2023-07/fiche_cre_tarif_bleu_non_residentiel_aout_2023.pdf
Heat	0.022	€/MJ	Enquête sur le prix de vente de la chaleur et du froid en 2020, AMORCE, Série économique Réf. AMORCE RCE 38 Février 2022
Water	4	€/m³	Eau France, 2021, https://www.eaufrance.fr/le-prix-de-leau
Workforce (technician)	24.2	€/h	Internal source
Workforce (worker)	17.5	€/h	Internal source
40t truck exploitation cost (25t payload)	166.73 6.6692	€/100km €/(100km.t)	Cadre de référence - ACV comparatives entre différentes solutions d'emballages, ADEME, 2022 https://www.europe-camions.com/news/oil-price https://www.cnr.fr/prix-revient/9 Garcia-Gutierrez, et al., 2023, JRC technical report: Environmental and economic assessment of plastic waste recycling. comparison of mechanical, physical, chemical recycling and energy recovery of plastic waste JRC Publications Repository - Environmental and economic assessment of plastic waste recycling (europa.eu)
Private car kilometric cost (state tax)	0.529	€/km	Service public France, 2023 https://www.service-public.fr/particuliers/actualites/A14686
Cost for landfilling	150	€/t	Impot.gouv 2019: BOI-BAREME-000039 - BAREME - TCA - Taxe générale sur les activité polluantes | bofip.impots.gouv.fr WRAP, Gate Fees 2018/19 Report, Comparing the costs of alternative waste treatment options

2.2.3 Alignment with WP4

WP4 investigates sustainable business-driven strategies. Within T4.1, the project partners will perform the cost-benefit analysis throughout the cycle of reusability to ensure profitability. They will ultimately identify the best drivers to improve profitability. Hence, within WP4, the analysis of the economic performance of the different solutions will be studied.

For WP7, the cost related to the manufacture, transport, cleaning and end of life will be collected in the LCA /LCC tasks and will serve as a basis for the economic performance assessment that will be carried out in WP4.

Breakeven point in this LCC task are calculated to highlight the costs that are collected, but no analysis of the economic performance is reported in this deliverable.

2.2.4 Limitation of the LCCA and link with the full circularity assessment

The LCCA screening as described before is a collection of costs along the product value chain. It only describes the cost incurred by the product for several uses.
Several external costs related to the global business model will then be taken into account later in the full circularity assessment, such as:

- % products returns = % of packaging product that returns after use
- % of defects during cycles = % of packaging product discarded after a cycle due to non-quality (according to aging protocol).

3 Screening studies

3.1 Vytal use-case: Take-away food container

3.1.1 Goal and scope of the study

The aim of this life cycle assessment is to assess the cradle-to-grave environmental impacts of a reusable takeaway food container, compared to the single-use baseline. After impact assessment, a break-even point (BEP) is evaluated for the system to identify the minimum number of uses for a reusable container to be considered preferable to a disposable container.

For this use-case, the reusable container and lid considered are made from polypropylene. The single-use container is a corrugated paper box with a PET window and lining (Table 6).

The chosen functional unit is: "the use of a container that can hold 1250 ml of takeaway food in one go from a restaurant to home in Berlin, Germany".

The corresponding reference flows are:

- One use of the reusable container (used 20 times);
- One disposable container.

Table 6: Average weight of the reusable and disposable containers (1250 ml).

Samples	Packaging unit	Material	Weight (g)
	Reusable bowl + lid	PP	182
	Disposable container + lid	Corrugated paper box, PET	32

Figures 5 and 6 depict a generic system boundary diagram for the reuse and disposable containers. The system consists of four stages: production and manufacturing, consumption (use phase), waste collection and waste treatment (End-of-life).

Assumptions:

- For this LCA screening, we did not consider secondary packaging and labelling as they are not expected to contribute significantly to the environmental impacts. They will, however, be included in the full LCA.
- Recycling and energy recovery (incineration) were considered as EOL for reusable and single-use packaging respectively. For the reusable packaging (Vytal bowl), recycling was selected based on data from Vytal. Energy recovery was selected for the EOL of the single-use packaging, based on the Many Happy Return project. The single-use packaging (cardboard box with PET window) goes into mixed waste and is taken to an energy recovery plant.
- Two scenarios are assumed for customer transportation: the customer uses their car only to get food from the takeaway (i.e. the journey is just for the purpose of collecting the takeaway – this is the worst-case scenario) or they walk to take their food home (best-case scenario). We will study real scenarios in the full LCA study.

For the washing phase for the reusable packing, data was taken from the Many Happy Returns (MHR) project, assuming the same commercial dishwasher is used in takeaways in Germany.

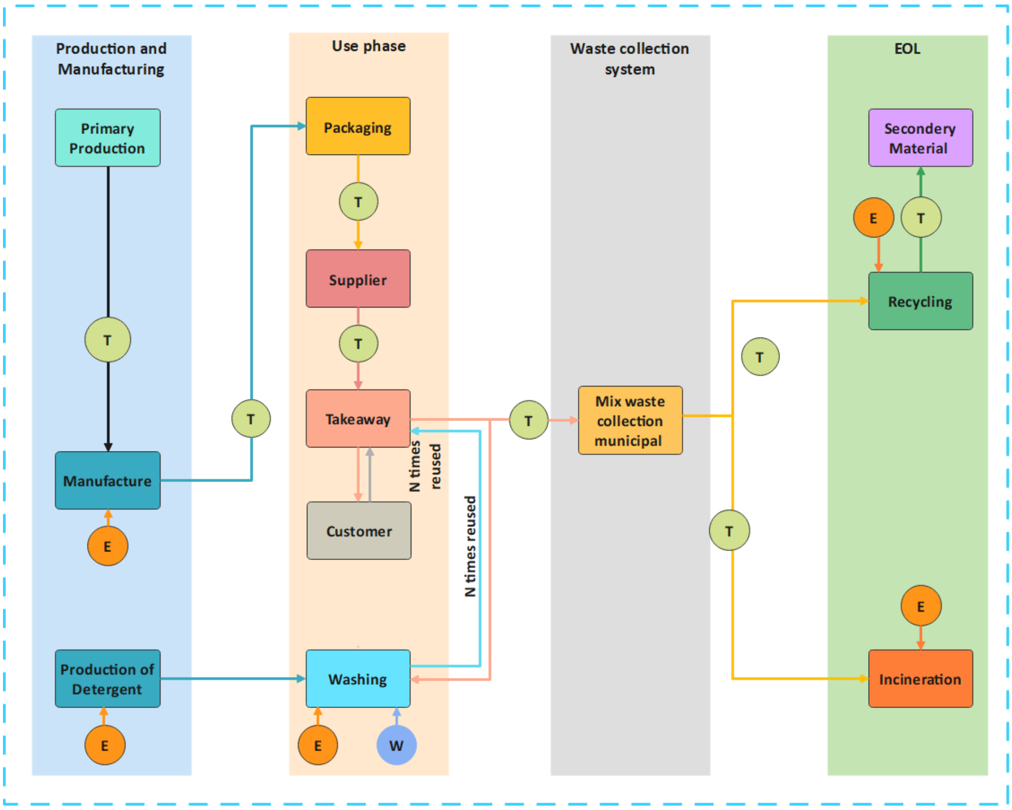


Figure 5: System boundary for life cycle assessment of a reusable container. Products, processes and locations are shown, with major transport (T), energy (E) and water (W) inputs highlighted.

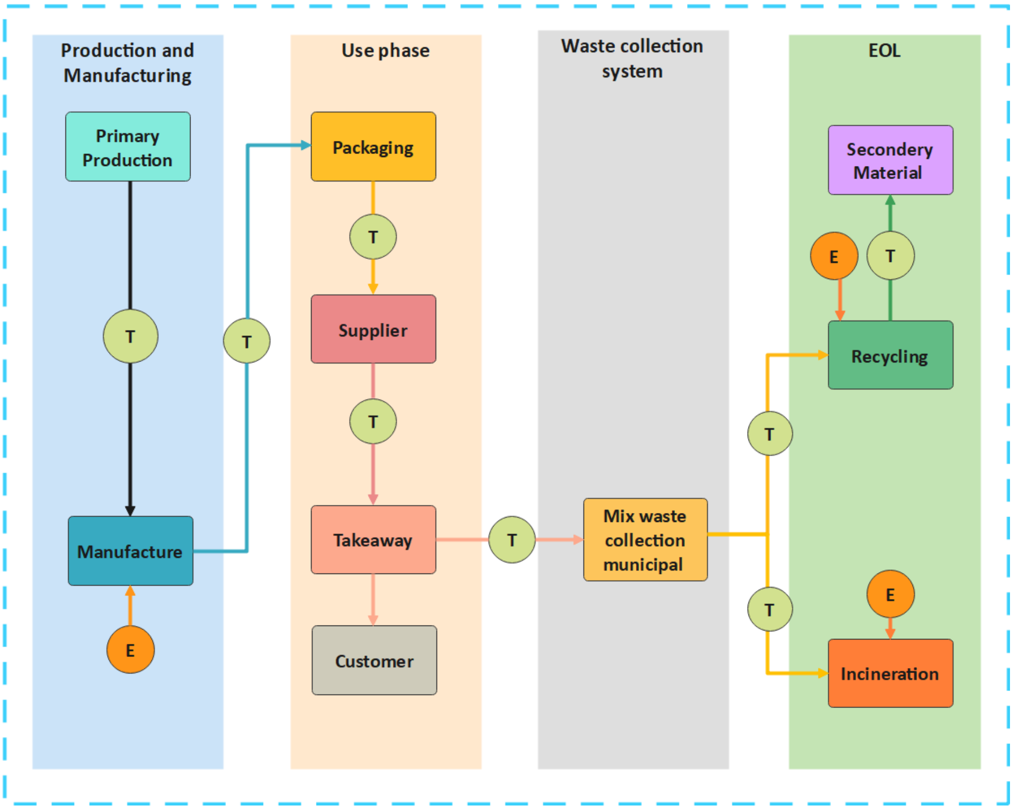


Figure 6: System boundary for life cycle assessment of a disposable single-use container. Products, processes and locations are shown, with major transport (T), energy (E) and water (W) inputs highlighted.

Raw materials are produced, then converted into the container (production and manufacturing phase in Figure 5 and Figure 6). Manufactured containers are then transported to a packaging supplier. Secondary packaging for the bulk transport of containers is not included in LCA screening calculations. The containers are purchased from a supplier by takeaways in Berlin to distribute to restaurants around the city. They are stored at the restaurants and enter a loop, where they are filled, then taken by customers, then back to the restaurants to be washed and stored, ready for reuse. Washing of reusable containers takes place on site at the takeaway. Therefore, there is no transport contribution for the washing stage. After the lifespan of containers, they are collected as municipal waste before entering the waste treatment stage, which could be recycling or incineration.

For consumer transportation between takeaways and their home, two scenarios are assumed: walk (to have no energy consumption or environmental impacts attached to it) or transport by car for a distance of 1 km. Additional packaging for ordering takeaway food is not included in the screening study, since it is assumed that such packaging would be required regardless of the takeaway container used.

3.1.2 Life Cycle Inventory (LCI)

The life cycle inventory is given in Table 7 to Table 10. Inventory data was taken from various primary sources, with some general manufacturing process information being modelled based on the Ecoinvent 3.9. database. For each container, the main manufacturing processes were applied using representative processes from the Ecoinvent 3.9 database in SimaPro. These processes were modified if necessary to represent the correct country of manufacture. For the washing stage, the required water and energy are included in the analysis, however the treatment of wastewater produced during the washing is not considered. For washing, a small commercial dishwasher was chosen which required 1.4 to 3.6 litres of cold water and 0.232 kWh electricity per cycle. It is assumed that the whole volume of each cycle is allocated to 9 containers.

The default cut-off approach is used in the model, with the Circular Footprint Formula (CFF) approach used to model the end-of-life. Avoided products of recycling (material) and/or incineration (heat and electricity) are credited to the system.

The reference scenario for reusable container uses a weight of 182 g, customer transportation by foot and recycling as end-of-life. Sensitivity analysis varying the weight, EoL, energy for the dishwasher and mode of customer transportation were carried out. The reference scenario for the single-use container includes energy recovery as the EoL and container weight of 32 g.

Table 7: Life cycle inventory for production and manufacturing single-use and reusable containers.

Activity	Primary production (Material)						Manufacturing			
	Material		Mass (g)	Recycled content (%)	Country of origin	Model in SimaPro	Process	Country	Loss rate (%)	Model in SimaPro
Reusable container	PP		182	0	Belgium	Polypropylene, granulate {RER}| production | Cut-off, U	Injection molding	Germany	0.6%	Injection moulding {RER}| processing | Cut-off, U
Single-use container	Card-board box	Paper	25.5	0	Germany	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	Corrugated board box production	Germany	1%	Corrugated board box {RER}| market for corrugated board box | Cut-off, U
	Lining and window	PET	6.5	0	Greece	Polyethylene terephthalate, granulate, amorphous	Extrusion	Germany	2.4%	Polyethylene terephthalate, granulate, amorphous

						{RER}| production | Cut-off, U				{RER}| production | Cut-off, U

Table 8: Life cycle inventory for transportation of single-use and reusable containers.

Activity	Transportation					
	Name	Type	Distance (km)	Departure region	Arrival region	Model in SimaPro
Reusable container	Primary material for lid to manufacturing	Road	250	Lichtenfels, Germany	Erbach, Germnay	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Primary material for bowl to manufacturing	Road	700	Belgium	Erbach, Germnay	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	from manufactur to Central warehouse	Road	270	Erbach, Germnay	Vitalisstraße, Köln	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	centeral warehouse to Takeaway, Berlin	Road	580	Vitalisstraße, Köln	Berlin	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Takeaway to customer	Road	1	Berlin	Berlin	Transport, passenger car, EURO 5 {RER}| market for | Cut-off, U
	customer to takeaway		1	Berlin	Berlin	Transport, passenger car, EURO 5 {RER}| market for | Cut-off, U
	takeaway to Recycling, facility, ARBITRAGE PLASTIK RECYCLING SOLUTION		630	Berlin	Cologne	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
Single-use container	Polisan Hellas, PET production	Road	2260	Greece	Germany	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Huhtamaki manufacturer	Road	0	Germany	Germany	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Warehouse in Berlin	Road	690	Bullay,Germany	Berlin, Germany	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Takeaway	Road	15	Berlin, Germany	Berlin, Germany	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Takeaway to EEW Energy from Waste Premnitz GmbH	Road	117	Berlin, Germany	Premnitz, Germany	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U

Table 9: Life cycle inventory for washing use (use phase for reusable container)

Dishwasher type	Commercial dishwasher (on site)	Model in SimaPro
Water use per wash (litres)	2.493	
Energy use per wash (kWh)	0.2313	
Reuse container allocation of total dishes in each basket of washing (%)	100 (9 reusable containers are fitted in per basket)	
Water use per reusable container (litres)	0.277	Tap water {RER}| market group for tap water | Cut-off, U

Energy use per reusable container (kWh)	0.0257	Electricity, high voltage {DE}| market for electricity, high voltage | Cut-off, U
Detergent use per reusable container (g)	0.693	Polycarboxylates, 40% active substance {RER}| polycarboxylates production, 40% active substance | Cut-off, U

Table 10: Life cycle inventory for End-of-Life scenarios

Activity	End-of-life scenario	Model in SimaPro	
Reusable container	Recycling (100%)	Input process	Recycling of PP based on Franklin, 2018. (6)
		Avoided product	Polypropylene, granulate {RoW}| polypropylene production, granulate | Cut-off, U
Single-use container	Incineration (energy recovery) (100%)	Input process	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration | Cut-off, U
		Avoided product	Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U
			Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U

3.1.3 LCA Results and Sensitivity Analyses

3.1.3.1 Analysis of contributors

Results of the impact categories assessed are shown in Figure 7 and Figure 8 for one and twenty uses of the reusable container respectively, according to the reference scenario. The materials phase represents the biggest contribution to most of environmental indicators except for land use, freshwater ecotoxicity, freshwater eutrophication, ozone depletion and Ionizing radiation. For one use (one washing), the washing phase represents the lowest impact for most of environmental indicators. However, for twenty uses, this phase shows significant effect on environmental impacts. The washing phase has significative impacts on the Break-Even-Point (BEP) due to the water used and energy use.

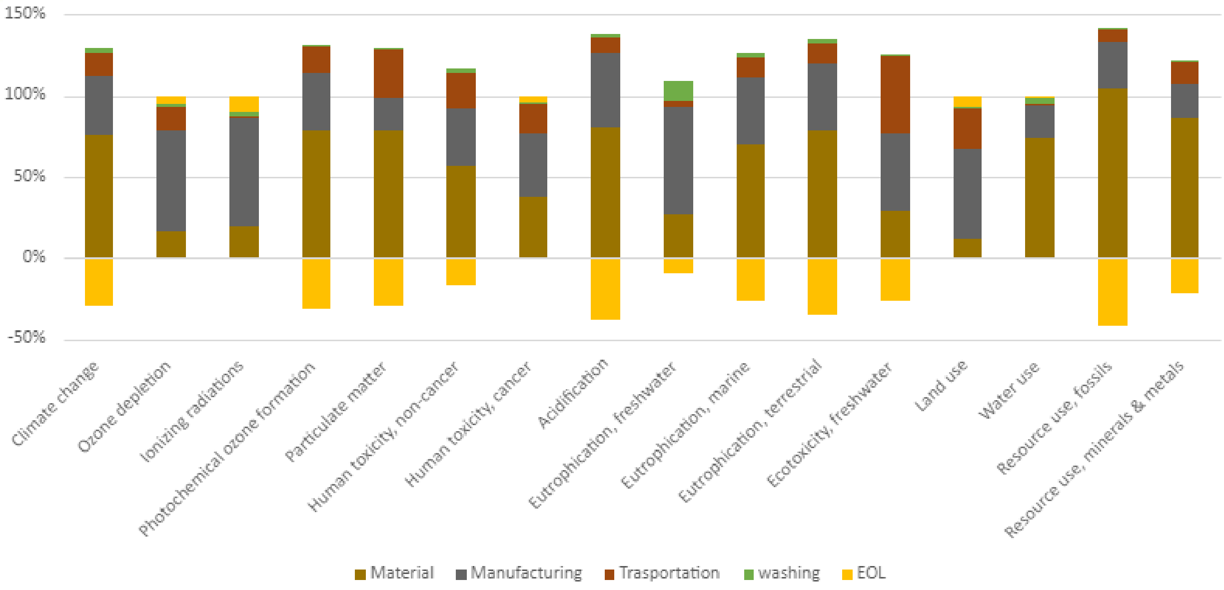


Figure 7: All environmental impacts categories based on the EF 3.0 model for one use of the reusable container.

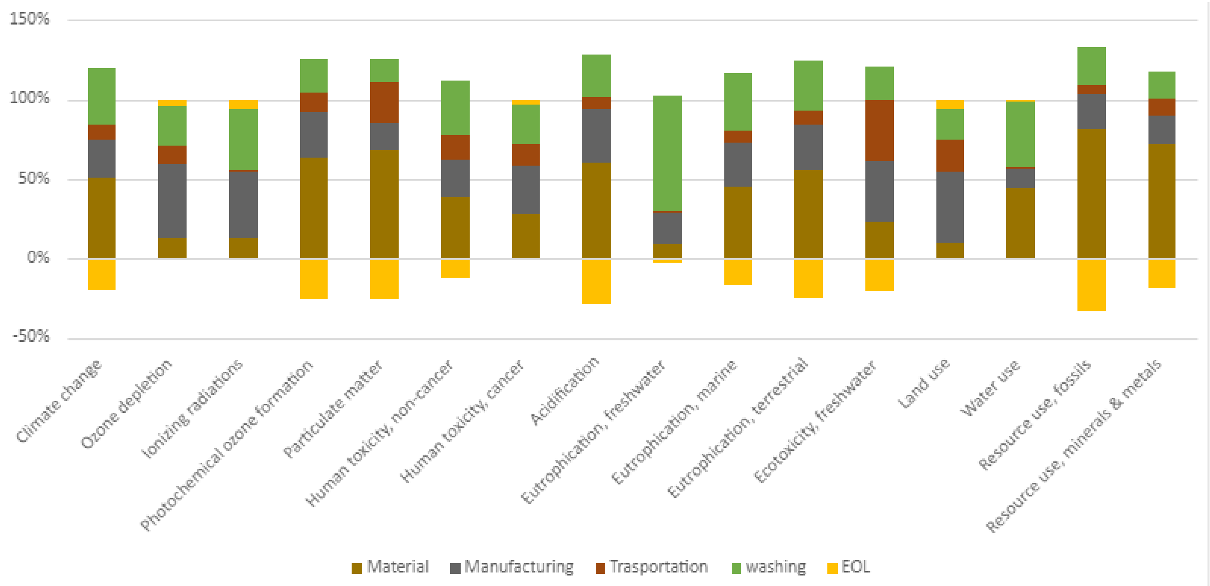


Figure 8: All environmental impacts categories based on the EF 3.0 model for 20 uses of reusable container.

Figure 9 shows the impact of the of the EoL scenarios on climate change and water usage, for a total of 20 takeaways (i.e. 20 single-use containers or one reusable container used 20 times). The reusable container showed 13% lower climate change impact than the single-use container with recycling as the end-of-life scenario. The negative end-of-life climate change impact for the single-use container is ascribed to the type of carbon embedded in the single-use container (biogenic carbon) and the avoided emissions associated with energy recovery. If the reusable container is burned to recover energy at end-of-life, the climate change impact is 0.842 kg CO_2 eq which is 4% higher than the single-use counterpart (0.8077 kg CO_2 eq). The EoL phase can therefore significantly change the climate change impact. The reusable container shows approximately 8% higher water usage than the single-use counterpart assuming energy recovery at EoL. A move to recycling the reusable container increases water usage by 25%, which is still higher than for a single-use container.

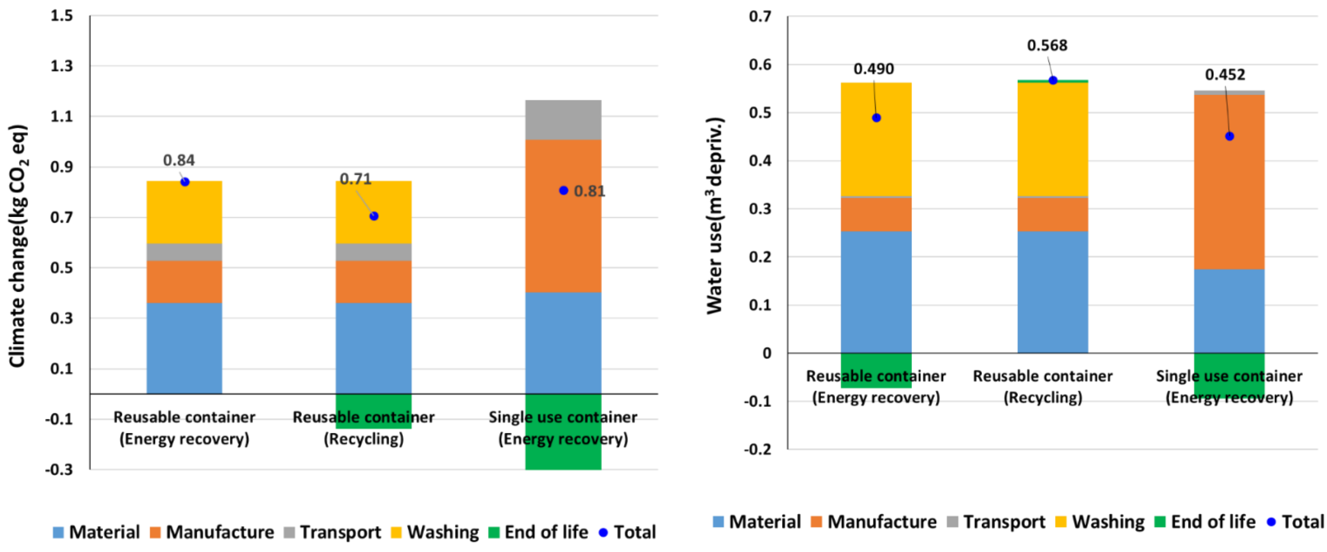


Figure 9: Climate change and water use for 20 takeaways (i.e. 20 single-use containers and 1 reusable container used 20 times) evaluating different EoL scenarios.

3.1.3.2 Sensitivity analysis on Break-Even Point

The minimum number of uses after which a reusable product is environmentally better than the single-use equivalent can be expressed with the break-even point (BEP). The lowest BEP is targeted to achieve best environmental performance of a reuse scheme. BEP was calculated for different scenarios of container weight, energy type for the washing phase, EoL scenario, mode of customer transportation and reusable container material.

3.1.3.2.1 Container mass

As the reusable container design may change during the project, to try to make it less material intensive, it is interesting to see the impact of weight change on the BEP to help WP1 choose the best combination of mechanically attainable yet with low environmental impact. To do so, the baseline scenario of a 180 g container is compared to a 40 g, 80 g, 120g and 160 g container scenario.
Figure 10 shows that the container weight has a significant impact on the BEP for climate change impact. The BEP shows significant reduction from 17 to 4 uses (76% reduction) when the weight of the reusable container decreases from 182 g to 40 g (78% mass reduction). Note that the viability and durability of such a lightweight container would need to be investigated, these results merely indicate the climate change impact that could be achieved if such a lightweight container can be used sufficient times.
Taking the reusable container from 182 g to 40 g (78% mass reduction) also reduces the BEP for water use by 78% (from 32 to 7 uses). By reducing the water required for the material production, manufacturing and EoL phases, the BEP for water use is reduced.

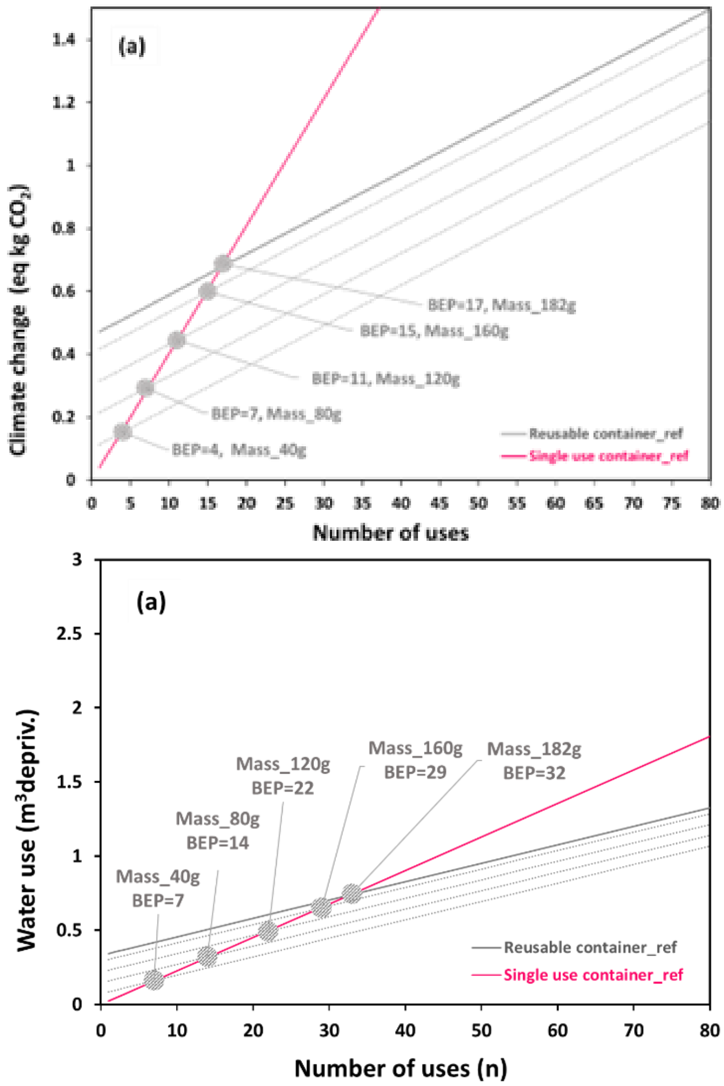


Figure 10: Climate change & Water use BEP evolution depending on container mass

3.1.3.2.2 Washing energy mix

For this sensitivity analysis, renewable (wind, hydro and solar) energies are considered as the source of electricity in the washing phase of reusable containers instead of the national energy mix,

As it can be seen Figure 11, moving to renewable electricity for washing reduces the BEP for Climate change from 17 to 12 uses for wind and hydro energies or 13 uses for solar energy.

For Water use, the BEP is not significantly changed when shifting to hydro or wind energies. However, the BEP increases from 32 to 41 uses by moving from grid energy to solar energy for washing phase. This is due to the water used in the production of solar panels.

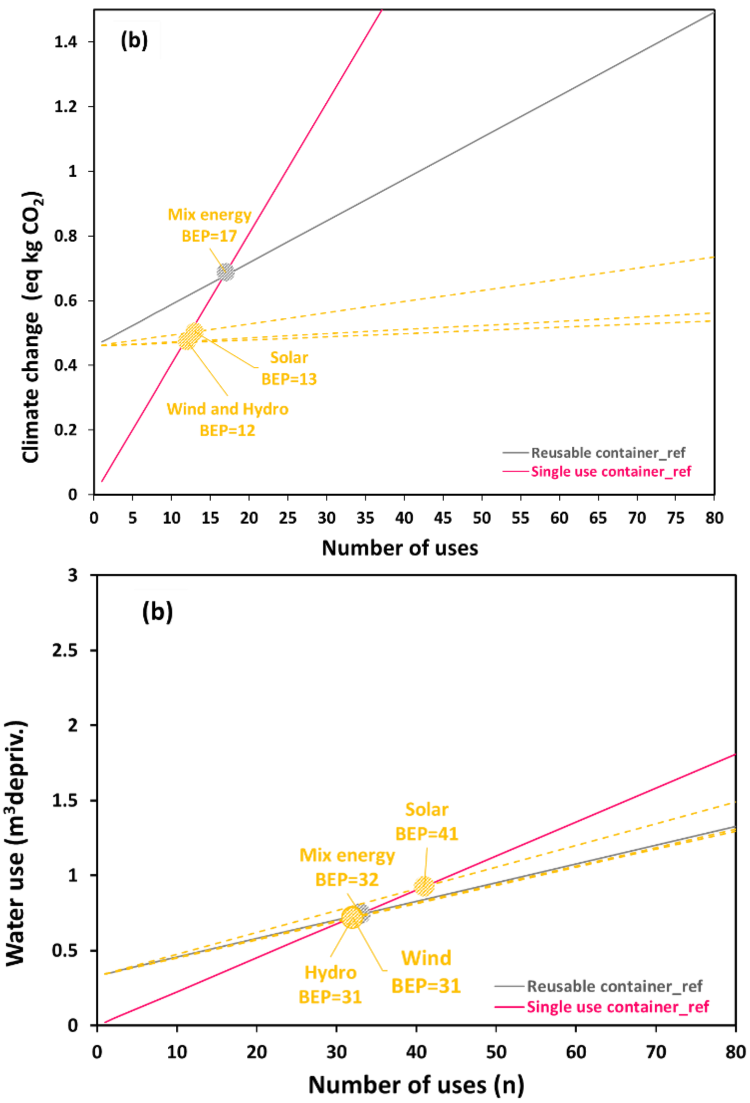
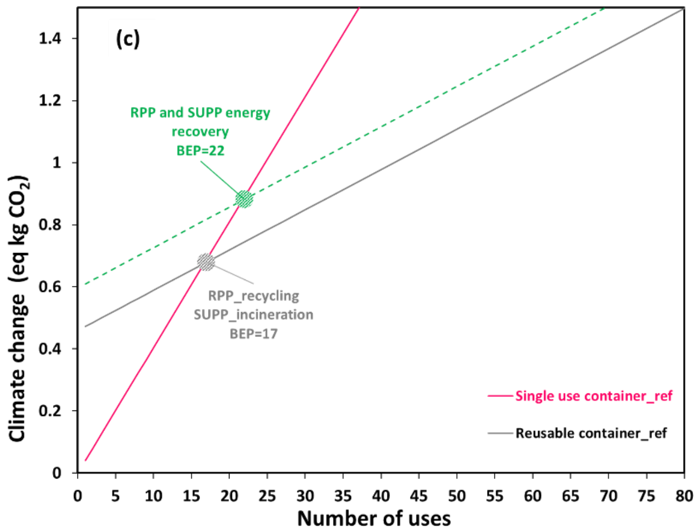


Figure 11: Climate change & Water use BEP evolution depending on washing energy mix

3.1.3.2.3 End-of-Life scenario

The baseline EoL scenario considered is a 100% recycling rate as it has been stated in the methodology that extreme scenarios will be analysed. It is compared with a 100% incineration with energy recovery scenario.

The results are shown Figure 12. When the reusable container is incinerated rather than recycled, the BEP on Climate change shifts from 22 to 17 uses, assuming the single-use container is still incinerated. For Water use, the BEP is 22% lower with energy recovery (25 uses) compared to recycling (32 uses) as more water is needed for recycling than for incineration with energy recovery.



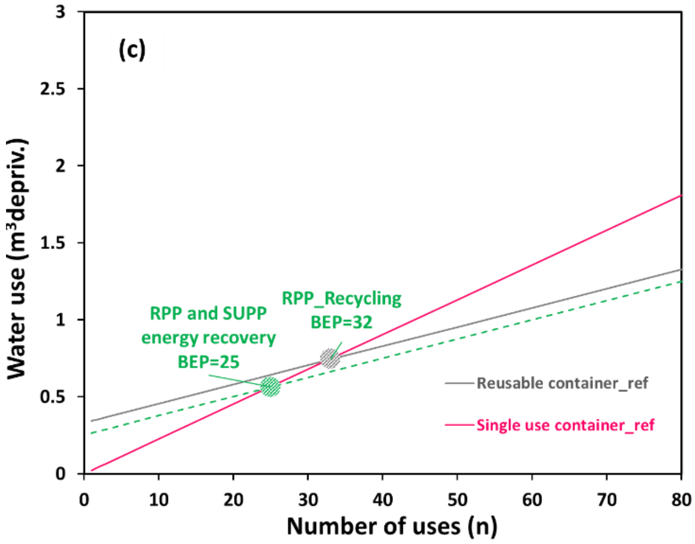


Figure 12: Climate change & Water use BEP evolution depending on container EoL scenario

3.1.3.2.4 Consumer transportation

Two scenarios for customer transportation were considered:

- transportation on foot was defined as the reference scenario;
- the customer goes to a restaurant to collect the takeaway food and drives a distance of 1km home in a car is considered for the second scenario. For allocation, the whole impact of passenger transportation is attributed to the transportation of reusable container.

The BEP for climate change and an overview of all environmental impacts for these two scenarios are shown in Figure 13. The BEP for transportation by car is 42 uses; this is 60% higher than transportation by foot. This significant difference between BEP for customer transportation is due to attribution of 100% of passenger transport to the reusable container.

Transportation by car shows higher impacts on all categories than transportation on foot. For ionizing radiation and water use the difference is not significant.

The way the customer takes the takeaway home is therefore very important.

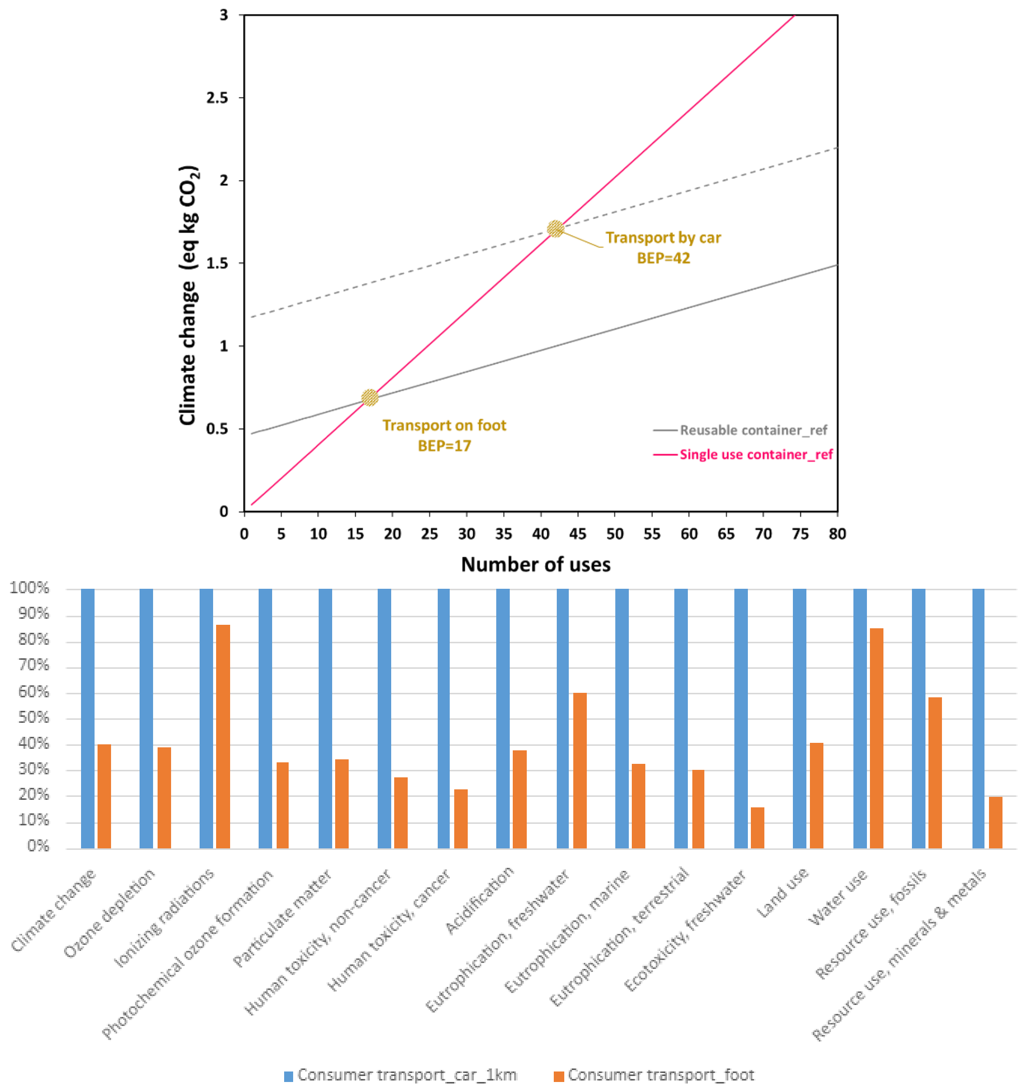


Figure 13: Effect of customer transportation on BEP for climate change and environmental impacts categories for reusable container (for 1 use).

Figure 14 shows a comparison of the climate change impacts for 20 takeaways (i.e. the use of 20 single-use containers or one reusable container used 20 times) with different modes of customer transportation for reusable container. Climate change impact increases by 90% if customers use car for takeaway food in reusable container.

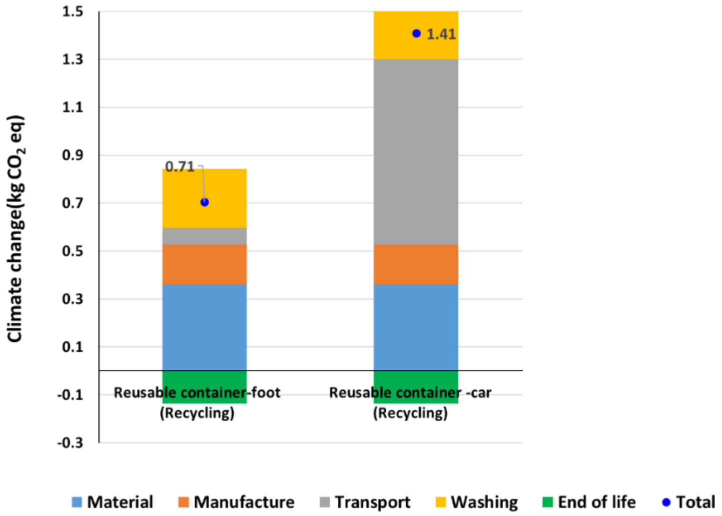


Figure 14: Climate change due to reusable containers used 20 cycles with different customer transportation scenarios.

3.1.3.2.5 Reusable container material

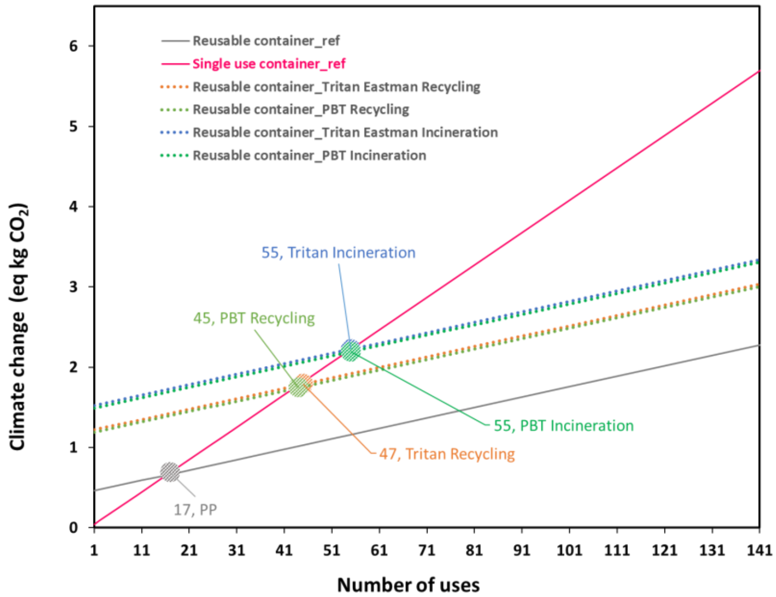
PBT and Tritan are being considered as alternative materials to PP. The Global Warming Potential for the production of 1 kg of each of these materials is given below:

- PP: 2.4 kg CO_2e/kg
- PBT: 3.6 kg CO_2e/kg (European data), 4.8 kg CO_2e/kg (global)
- Tritan: 4.8 kg CO_2e/kg

In addition to the 182 g PP bowl, two alternatives were considered:

1. A bowl made from Tritan weighing 215 g
2. A 222 g PBT bowl with an 84 g PP lid

Figure 15 shows the break-even points for the different containers. The Tritan and PBT containers need to be used almost 3 times as many times than the PP container to break-even on climate change. Considering water use this is even greater, as almost 4 times as many uses are required.



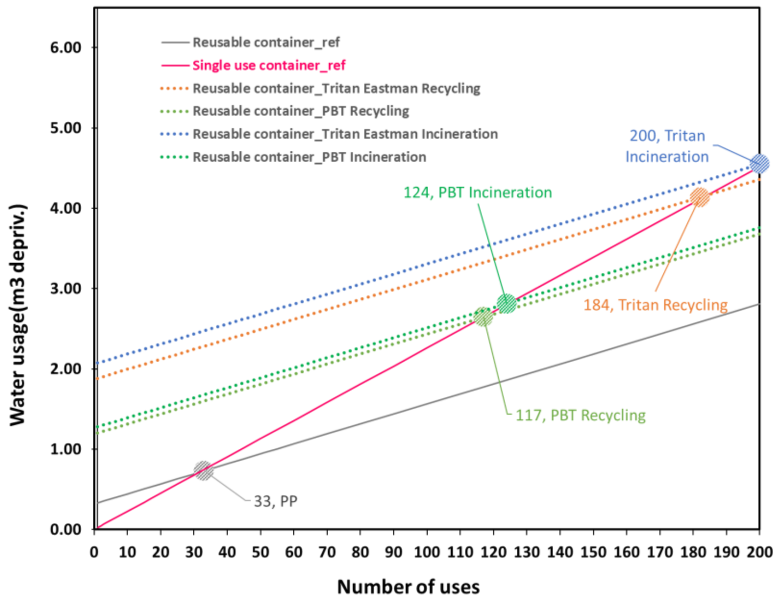


Figure 15: Break-even points when considering different container designs and materials in the Vytal use-case (PP bowl 182 g, Tritan bowl 215 g, PBT bowl 222 g with 84 g PP lid).

Figure 16 shows the GWP of the three types of container. PET recycling is used to estimate the end-of-life recycling of Tritan and PBT as no operational data exists. Note that Tritan is highly unlikely to be recycled due to its material structure and the lack of processing facilities. The incineration bars therefore represent a more likely end-of-life scenario. As expected, the GWP of the PP bowl is lower than that of the Tritan and PBT.

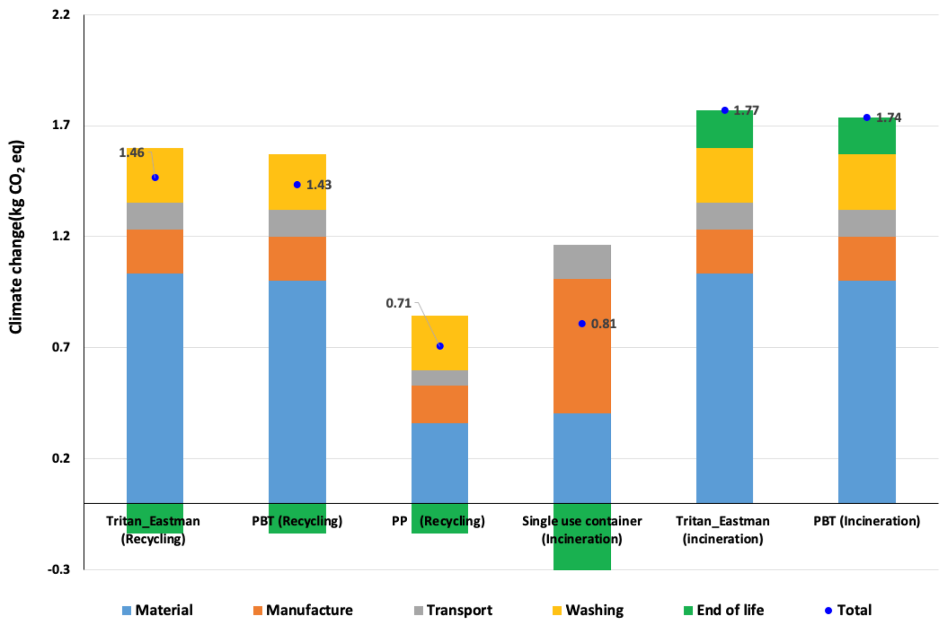


Figure 16: Comparative contributor analysis on Climate change

Note that this analysis assumes all the reusable bowls are used the same number of times. Operational data on the durability of materials will be needed for the full LCA study.

3.1.4 LCCA

Figure 17 shows the different steps of the value chain that are integrated in the LCC study for the Vytal use-case. Market purchase prices are used to describe the cost of the product used in both SUPP and RPP scenario. Indeed, the partners involved in this use-case do not transform the material but purchase it ready to be used.

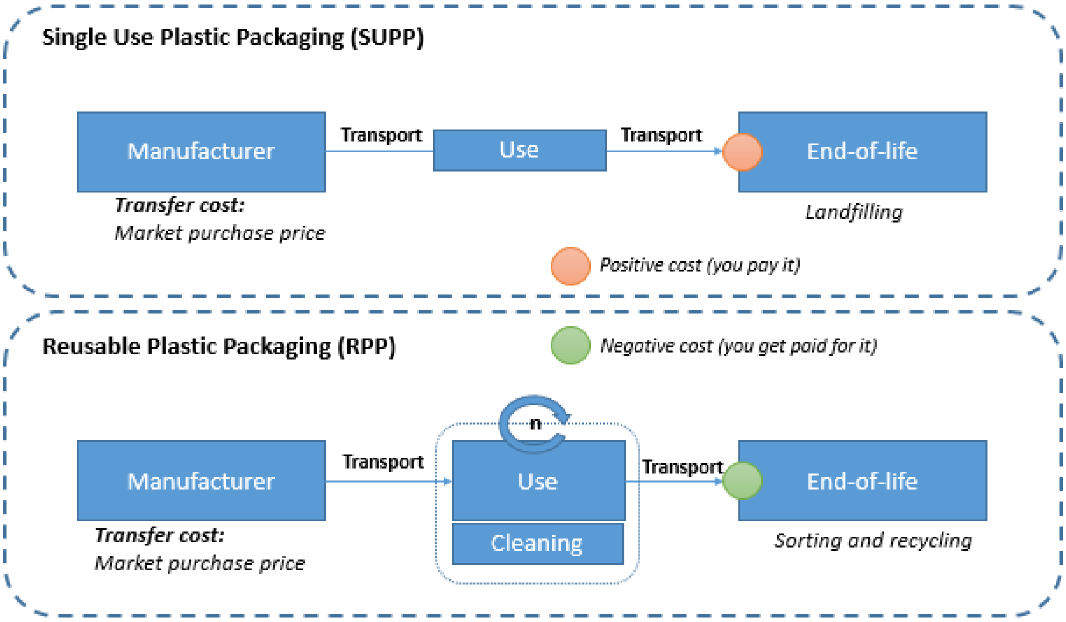


Figure 17: Schematic representation of the LCC analysis performed for the Vytal use-case

3.1.4.1 Direct cost for RPP

For the Vytal's use-case, the costs for the RPP scenario are described in Table 11. The RPP solution is designed for 20 reuse cycles. The EoL cost of PP is 680 €/t. The purchase cost of the 1250ml Bowl is 3.14 €.

Table 11: Cost screening for Vytal's use-case RPP scenario

LCC		
Targeted reuse cycles	20	
Purchase price	3.140 €	per item
Transport	0.018 €	per item
EoL	-0.125 €	per item
Cleaning (OPEX +CAPEX per product)	0.213 €	per cycle
Transport for cleaning	0 €	per cycle
Total fixed	3.034 €	per item
Total variable	0.213 €	per cycle

Hence, total cost of the VYTAL RPP solution is (3.034+ n * 0.213) €/item.

3.1.4.2 Direct cost for SUPP

For the Vytal's use-case, the costs for the SUPP scenario are detailed in Table 12. Those costs are market purchase price. A 1200 ml takeaway food box, similar to that analysed in the LCA, was chosen at a price of 0.41€ per item (8).

Table 12: Cost screening for Vytal's use-case SUPP scenario

LCC		
Purchase price)	0.410 €	per item
Transport	0.002 €	per item
EoL	0.005 €	per item
Total	0.417 €	per item

Hence, total cost of the SUPP solution is 0.417 €/item.

3.1.4.3 Break-even point

According to Figure 18, the break-even point for cost is 15 uses. This breakeven point only considered the cost of the different packaging, their transport, the cleaning step and EoL. This very simple model gives us a first indication if the target number of uses of the RPP is attainable.

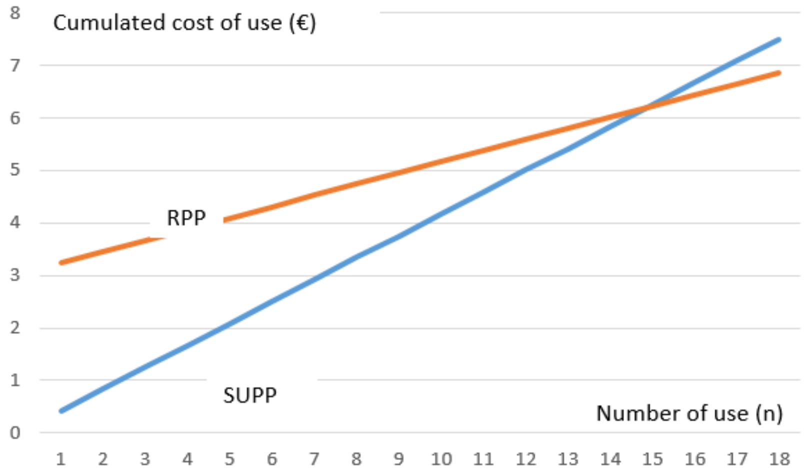


Figure 18: Break-even point analysis for cost for the Vytal's use-case

3.1.5 Conclusion on hotspots and design guidelines

The main hotspots identified in this screening study for climate change, water use and total cost of the reusable packaging are:

- Primary material – both the choice of material and the weight of the container have significant impact;
- Washing phase – the source of electricity used is important;
- Transportation - climate change and total cost rise if the customer gets the take-away meal by car;
- End-of-Life - recycling improves the climate change impact and total cost, whereas incineration with energy recovery improves water use.

The corresponding guidelines are :

- Reduce the mass of the packaging whilst retaining durability and functionality;
- Reduce the energy consumption of the washing phase, and use as much renewable energy as possible;

- Carry out a precise analysis of consumer behaviour to encourage people to get the food by foot;
- Choose a material for the packaging that is recyclable.

3.1.6 Data gaps

Regarding the Vytal reusable container, more precise data on the washing phase and end-of-life scenario are needed. The real word scenario for EoL is needed for the chosen reusable container. The real world scenario for customer transportation is difficult to predict because it depends on people and evolves rapidly.

Data missing for the LCCA screening:

- For the RPP test-case:
    - The cleaning steps direct and indirect costs

3.2 Asevi and Smurfit Kappa use-cases: refillable system for laundry detergent

3.2.1 Goal and scope of the study

The objective of this life cycle assessment is to evaluate the environmental impacts from cradle-to-grave of a reusable laundry detergent system in comparison to a single-use baseline. The assessment aims to identify the primary contributors influencing the environmental impact of the reusable system. Additionally, a break-even point (BEP) analysis is conducted, exploring various modifications to the system to determine the minimum number of uses required for the reusable system to be considered more favourable than the disposable one.

This use-case is a two-part reuse system resulting from a partnership between ASEVI and Smurfit Kappa: a detergent bottle and a bag-in-box (BiB). The BiB, produced by Smurfit Kappa, allows for the storage of 10-liters of detergent. The stored detergent is then used to fill a reusable bottle produced by ASEVI with a volume of 1 litre. The single-use baseline of this system is a larger, 2 litre disposable bottle. A description of both systems and their respective components can be found in Table 13.

Table 13: Description of the Asevi and Smurfit Kappa use-cases

Subject of study	System element	Components	Weight (g)	Volume (L)
Single-use baseline	Single-use bottle 	Bottle core Cap Label	95 11 2	2L
Reusable system	Reusable bottle 	Bottle core Cap Label	70 11 2	1L
	Bag-in-Box 	Flexible pouch Tap Box	42,95 10,17 330	10L

To define the functional unit, it is important to account for the difference in volume and concentration between the single-use and reusable bottles. For the reusable bottle, it was assumed that the distributed detergent is twice as concentrated. This means that the same cleaning power is achieved with a 2-liter bottle at concentration X and a 1-liter bottle at concentration 2*X. Thus, the chosen functional unit is as follows:
"Contain and distribute enough laundry detergent to do 50 loads of laundry, in Spain, for large scale retail trade."

The corresponding reference flows are:

- One single-use bottle, volume 2 l, containing x g/l of detergent
- One use of a reusable bottle (used 10 times), volume 1 l, containing 2*x g/l of detergent and one tenth of a 10 l Bag-in-Box

This study is conducted within a "cradle-to-grave" boundary. The system boundary for this use-case is presented in Figures 19 & 20.

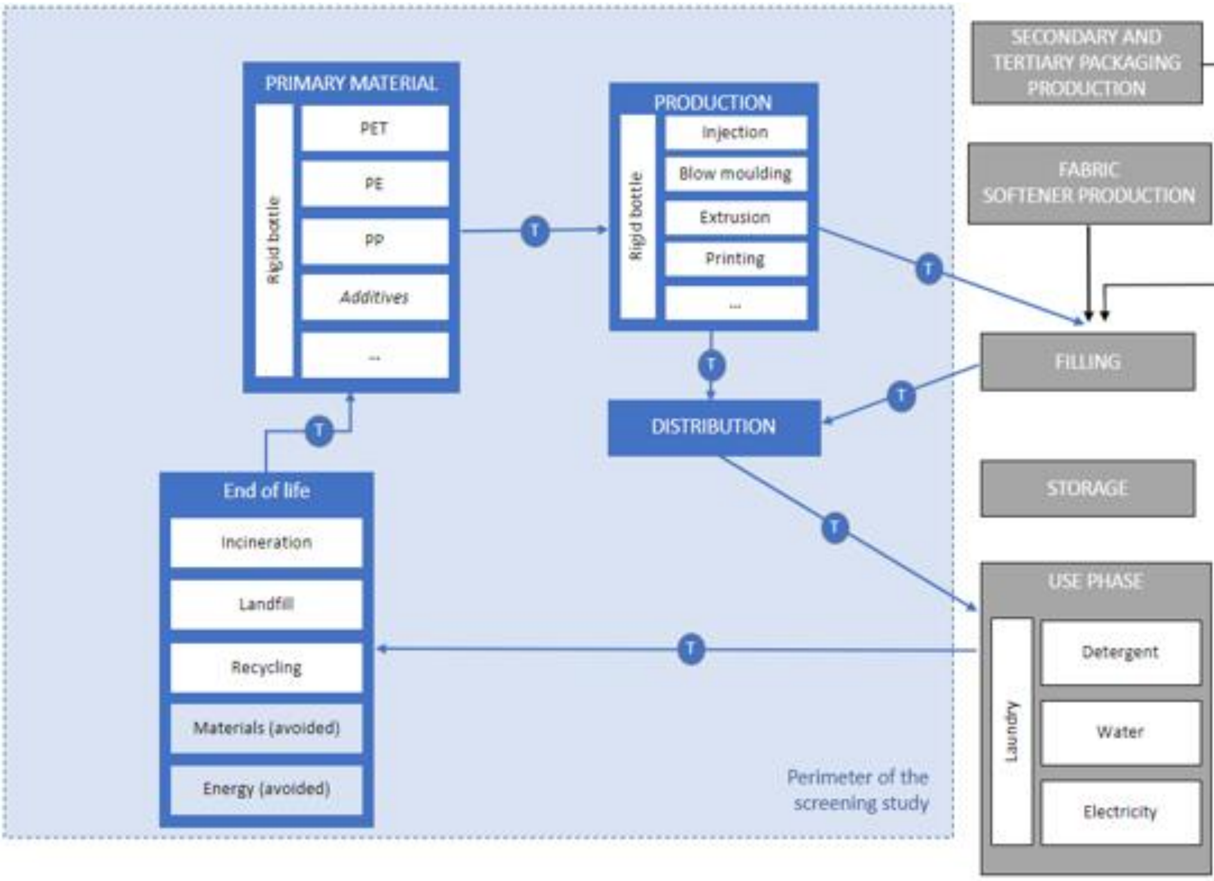


Figure 19: System boundary for life cycle assessment of a single-use detergent bottle

The single-use laundry detergent bottle is manufactured and filled in Spain by ASEVI. ASEVI is responsible for blow moulding the core of the bottle. The tap is sourced from suppliers in Italy, while the label is obtained from a supplier in Spain. After production, the bottles are distributed to supermarkets for large-scale retail. Once used in laundry activities, the bottles are disposed of as household waste.

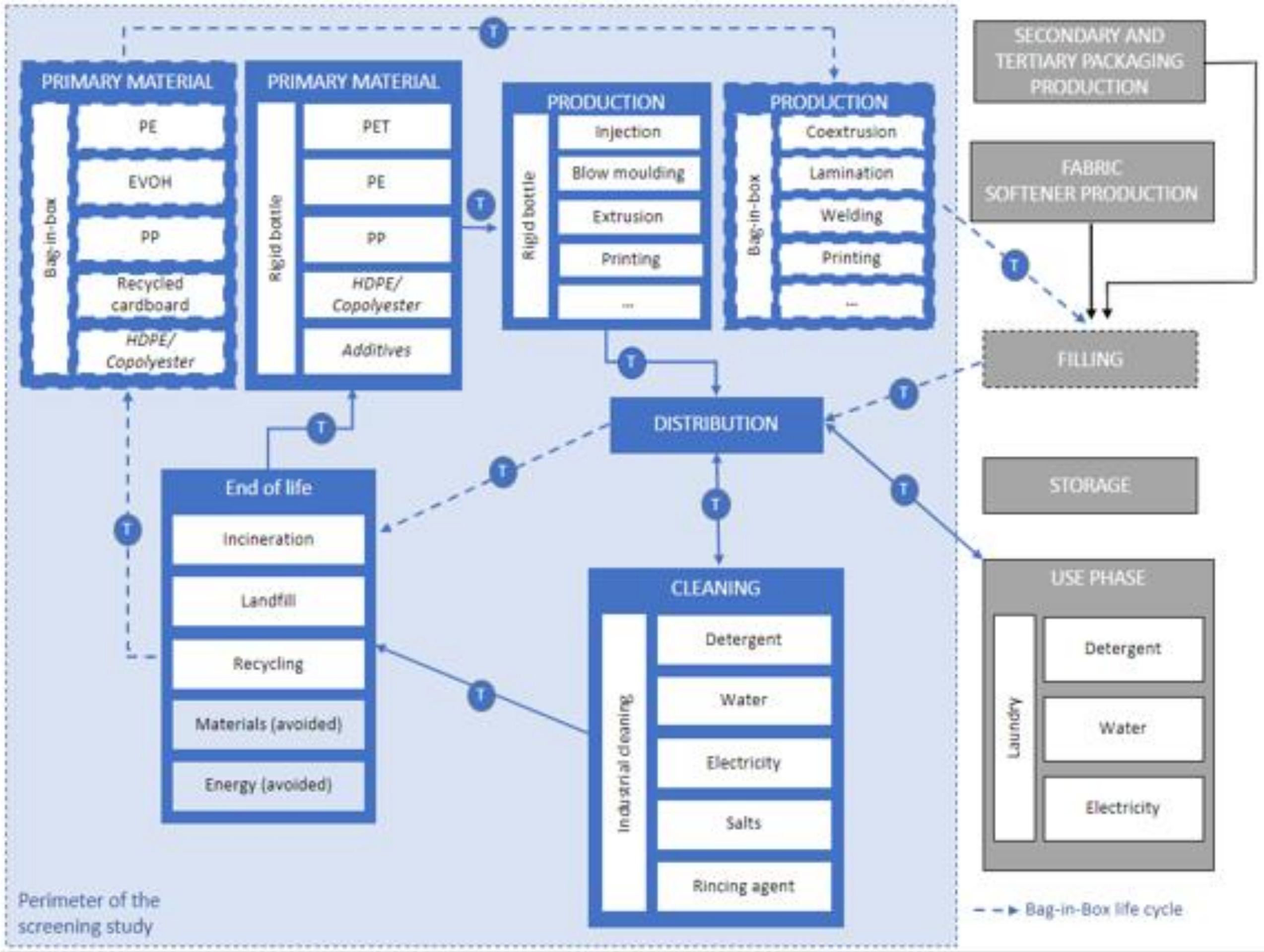


Figure 20: System boundary for life cycle assessment of a reusable detergent bottle

In the reusable system, the Bag-in-Box is manufactured by Smurfit Kappa and then sent to ASEVI to be filled with laundry detergent before being distributed to large-scale retail outlets. The reusable bottle undergoes the same manufacturing and distribution processes as the single-use baseline. Once used by the customer at home, the reusable bottle is returned to the supermarket to be refilled with the Bag-in-Box. After several uses, the reusable bottle is sent to a cleaning facility. Following the cleaning process, it is returned to the supermarket to continue the loop.

The following stages are excluded from the study:

- Laundry detergent production
- Filling of bottles and BiB
- Secondary and tertiary packaging
- Storage
- Usage phase of the product (laundry by the consumer)
- Refilling of the bottle
- Transportation from the supermarket to the consumer's house

3.2.2 Life Cycle Inventory (LCI)

3.2.2.1 Assumptions

The main challenge of this study lies in the lack of a clear definition of the economic model and the design of the bottle. To successfully conduct this LCA and LCCA, several assumptions were made:

- The reusable bottle is used 10 times.
- The design of the reusable bottle is assumed to be identical to the single-use bottle, with any modifications made to the cap and label having negligible impact. The mass of the reusable bottle was arbitrarily set at 70g, which is lower than that of the single-use baseline due to its reduced volume. Furthermore, we selected HDPE as the material for the core. Both mass and material will be thoroughly examined in the sensitivity analysis.
- The manufacturing processes and distribution of the single-use and reusable bottles are considered identical.
- The refilling step is excluded from the analysis (machine production, energy consumption, ...).
- Due to lack of data around customer behaviour with respect to reusable bottles, each bottle is assumed to be returned to the supermarket then routed to a washing facility (as opposed to being washed at home and reused by the customer directly, eliminating the need for transport to and washing at an external facility). This represents a "worst-case scenario" where customers never clean the bottle and always opt for a new one.
- The reverse logistics involved in transporting to and from the washing facility were assumed to cover 100km. This aspect will undergo further analysis in the sensitivity analysis.
- As the selection of the washing facility remains undecided, we modelled this stage using data from the Uzaje use-case, specifically focused on the washing of food trays.

3.2.2.2 Inventory for the single-use detergent bottle

Table 14: Inventory raw material data for the single-use detergent bottle

Primary production (Material)						Manufacturing			
Component	Material	Mass (g)	Recycled content	Country of origin	LCI dataset	Process	Country	Loss rate	Model in SimaPro
Bottle	HDPE TiO2	92.15 2.85	0 %	Saudi Arabia	Polyethylene, high density, granulate {RoW}| polyethylene production, high density, granulate Titanium dioxide {RoW}| market for titanium dioxide | Cut-off, U	Blow moulding	Spain	0.3 %	Blow moulding {RER}| blow moulding Adapted to Spain for water, electricity and waste
Cap	PP	11	0 %	GLO	Polypropylene, granulate {GLO}| market for polypropylene, granulate	Injection	Italy	0.6%	Injection moulding {RER}| injection moulding Adapted to Italy for water, electricity and waste
Label	LDPE	4	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate	Film extrusion Flexographic printing	France	2.4 %	Extrusion, plastic film {RER}| extrusion, plastic film Adapted to Spain for water, electricity and waste Confidential inventory data from IPC, specific for the process, adapted to Spain for electricity

Table 15: Inventory transportation data for the single-use detergent bottle

Transportation					
Route	Type	Departure region	Arrival region	Value (kg.km)	Model in SimaPro
Primary material to ASEVI	Boat	Saudi Arabia	ASEVI, Spain	429	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship
Primary material to ASEVI	Road	Saudi Arabia	ASEVI, Spain	9.53	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Tap supplier to ASEVI	Road	Italy	ASEVI, Spain	18.1	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Label supplier to ASEVI	Road	Spain	ASEVI, Spain	0.4	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Distribution	Road	ASEVI, Spain	Spain	43.5	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Waste collection	Road	French average		0.00095	Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U
Transfer to sorting facility	Road	French average		0.1565	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
Transfer to recycling facility	Road	French average		1.35	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

3.2.2.3 Inventory for the reusable system – bottle and BiB

Table 16: Inventory raw material data for the reusable detergent bottle

Primary production (Material)						Manufacturing			
Component	Material	Mass (g)	Recycled content	Country of origin	Model in SimaPro	Process	Country	Loss rate	Model in SimaPro
Bottle core	HDPE TiO2	67.9 2.1	0 %	Saudi Arabia	Polyethylene, high density, granulate {RoW}| polyethylene production, high density, granulate Titanium dioxide {RoW}| market for titanium dioxide	Blow moulding	Spain	0.3 %	Blow moulding {RER}| blow moulding Adapted to Spain for water, electricity and waste
Cap	PP	11	0 %	GLO	Polypropylene, granulate {GLO}| market for polypropylene, granulate	Injection moulding	Italy	0.6%	Injection moulding {RER}| injection moulding Adapted to Italy for water, electricity and waste
Label	LDPE	4	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate	Film extrusion Flexographic printing	France	2,4 % /	Extrusion, plastic film {RER}| extrusion, plastic film Adapted to Spain for water, electricity and waste Confidential inventory data from IPC, specific for the process, adapted to Spain for electricity

Table 17: Inventory transportation data for the reusable detergent bottle

Transportation					
Name	Type	Departure region	Arrival region	Value (kg.km)	Model in SimaPro
Primary material to ASEVI	Boat	Saudi Arabia	ASEVI, Spain	316	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship
Primary material to ASEVI	Road	Saudi Arabia	ASEVI, Spain	7.02	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Tap supplier to ASEVI	Road	Italy	ASEVI, Spain	18.1	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Label supplier to ASEVI	Road	Spain	ASEVI, Spain	0.4	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Distribution	Road	ASEVI, Spain	Spain	33.6	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Waste collection	Road	French average		0.00095	Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U
Transfer to sorting facility	Road	French average		0.1565	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
Transfer to recycling facility	Road	French average		1.35	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

In Table 18, the inventory data gathered pertains to Smurfit Kappa's 10L bag-in-box, which is currently available in the market. Discussions within BUDDIE-PACK are underway to develop a 100% recycled flexible pouch. Since this innovative solution is still in the design phase and has not been implemented, the existing data from the current solution has been utilized. This data will be revised and updated in the Full Circularity Assessment.

Table 18: Inventory raw material data for the Bag-in-box production

Primary production (Material)						Manufacturing			
Component	Material	Mass (g)	Recycled content	Country of origin	Model in SimaPro	Process	Country	Loss rate	Model in SimaPro
Vitop Tap	HDPE PP NBR	1.28 8.12 0.77	0 %	Middle East	Polyethylene, high density, granulate {RoW}| polyethylene production, high density, granulate Polypropylene, granulate {RoW}| polypropylene production, granulate 70% of Polybutadiene {RoW}|polybutadiene production 30% of Acrylonitrile {RoW}|Sohio process	Injection moulding	Spain	0.6%	Injection moulding {RER}| injection moulding Adapted to Spain for water, electricity and waste
AMKF neck	LLDPE	6.13	0 %	Middle East	Polyethylene, linear low density, granulate {RoW}| polyethylene production, linear low density, granulate	Injection moulding	Spain	0.6%	Injection moulding {RER}| injection moulding

									Adapted to Spain for water, electricity and waste
Outer pouch	LLDPE EVOH	23.9 2.4	0 %	Middle East	Polyethylene, linear low density, granulate {RoW}| polyethylene production, linear low density, granulate Confidential inventory data from IPC	Blown film extrusion	Spain	1%	Confidential inventory data from IPC, specific for the process, adapted to Spain for electricity
Inner pouch	LLDPE	16.65	0%	Middle East	Polyethylene, linear low density, granulate {RoW}| polyethylene production, linear low density, granulate	Blown film extrusion	Spain	1%	Confidential inventory data from IPC, specific for the process, adapted to Spain for electricity
Box	Cardboard	330	50%	Europe	Solid bleached and unbleached board carton {RER}| solid bleached and unbleached board carton production	Flexographic printing	Spain	-	Confidential inventory data from IPC, specific for the process, adapted to Spain for electricity

Table 19: Inventory transportation data for BiB

Transportation					
Name	Type	Departure region	Arrival region	Value (kg.km)	Model in SimaPro
Primary material to Smurfit Kappa	Boat	Saudi Arabia	Smurfit Kappa, Spain	267	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship
Primary material to Smurfit Kappa	Road	Saudi Arabia	Smurfit Kappa, Spain	5.93	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Box supplier to Smurfit Kappa	Road	Spain	Smurfit Kappa, Spain	33	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Distribution	Road	Smurfit Kappa, Spain	ASEVI, Spain	19.5	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6
Waste collection	Road	French average		0.00095	Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U
Transfer to sorting facility	Road	French average		0.1565	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
Transfer to recycling facility	Road	French average		1.35	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

3.2.2.4 End-of-life inventory

The scenarios chosen for end-of-life waste management are based on ADEME methodology (3) numbers for household waste disposal in France. These scenarios are considered suitable to our study, but they will need to be adjusted for the final evaluation. The models in SimaPro have been adapted to a European geography, when possible.

Table 20: Inventory data for the End-of-life modelling

Material	End-of-life percentage	End-of-life scenario	Model in SimaPro	
Polypropylene - rigid	55.8%	Recycling	Input process	Recycling of PP in Europe based on Franklin, 2018 (6)
			Avoided product	Polypropylene, granulate {RoW}| polypropylene production, granulate | Cut-off, U
	31.4%	Incineration (energy recovery)	Input process	Waste polypropylene {CH}| treatment of waste polypropylene, municipal incineration | Cut-off, U
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	12.8%	Landfill	Input process	Waste polypropylene {CH}| treatment of waste polypropylene, sanitary landfill | Cut-off, S
Cardboard	68.9%	Recycling	Input process	White lined chipboard carton {RER}| white lined chipboard carton production | Cut-off, S
			Avoided product	Solid bleached and unbleached board carton {RER}| solid bleached and unbleached board carton production | Cut-off, S
	22.1%	Incineration (energy recovery)	Input process	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	9%	Landfill	Input process	Waste paperboard {CH}| treatment of waste paperboard, sanitary landfill | Cut-off, S
Polyethylene - soft	6.2%	Recycling	Input process	Recycling of HDPE in Europe based on Franklin, 2018 (6)
			Avoided product	Polyethylene, low density, granulate {RoW}| polyethylene production, low density, granulate | Cut-off, S
	66.6%	Incineration (energy recovery)	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	27.2%	Landfill	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, sanitary landfill | Cut-off, S
Polyethylene - rigid	55.8%	Recycling	Input process	Recycling of HDPE in Europe based on Franklin, 2018 (6)
			Avoided product	Polyethylene, high density, granulate {RoW}| polyethylene production, high density, granulate | Cut-off, S
	31.4%	Incineration (energy recovery)	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	12.8%	Landfill	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, sanitary landfill | Cut-off, S

3.2.3 LCA Results and Sensitivity Analyses

3.2.3.1 Comparative assessment

Figure 21 displays the results of the comparative assessment of the single-use detergent bottle and the reusable system for 50 loads of laundry, i.e. for one single-use bottle and one use of a reusable bottle. The reusable system presents lower impacts for every single indicator except for the Land Use indicator. For Climate change the reusable system has a lower impact by approximately 70%. For the Land Use indicator, the cardboard of the Bag-in-Box used in the reusable system is the main reason for this higher impact.

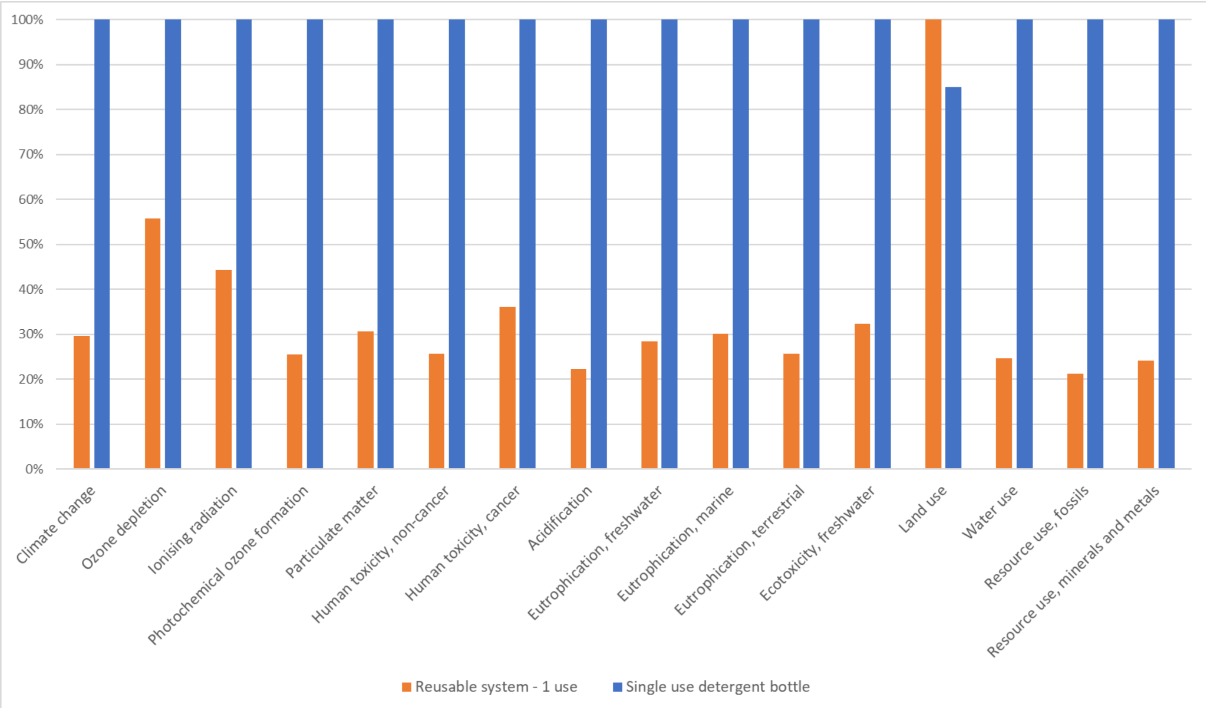


Figure 21: Comparative LCA between one use of the reusable system and one single-use bottle

These two comparisons enable us to conclude that the reusable system indeed holds the potential to significantly reduce the environmental impact of detergent distribution. Conservative hypotheses were taken for the screening study, such as the mass and material of the reusable bottle, the washing and reverse logistics and the end-of-life scenario. Iterative discussions with design and economic specialists of the project will give further perspectives for the reusable system in terms of environmental performance. Subsequent sections explore various scenarios to determine the extent to which the system would need to overcome potential barriers to consistently achieve a lower impact.

3.2.3.2 Analysis of contributors

Figure 22 shows the primary impact contributors throughout the life cycle of the reusable system used once, to assess the potential contribution of packaging production and End-of-Life in a worst case scenario.

- In blue, the "reusable bottle contributor" encompasses the primary materials and manufacturing processes involved in producing the bottle. It emerges as the most significant impact contributor, particularly for Climate Change and Water Use, accounting for 72% and 82% respectively.
- In orange, the "Bag-in-box" represents the impact of one-tenth of the Bag-in-box, incorporating all life cycle stages (from primary material extraction to end-of-life). Since the bottle is used only once, a full Bag-in-box is unnecessary, hence the quantity "one-tenth". Despite the bottle being

used only once, the Bag-in-box still constitutes a significant contributor, accounting for 10 to 20% of the impact across all indicators. Notably, there is a higher contribution to the "Land Use" indicator at 51%, primarily attributed to the cardboard used in the box.

– In grey, "Transportation" includes the supply of primary materials or components and the distribution of the bottle. This contributor is of lesser significance, accounting for less than 10% across all indicators.
– In yellow, the "Usage" phase encompasses the washing of the bottle and associated reverse logistics. As the bottle is washed only once in this scenario, the impact is relatively low across all indicators, with a notable 12% contribution to the Ionizing Radiation indicator.
– Lastly, in green, the "end-of-life" phase, including the disposal of the bottle (end-of-life for the Bag-in-box is considered within the Bag-in-box). The end-of-life accounts for 5% of the climate change impact, due to incineration. However, for all other indicators, the end-of-life presents negative contributions (i.e. positive impacts) due to recycling and energy recovery.

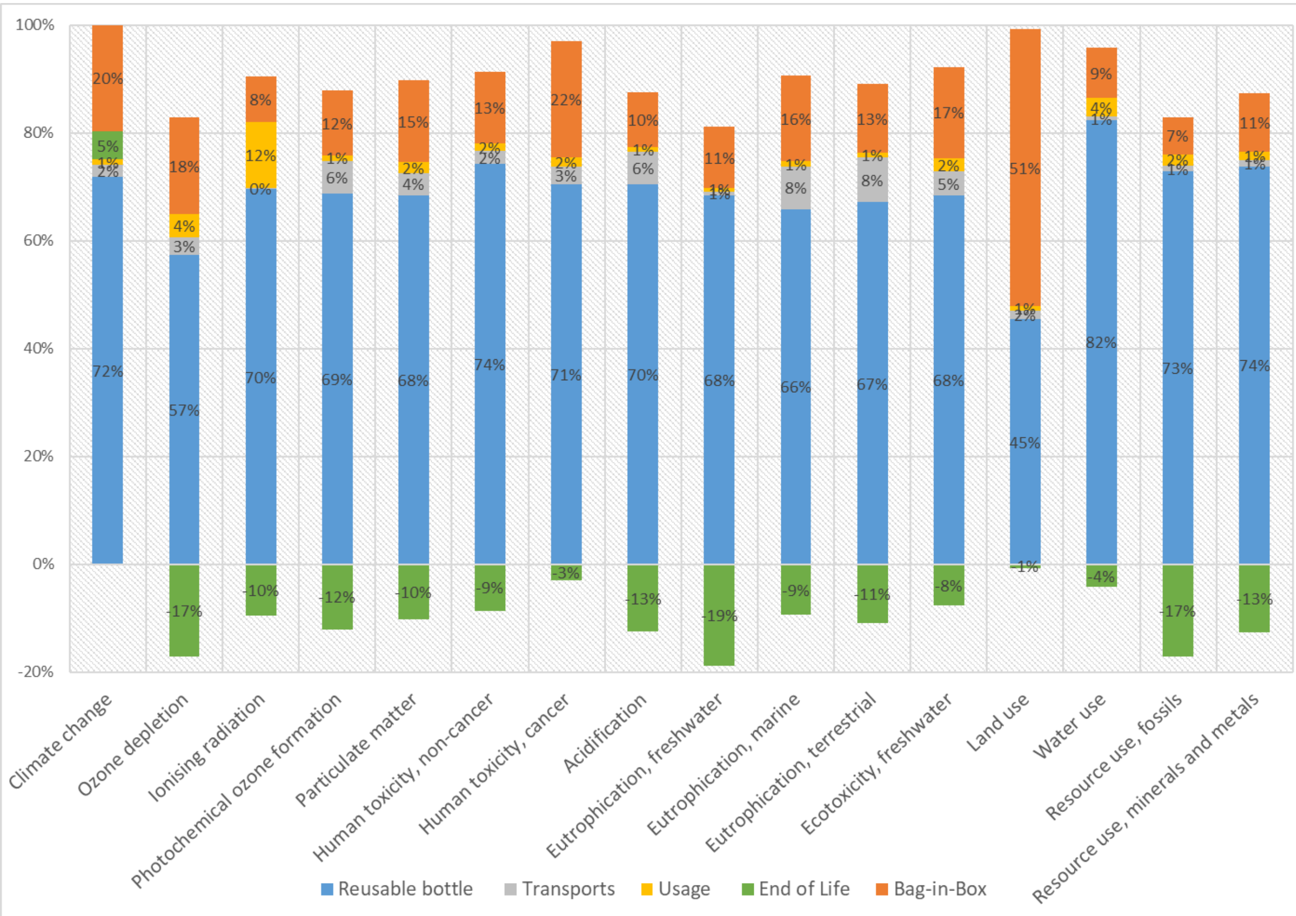


Figure 22: Life cycle contributors for the RPP system (1 use)

Figure 23 illustrates the main contributors to environmental impacts throughout the life cycle of the reusable system when it is used 10 times, requiring a full Bag-in-box for dispensing. The "Usage" phase includes bottle washing and associated reverse logistics.

– In orange, the "Bag-in-box" emerges as the primary contributor to impact for most indicators, particularly for Climate Change and Land Use, accounting for 69% and 90% respectively. Overall, its contribution varies from 30% to 90%. The only indicator where the bag-in-box does not have the largest impact is fossil resource use, where in the impact is comparable with the reusable bottle (38% and 40% respectively).

- In blue, the "reusable bottle" has the second greatest impact contribution. Notably, it contributes 25% of the Climate Change impact and more than 35% of the Resource Use (water, fossil and minerals) impacts.
- In yellow, the "Usage" phase represents a significant contributor for the Resource Use (fossil), and Water Use indicators. Washing accounts for most of the impact in the "Usage" stage, especially on Ionizing radiation due to the impact of nuclear energy within the mix used. For Ozone Depletion and Particulate Matter indicators reverse logistics have a greater impact.
- In grey, "Transportation" has a negligible impact, accounting for less than 5% for every indicator.
- Lastly, in green, the "End-of-life" phase still exhibits negative contributions (i.e. positive impacts) due to recycling and energy recovery.

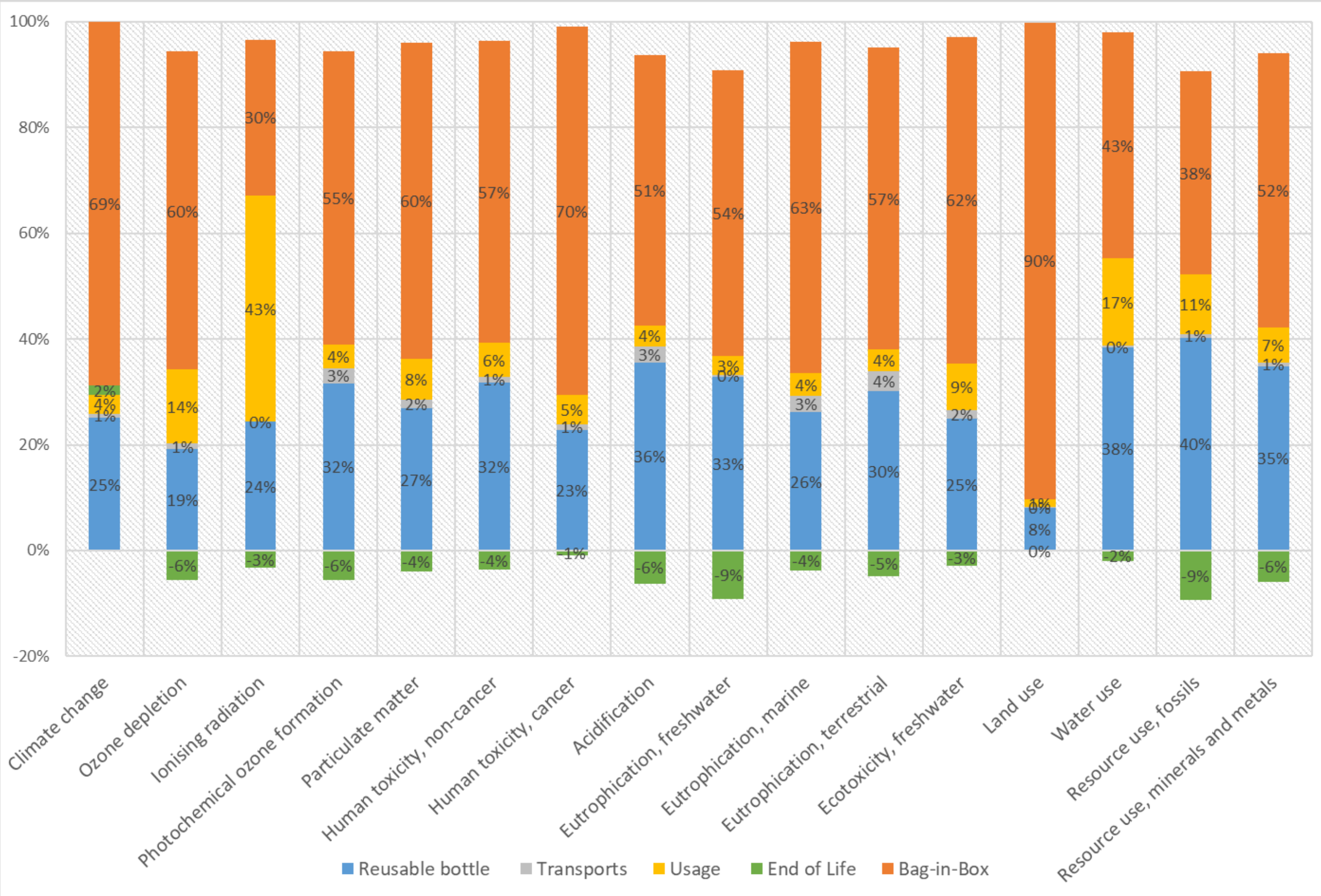


Figure 23: Life cycle contributors for the RPP system (10 uses)

3.2.3.3 Focus on the impact of the single-use bottle

Figure 24 shows the contribution to each indicator for the life cycle stages of the single-use bottle.

- In blue, "Primary materials" emerge as the primary impact contributor for most indicators, ranging from 11% to 72%. Notably, their contribution is particularly significant for Climate Change, reaching 72%.
- In orange, "Manufacturing" stands out as the second most significant contributor, exerting a substantial impact on ionizing radiation (75%), land use (79%), and water use (64%).
- In grey, "Transport" contributions are negligible, each falling below 10% for every indicator.

- Finally, in green, "End-of-life" presents mitigated impacts through recycling and energy recovery efforts.

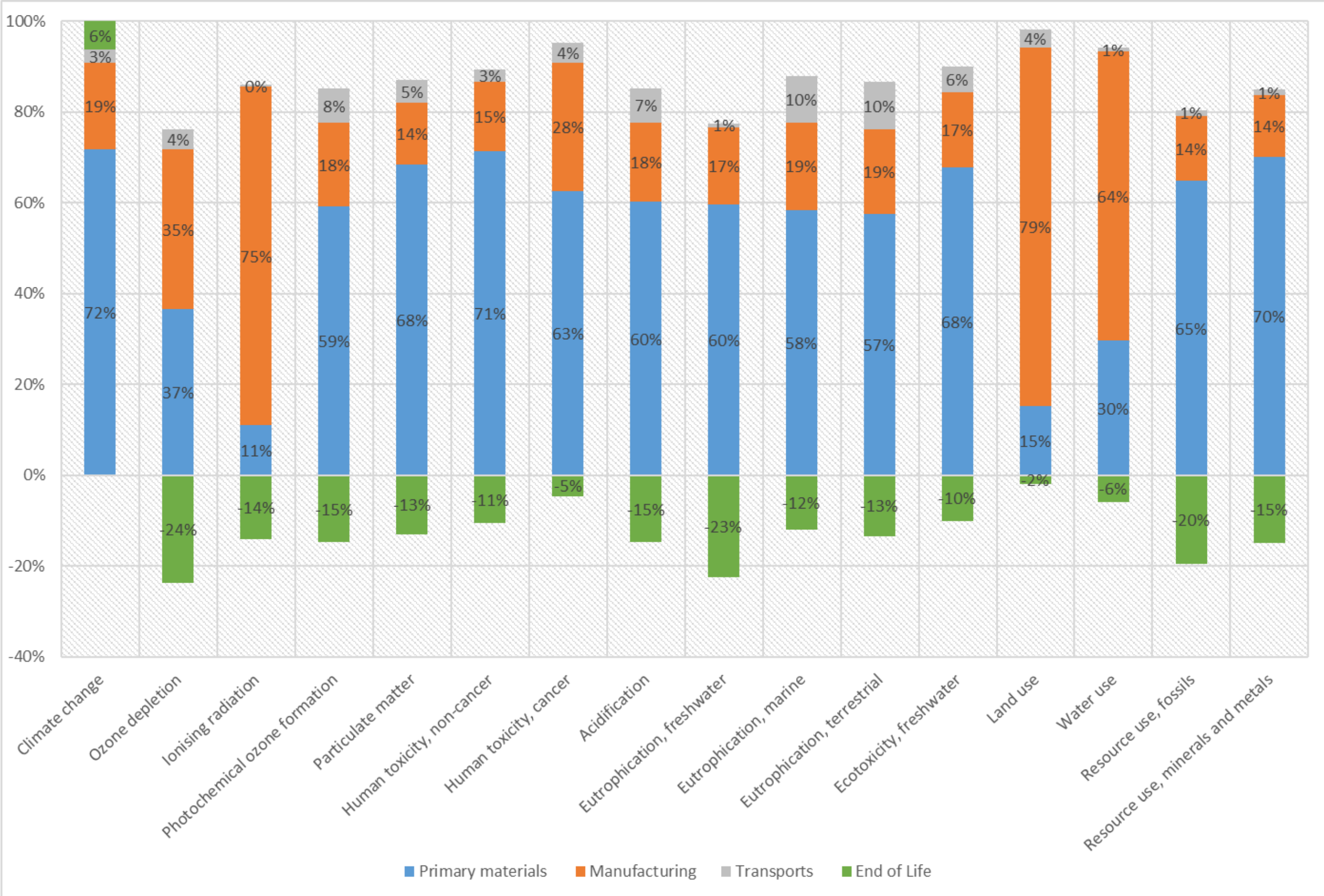


Figure 24: Life cycle impact contributions for the SUPP system

Although out of scope for the screening study, the secondary and tertiary packaging was assessed to evaluate the potential importance for the life cycle impacts, as seen in Table 21.

Table 21: Life Cycle Inventory for the secondary and tertiary packaging

Primary production (Material)						Manufacturing			
Component	Material	Mass (g)	Product per unit	Quantity/FU (kg)	Model in SimaPro	Process	Country	Loss rate	Model in SimaPro
Box	Cardboard	290	5	0.058	Solid bleached and unbleached board carton {RER}| solid bleached and unbleached board carton production	/	/	/	/
Film	LDPE	100	300	0.000337	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate	Blown film extrusion	Europe	1%	Confidential inventory data from IPC, specific for the process, adapted to Europe for electricity
Pallet	Wood	25000	300	0.0833	P EUR-flat pallet {RER}| market	/	/	/	

					for EUR-flat pallet				

The results of the analysis are depicted in Figure 25. As highlighted in yellow, the secondary and tertiary packaging significantly influences the life cycle of the bottle, with contributions to impacts ranging from 8% to 88%. Each cardboard box can fit five bottles in it, on a per-bottle basis, approximately 58g of cardboard is required for packaging. Detailed investigation of the secondary and tertiary packaging is therefore very important in the full life cycle assessment. Alternative materials, including reusable systems, should be considered for the secondary and tertiary packaging.

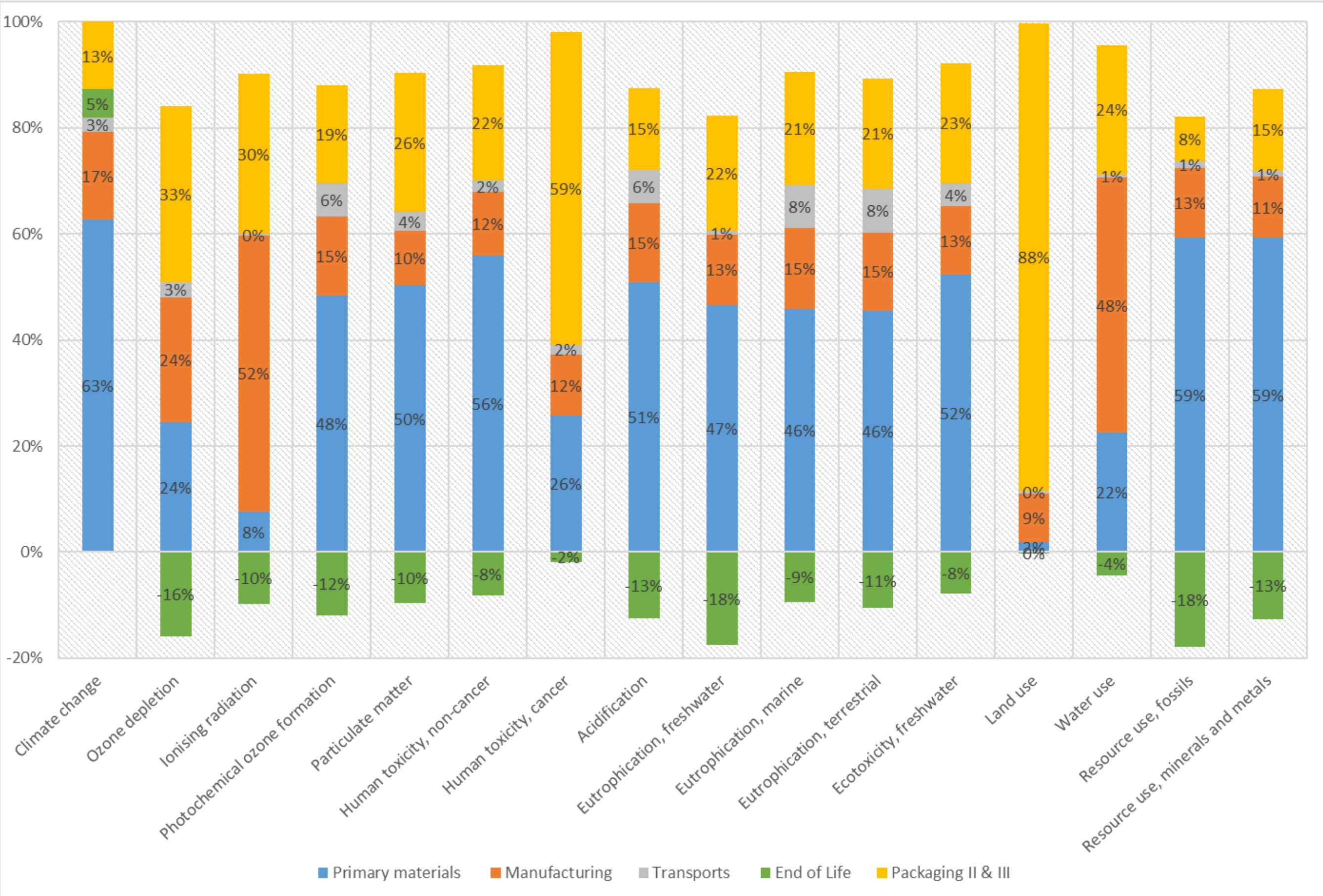


Figure 25: Life cycle contributors for the SUPP system, integrating secondary (II) and tertiary (III) packaging

3.2.3.4 Sensitivity analysis on Break-Even Point

The sensitivity analysis concentrates on evaluating various "worst case" scenarios, both for Climate Change and Water Use:

- Scenario 1: This scenario examines the influence of detergent concentration.
- Scenario 2: This scenario doubles the mass of the reusable bottle, resulting in a bottle weighing 190g.
- Scenario 3: This scenario maintains the reusable bottle mass increase from Scenario 2 and in addition changes the material to TRITAN.
- Scenario 4: Building upon the assumptions in Scenario 3, this scenario also multiplies the distance for washing by 5, referred to as "reverse logistics distances."

– Scenario 5: This scenario conserves the assumptions from Scenario 4 and alters the end-of-life scenario of the bottle to a 100% incineration scenario considering HDPE incineration as Tritan EoL data do not exist yet.

A summary of the scenarios is given in Table 22.

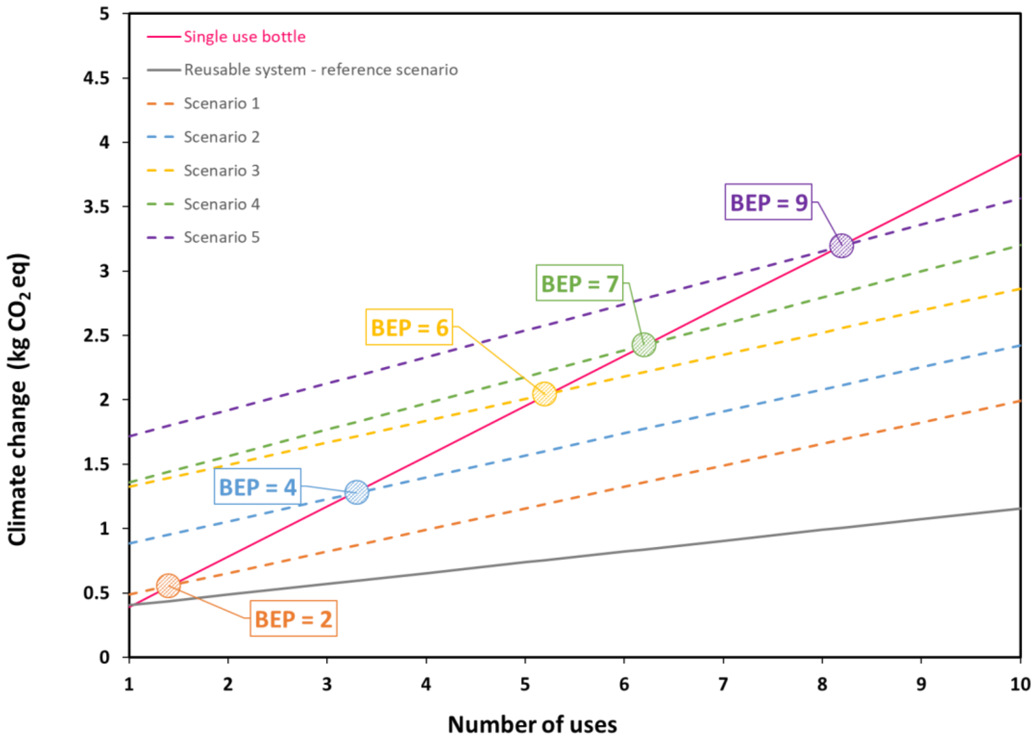
Table 22: Scenarios used for the sensitivity analysis

	Detergent concentration	Mass of the bottle	Bottle material	Reverse logistics distances	End-of-life scenario
Single-use bottle	X	95g	HDPE	-	EoL mix, see inventory
Reusable system – reference scenario	2*X	70g	HDPE	100km	EoL mix, see inventory
Scenario 1	X	70g	HDPE	100km	EoL mix, see inventory
Scenario 2	X	190g	HDPE	100km	EoL mix, see inventory
Scenario 3	X	190g	TRITAN	100km	EoL mix, see inventory
Scenario 4	X	190g	TRITAN	500km	EoL mix, see inventory
Scenario 5	X	190g	TRITAN	500km	100% HDPE incineration

The results of the scenarios are given in Figure 26. Regarding Climate Change, the Break-even point for the "reusable system - reference scenario" is 2 uses. In Scenario 1, where only the concentration of the detergent product is altered, minimal variation in impact is observed, with the Break-even point remaining at 2. However, for the other scenarios (mass, material, reverse logistics, end-of-life scenarios), the Break-even point is significantly affected. In the worst-case scenario i.e. Scenario 5, the Break-even point increases to 9 uses.

Concerning Water Use, the Break-even point for the "reusable system - reference scenario" also stands at 2 uses. Interestingly, the selected scenarios have less influence on the Break-even point for this indicator. The highest achieved Break-even point is 5 uses, observed in Scenarios 3, 4, and 5.

In this study, we assumed a target of 10 reuses for the reusable system. If the developed business model successfully achieves this objective, we can reasonably conclude that the reusable system will have a lower impact compared to the single-use baseline.



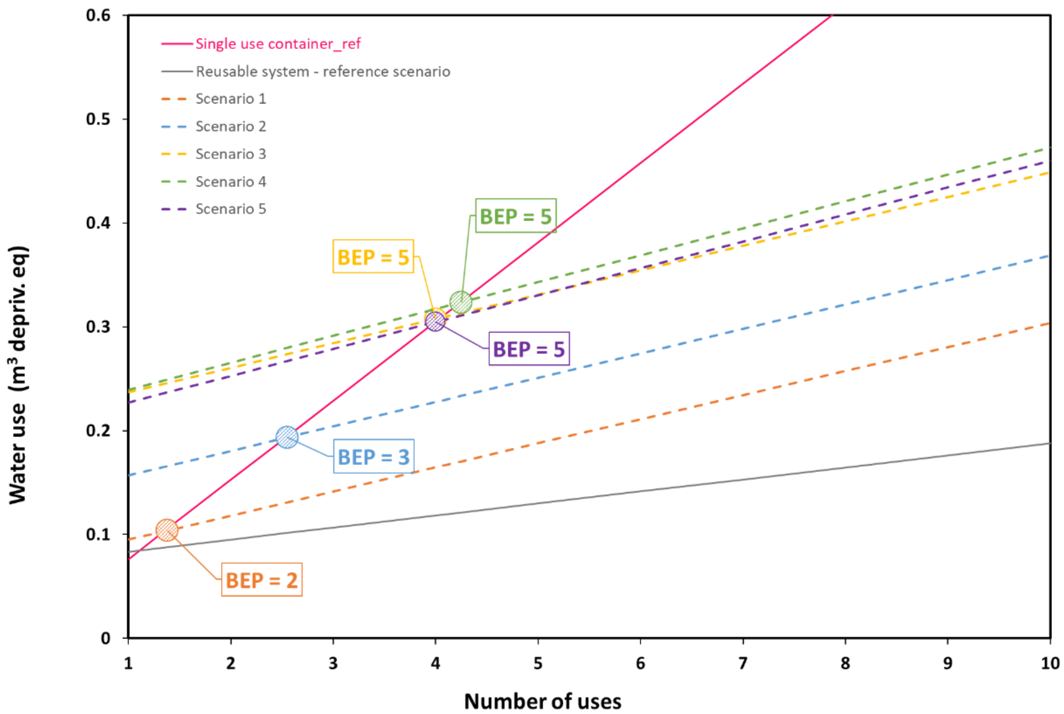


Figure 26: Sensitivity analysis of the break-even points for climate change and water use, investigating the scenarios summarised in Table 22: Scenarios used for the sensitivity analysis

3.2.4 LCCA Cost analysis

Figure 27 shows the different steps of the Asevi/Smurfit-Kappa value chain that are integrated in the LCCA study. Cost prices are used to describe the cost of the product used in both the ASEVI SUPP/RPP scenarios. Indeed, ASEVI transforms the material to the final product. Nonetheless, for the Smurfit Kappa use-case market transfer prices are use as the cost of the bag in box is not available.

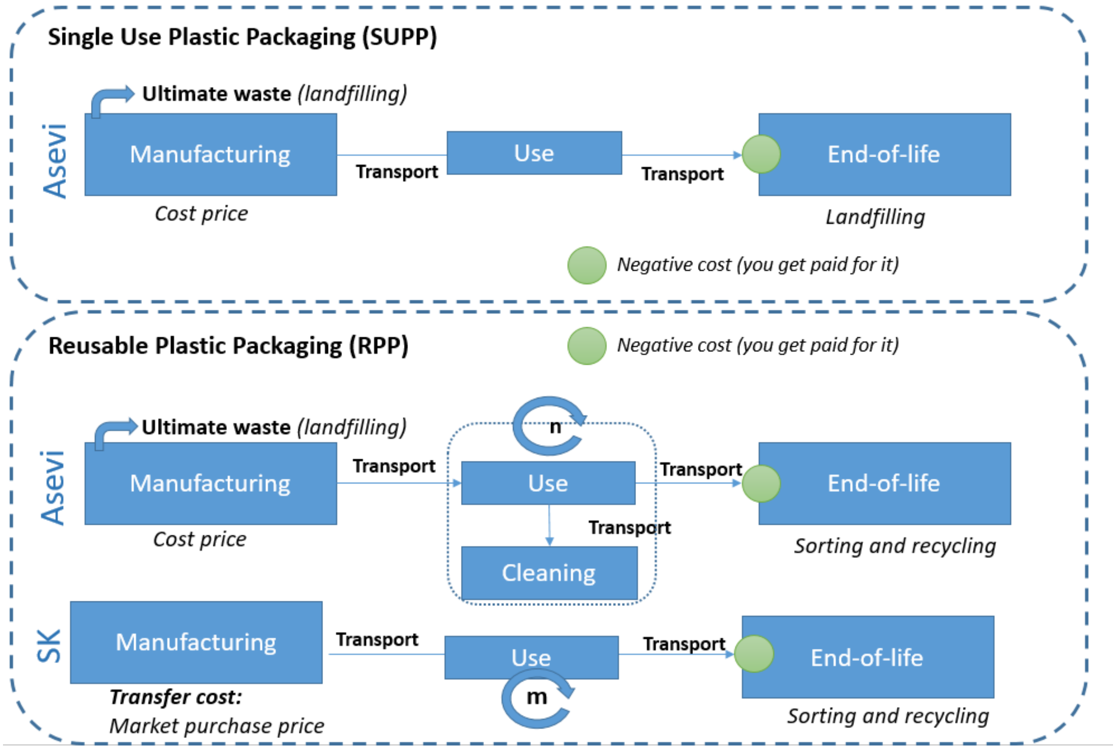


Figure 27: Study perimeter of refillable detergent bottle use-case LCCA

3.2.4.1 Cost structure for SUPP

The costs for the SUPP scenario are given in Table 23. The cost price was calculated considering the procurement of material, energy and water consumption as well as the distribution of the CAPEX and annual maintenance on each product following the definition proposed above in the document. The product is a 95g HDPE bottle with a 11g PP tap. The SUPP is considered recyclable as it is composed of mono-material parts that could be separated and recycled in their respective waste streams.

Table 23: Cost screening for Asevi/Smurfit-Kappa use-case SUPP scenario

LCC		
Cost price	0.288 €	per bottle
Transport	0.004 €	per bottle
EoL	- 0.093 €	per bottle
Total	0.199 €	per bottle

The total cost price of the ASEVI SUPP solution is 0.199 €/bottle.

3.2.4.2 Cost structure for ASEVI RPP

The costs for the RPP scenario are given in Table 24. The costs were modelled based on the SUPP scenario with the same product but lighter (70g for the bottle) and with the same cleaning data as used in the UZAJE use-case (3 million of items cleaned per year and cost 0.18 € per cleaning iteration) due to lack of other relevant data. The Full Circularity Assessment will include more details and relevant data for the cleaning step. The RPP product is a HDPE bottle with a PP cap that is separated and recycled.

Table 24: Cost screening for Asevi/Smurfit-Kappa use-case RPP scenario

LCC		
Targeted reuse cycles	10	
Cost price	0.232 €	per bottle
Transport	0.004 €	per bottle
EoL	0.069 €	per bottle
Cleaning (OPEX +CAPEX per product)	0.178 €	per cycle
Transport for cleaning	0.002 €	per cycle
Total fixed	0.166 €	per bottle
Total variable	0.180€	per cycle

The total cost price of the ASEVI RPP solution is (0.166 + n * 0.180) €/item.

3.2.4.3 Cost structure for SK Bag-in-Box

Commercially, a 10 l Bag-in-Box is sold at price of 3.36 €/ unit on European packaging sellers websites (9). The card box (330 g) is considered recyclable and goes in the paper recycling value chain. The outer and inner pouch (42.93 g) is considered recyclable and goes in the PE value chan. The neck and tap (16.3 g) are composed of different plastics and are not considered recyclable. After every 10 uses the 10 l BIB will be empty and is replaced by a new one.

Table 25: Cost screening of Bag-in-Box used for Asevi/Smurfit-Kappa use-case RPP scenario

LCC		
Purchase price	3.360 €	per item
Transport	0.001 €	per item
EoL	-0.136 €	per item
Total	3.225 €	per item

The total purchasing cost of the Smurfit Kappa bag in box is 3.225 €/item.

3.2.4.4 Break-even point

At this stage, the breakeven point cannot be calculated as we are comparing purchase price and cost price. These values will be homogenised during the Full Circulartity Assessment and the break-even point assessed.

3.2.5 Conclusions on hotspots and design guidelines

This screening study investigated a reusable system for detergent distribution compared to a single-use bottle.

If only used once, the impacts of the reusable bottle are primarily associated with the raw materials. For 10 uses of the reusable system, i.e. a reusable bottle associated with a Bag-in-Box, the impact shifts from the bottle to the BiB raw materials and the use phase. In both single-use and reusable cases, the end-of-life phase has a significant impact, especially on Climate Change.

Sensitivity analysis on the material and mass of the bottle, as well as the distance for reverse logistics and EoL treatment was conducted. In all cases the break-even point for climate change was less than 10 and that for water use less than 5. Current designs assume 10 uses of the reusable bottle, make it environmentally beneficial in all the scenarios investigated.

It should be noted that this screening LCA is subject to certain assumptions and methodological limitations due to early design and industrial stages, which may impact the obtained results. In the Full Circularity Assessment studies, a more refined business model will allow for the collection of specific data, particularly concerning the design of the bottle and the washing stage. Additionally, new contributors may be introduced, such as packaging, detergent distribution in retail, and user contributions (such as washing at home and consumer transportation). Discussions with project partners will continue to aid data collection for the Full Circularity Assessment.

The main identified hotspots of this screening study are:

- Primary material: the production of the bottle and of the bag-in-box are the biggest impact contributors. For a low number of uses, most of the impact is on the bottle. For a higher number of uses, the impact shifts to the Bag-in-box.
- Washing phase: not identified as a big hotspot in this study but the inventory data for the washing is highly uncertain. It usually is a big source of impact.
- Packaging: adding a simple analysis on the secondary and tertiary packaging of the single-use bottles highlighted that it is an important contributor for most of the indicators.
- End-of-Life: sensitivity analysis showed that the chosen end-of-life scenario greatly influences the BEP.

The corresponding guidelines are:

- To reduce the impact per use of the Bag-in-Box, the volume should be as high as practicable. The bigger the BiB, the lower the impact per use. Another option could be to make the box reusable.
- For the reusable bottle, the mass and material do not affect the break-even point beyond reach. We recommend focusing on the business model, with a strong tracking and rewarding system, ensuring a high return rate of the bottles.
- Vigilance for the washing phase: the electricity and water consumption during this stage can be an important factor.
- To lower the relative impact of secondary and tertiary packaging of the bottles, working on stackability or reusable boxes would be a great way to lower the impact.
- Since a high incineration rate scenario influence greatly the Climate Change impact, it is crucial to ensure the recyclability and recycling of both the bottle and the Bag-in-box. A good way to do so is to set up a closed loop recycling scheme and avoid the components of the system ending up in household waste.

3.2.6 Data gaps

Regarding the Asevi/Smurfit-Kappa use-case, data for the whole SUPP value chain has been collected. For the RPP scenario the following data are required:

  - Mass and material for the bottle
  - Manufacturing stage for the bottle

- Transport (primary material, components, distribution, washing, ...)
- Cleaning step
- End-of-life scenarios
- Direct and indirect costs for the bottle
- Direct and indirect costs for the Smurfit Kappa bag-in-box
- Direct and indirect costs for the cleaning step

3.3 Ausolan use-case: Semi-rigid catering tray for schools and nursing homes

3.3.1 Goal and scope of the study

The aim of this life cycle assessment is twofold. The first is to assess the cradle-to-grave environmental impacts of a reusable multi-portion plastic catering tray, compared to reusable multi-portion metal baseline. The second is to assess the cradle-to-grave environmental impacts of a reusable single-portion plastic container, compared to a single-use single-portion plastic container baseline. The studied systems are used to contain food portions during heating, transport and serving. The trays are used for the majority of meals served, whereas the single-portion containers are used for meals which must be packaged individually to avoid contamination risk (such as in the case of consumers with allergies to certain ingredients).

Four container types were considered during this use-case: The reusable stainless steel tray and reusable plastic tray, (which have capacity for forty and eight portions respectively), and the reusable and single-use single-portion plastic containers, which each contain a single-portion. Three comparisons were undertaken:

- steel trays vs reusable plastic trays;
- single-use single-portion plastic containers vs reusable single-portion plastic containers;
- steel trays and single-use single-portion plastic containers (the current system) vs plastic trays and reusable single-portion plastic containers (the fully reusable plastic system).

After impact assessment, break-even analysis was undertaken for the three comparisons. This comparison aimed to identify:

- In the tray case, the number of uses of each type of reusable tray which gave comparable impacts;
- In the container case, the minimum number of uses required for a reusable container to have lower impact than single-use containers;
- In the combined case, the minimum number of uses required for the fully reusable system to have lower impact than the current system.

In the tray case, the selected functional unit was "the containment during heating, transport and serving of 40 meals from a central kitchen to a school in the Gipuzkoa, Bizkaia, or Araba region of Spain". The corresponding reference flows are:

- One reusable stainless steel tray per use (with a lifetime of 100 cycles);
- Five reusable plastic trays per use (with a lifetime of 50 cycles each).

The two product cases are shown in Table 26.

Table 26: Average weight of the reusable trays.

Samples	Packaging unit	Material	Weight (g)
	Reusable tray + lid	Stainless steel	2268

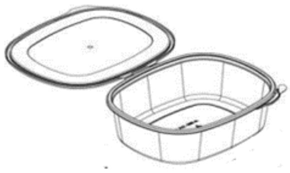
	Reusable tray + lid	Crystalline PET	475

In the container case, the selected functional unit was "the containment during heating, transport and serving of one meal from a central kitchen to a school in the Gipuzkoa, Bizkaia, or Araba region of Spain". The corresponding reference flows are:

- One single-use plastic containers per use
- One reusable plastic container (with a lifetime of 50 cycles)

The two product cases are shown in Table 27.

Table 27: Average weight of the reusable and disposable containers.

Samples	Packaging unit	Material	Weight (g)
	Single-use container + lid	PP	24.4
	Reusable container + lid	PBT + PP	120

3.3.2 Life Cycle Inventory (LCI)

The life cycle inventory is indicated in Table 28 to Table 35. Data is first given for the trays (Table 28 to Table 31), then for the containers (Table 32 to Table 35). Inventory data was taken from several primary sources and some general manufacturing process information was modelled based on the Ecoinvent 3.9. database. These processes were modified if necessary to represent the correct country of manufacture. For the washing stage, the required water and energy are included in the analysis, however the treatment of wastewater produced during the washing is not considered. For washing, a small commercial dishwasher was chosen with required 1.4 to 3.6 litres of cold water and 0.232 kWh electricity per cycle. It is assumed that the whole volume of each cycle could incorporate one of either four steel trays or eight steel lids. As the reusable plastic trays and containers do not exist yet, an estimate was made as to how many will fit in a dishwasher. Extrapolating from the steel tray data, capacity in plastic trays has been estimated at 15 trays or 30 lids (based on the same capacity of portions, minus a 25% estimate for space inefficiency due to the edges of the trays). The impact of a washing cycle is allocated to each element on that basis. In the case of reusable containers, it was assumed that the whole volume of the dishwasher could incorporate either 40 containers or 80 lids (based on the same capacity of portions, and an estimate that a meal in a container requires four times the space of a meal on a tray). The accuracy of the estimate of dishwasher capacity should be verified once the containers have been made, and these values can be changed as needed in the Full Circularity Assessment.

Table 28: Life cycle inventory for production and manufacturing of steel and plastic reusable trays.

Activity	Primary production (Material)	Manufacturing

	Material		Mass (g)	Recycled content (%)	Country of origin	Model in SimaPro	Process	Country	Loss rate (%)	Model in SimaPro
Reusable plastic tray + lid	CPET		475 (265+210)	0%	Spain	Polyethylene terephthalate, granulate, amorphous {RER}| polyethylene terephthalate production, granulate, amorphous | Cut-off, U	Extruding + Thermo-forming	Spain	4.7%	Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, U Thermoforming, with calendering {RER}| thermoforming, with calendering | Cut-off, U
Reusable steel tray + lid	Tray + lid	Stainless steel AISI 304	2086 (1150 + 936)	58%	Italy	Steel, chromium steel 18/8 {RER}| steel production, electric, chromium steel 18/8 | Cut-off, U	Rolling + Drawing	Italy	0%	Sheet rolling, chromium steel {RER}| sheet rolling, chromium steel | Cut-off, U Deep drawing, steel, 3500 kN press, automode {RER}| deep drawing, steel, 3500 kN press, automode | Cut-off, U
	Lid seal	Rubber	182	0%	Italy	Synthetic rubber {RER}| synthetic rubber production | Cut-off, U	Injection moulding	Italy	0.6%	Injection moulding {RER}| injection moulding | Cut-off, U

Table 29: Life cycle inventory for transportation of steel and plastic reusable trays.

Activity	Transportation					
	Name	Type	Distance(km)	Departure region	Arrival region	Model in SimaPro
Reusable plastic tray + lid	Primary material for lid and bowl from supplier (Indorama) to manufacturing (NovaPET)	Road	1084	Cadiz, Spain	Barbastro, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	From manufacturer to central kitchen	Road	315	Barbastro, Spain	Gipuzkoa, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Central kitchen to school	Road	120	Gipuzkoa, Spain	Gipuzkoa / Bizkaia / Araba, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	School to central kitchen (for washing)	Road	120	Gipuzkoa / Bizkaia / Araba, Spain	Gipuzkoa, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	Central kitchen to recycling (Reydesa Recycling)	Road	60	Gipuzkoa, Spain	Alava, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
Reusable steel tray + lid	Primary material for lid and bowl from supplier (Acciai Speciali Terni S.p.A.) to manufacturer (Sambonet Paderno)	Road	595	Terni, Italy	Novara, Italy	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	From manufacturer to central kitchen	Road	1243	Novara, Italy	Gipuzkoa, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market

						for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Central kitchen to school	Road	120	Gipuzkoa, Spain	Gipuzkoa / Bizkaia / Araba, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	School to central kitchen (for washing)	Road	120	Gipuzkoa / Bizkaia / Araba, Spain	Gipuzkoa, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	Central kitchen to recycling (Reydesa Recycling)	Road	60	Gipuzkoa, Spain	Alava, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Rubber from recycling to energy recovery facility (Zabalgarbi)	Road	90	Alava, Spain	Bilbao, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U

Table 30: Life cycle inventory for washing use (use phase for of steel and plastic reusable trays)

Dishwasher type		Commercial dishwasher (on site)	Model in SimaPro
Water use per wash (litres)		1.7	
Energy use per wash (kWh)		0.2375	
Reusable plastic tray + lid	Reuse container allocation of total dishes in each basket of washing (%)	6.7+3.3 = 10% (capacity of dishwasher = 15 trays or 30 lids)	
	Water use per reusable container (litres)	0.1139+0 0.0567=0.17	Tap water {RER}| market group for tap water | Cut-off, U
	Energy use per reusable container (kWh)	0.0159+0.0078=0.02375	Electricity, high voltage {ES}| market for electricity, high voltage | Cut-off, U
	Detergent use per reusable container (g)	0.425	Polycarboxylates, 40% active substance {RER}| polycarboxylates production, 40% active substance | Cut-off, U
Reusable steel tray + lid	Reuse container allocation of total dishes in each basket of washing (%)	25+12.5 = 37.5% (capacity of dishwasher = 4 trays or 8 lids)	
	Water use per reusable container (litres)	0.425+0.2125=0.6375	Tap water {RER}| market group for tap water | Cut-off, U
	Energy use per reusable container (kWh)	0.0297+0.0594=0.0891	Electricity, high voltage {ES}| market for electricity, high voltage | Cut-off, U
	Detergent use per reusable container (g)	1.594	Polycarboxylates, 40% active substance {RER}| polycarboxylates production, 40% active substance | Cut-off, U

Table 31: Life cycle inventory for End-of-Life scenarios of steel and plastic reusable trays.

Activity	End-of-life scenario	Model in SimaPro		
Reusable plastic tray + lid	Recycling (100%)	Input process		Recycling of PET based on PEF Annex C and 100% recycling rate. (sensitivity analysis also undertaken at 0% recycling)
		Avoided product		Polyethylene terephthalate, granulate, amorphous {RER}| polyethylene terephthalate production, granulate, amorphous | Cut-off, U
Reusable steel tray + lid	Recycling (100% steel) + Incineration (energy recovery) (100% rubber)	Input process		Iron scrap, sorted, pressed {RER}| sorting and pressing of iron scrap | Cut-off, U Waste rubber, unspecified {Europe without Switzerland}| treatment of waste rubber, unspecified, municipal incineration | Cut-off, U
		Avoided products	Steel	Iron scrap, unsorted {RoW}| steel production, electric, low-alloyed | APOS, U
			Rubber	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U

				Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U

Table 32: Life cycle inventory for production and manufacturing of single-portion single-use and reusable containers.

Activity	Primary production (Material)						Manufacturing			
	Material		Mass (g)	Recycled content [%]	Country of origin	Model in SimaPro	Process	Country	Loss rate [%]	Model in SimaPro
Reusable container	Container	PBT	80	0	Belgium	PBT, prod {RER} Système	Injection moulding	Spain	0.6%	Injection moulding {RER}| processing | Cut-off, U
	Lid	PP	40	0	Belgium	Polypropylene, granulate {RER}| production | Cut-off, U	Injection moulding	Spain	0.6%	Injection moulding {RER}| processing | Cut-off, U
Single-use container	PP		25.5	0	Belgium	Polypropylene, granulate {RER}| production | Cut-off, U	Injection moulding	Spain	0.6%	Injection moulding {RER}| processing | Cut-off, U

Table 33: Life cycle inventory for transportation of single-portion single-use and reusable containers.

Activity	Transportation					
	Name	Type	Distance(km)	Departure region	Arrival region	Model in SimaPro
Reusable container	Primary material for lid and bowl from supplier (ENVALIOR) to manufacturer (Envases CUI)	Road	1668	Genk, Belgium	Madrid, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	From manufacturer to central kitchen	Road	420	Madrid, Spain	Gipuzkoa, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Central kitchen to school	Road	120	Gipuzkoa, Spain	Gipuzkoa / Bizkaia / Araba, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	School to central kitchen (for washing)	Road	120	Gipuzkoa / Bizkaia / Araba, Spain	Gipuzkoa, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	Central kitchen to recycling (Reydesa Recycling)	Road	60	Gipuzkoa, Spain	Alava, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	PP from recycling to energy recovery facility (Zabalgarbi)	Road	90	Alava, Spain	Bilbao, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
Single-use container	Primary material for lid and bowl from supplier (ENVALIOR) to manufacturer (NovaPET)	Road	1344	Genk, Belgium	Barbastro, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	From manufacturer to central kitchen	Road	315	Barbastro, Spain	Gipuzkoa, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U

	Central kitchen to school	Road	120	Gipuzkoa, Spain	Gipuzkoa / Bizkaia / Araba, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	School to central kitchen (for washing)	Road	120	Gipuzkoa / Bizkaia / Araba, Spain	Gipuzkoa, Spain	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U
	Central kitchen to recycling (Reydesa Recycling)	Road	60	Gipuzkoa, Spain	Alava, Spain	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U

Table 34: Life cycle inventory for washing use (use phase for plastic reusable containers)

Dishwasher type		Commercial dishwasher (on site)	Model in SimaPro
Water use per wash (litres)		1.7	
Energy use per wash (kWh)		0.2375	
Reusable plastic container + lid	Reuse container allocation of total dishes in each basket of washing (%)	2.5+1.25= 3.75% (capacity of dishwasher = 40 trays or 80 lids)	
	Water use per reusable container (litres)	0.0425+ 0.02125= 0.0318	Tap water {RER}| market group for tap water | Cut-off, U
	Energy use per reusable container (kWh)	0.00593+ 0.00297= 0.00890	Electricity, high voltage {ES}| market for electricity, high voltage | Cut-off, U
	Detergent use per reusable container (g)	0.1594	Polycarboxylates, 40% active substance {RER}| polycarboxylates production, 40% active substance | Cut-off, U

Table 35: Life cycle inventory for End-of-Life of single-portion single-use and reusable containers.

Activity	End-of-life scenario		Model in SimaPro	
Reusable container	Lid	Recycling (100%)	Input process	Recycling of PP based on Cottafavaa et.al 2021 (sensitivity analysis also undertaken at 0% recycling)
			Avoided product	Polypropylene, granulate {RoW}| polypropylene production, granulate | Cut-off, U
	Bowl	Recycling (100%)	Input process	Recycling of PBT based on PEF Annex C quality and 100% recycling rate (sensitivity analysis also undertaken at 0% recycling)
			Avoided product	PBT, prod {RER} Système
Single-use container	Incineration (energy recovery) (100%)		Input process	Polypropylene, granulate {RoW}| polypropylene production, granulate | Cut-off, U
			Avoided product	Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U
				Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U

In all plastic cases, it has been assumed that trays and containers are manufactured from virgin plastic. At this screening stage, two recycling rates have been assumed for plastic materials at the end-of-life. Initially, plastics were assumed to be recycled. This is known as case A.
A second case (case B) has also been applied in all plastic cases, where the other extreme is assumed, meaning that reusable plastics are assumed to be incinerated with energy recovery. Modelling these extremes during this screening phase allows the range of potential impacts to be understood. Details are given inTable 36, and both cases are illustrated in subsequent break-even analysis results graphs.

Table 36: Life cycle inventory for End-of-Life of single-portion single-use and reusable plastic containers.

Product	Material	Case	Treatment	Process or source
Reusable tray	CPET	A	Recycling (100%)	Recycling of PET based on PEF Annex C with R2=100%
		B	Incineration (100%)	Incineration with energy recovery (heat and electricity generation)
Reusable container	PP	A	Recycling (100%)	Recycling of PP based on Cottafavaa et.al 2021
		B	Incineration (100%)	Incineration with energy recovery (heat and electricity generation)
	PBT	A	Recycling (100%)	Recycling of PBT based on PEF Annex C with R2=100%
		B	Incineration (100%)	Incineration with energy recovery (heat and electricity generation)
Single-use container	PP	A	Recycling (100%)	Recycling of PP based on Cottafavaa et.al 2021
		B	Incineration (100%)	Incineration with energy recovery (heat and electricity generation)

3.3.3 LCA Results and Sensitivity Analyses

3.3.3.1 Analysis of contributors

Results of impact categories assessed are shown in Figure 28 and Figure 29 for the trays and in Figure 30 and Figure 31 for the single-portion containers. In all cases, results are shown for case A end-of-life treatment methods (100% recycling). Cases A and B are included in subsequent break-even sensitivity analysis.

The results for the trays show the relatively large contribution of transport in both the reusable steel and reusable plastic tray cases. In the steel case, materials make a significant contribution to some impact categories, particularly cancer-causing human toxicity and mineral and metal resource use. In the plastic case, materials make a large contribution to ozone depletion. The impact of manufacturing is relatively minor in most cases, though more significant in the freshwater eutrophication and water use categories in the plastic tray case. Washing is also relatively insignificant in many cases, aside from water use and ionising radiation in both plastic and steel cases.

In comparison to trays, single-use containers show a much greater impact from manufacture, as would be expected. Materials also make a significant contribution in the single-use case, but are less prominent (though still significant) in the reusable plastic container case. In this case, washing is also significant, as in the reusable tray case.

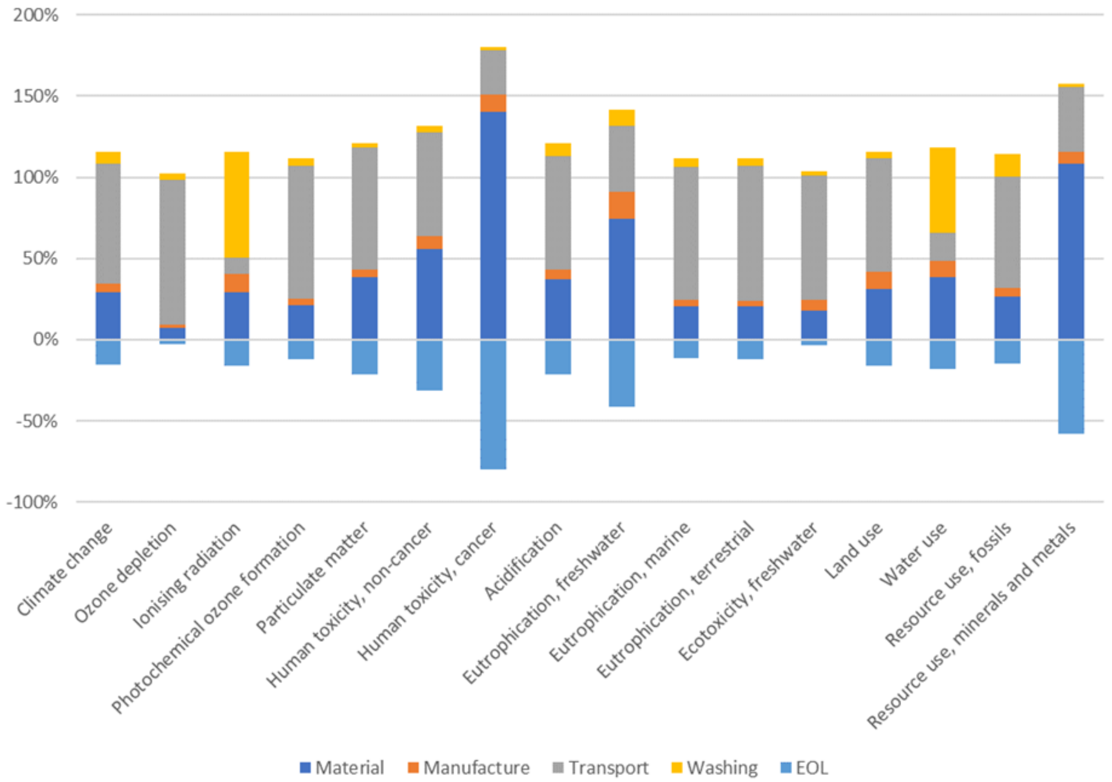


Figure 28: Reusable steel tray: Environmental impact category results based on the EF 3.0 model for a reusable steel tray.

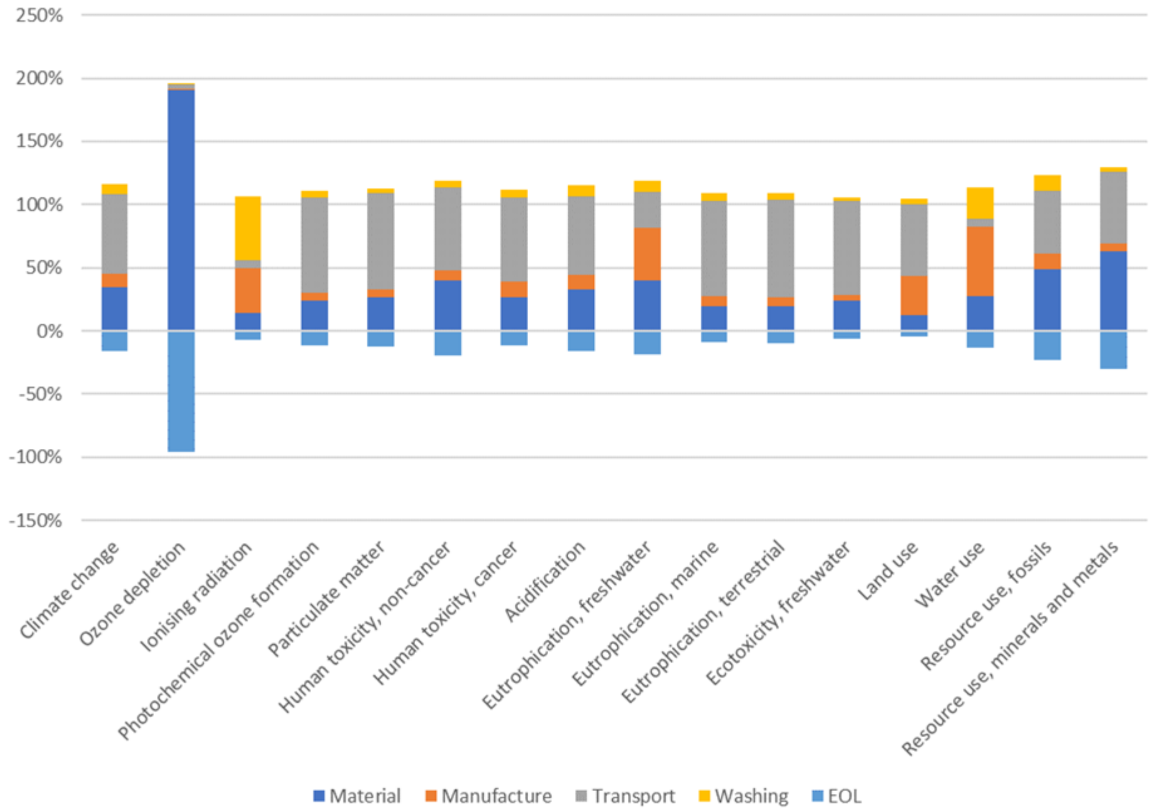


Figure 29: Reusable plastic trays: Environmental impact category results based on the EF 3.0 model for five reusable trays (assuming 100% recycling).

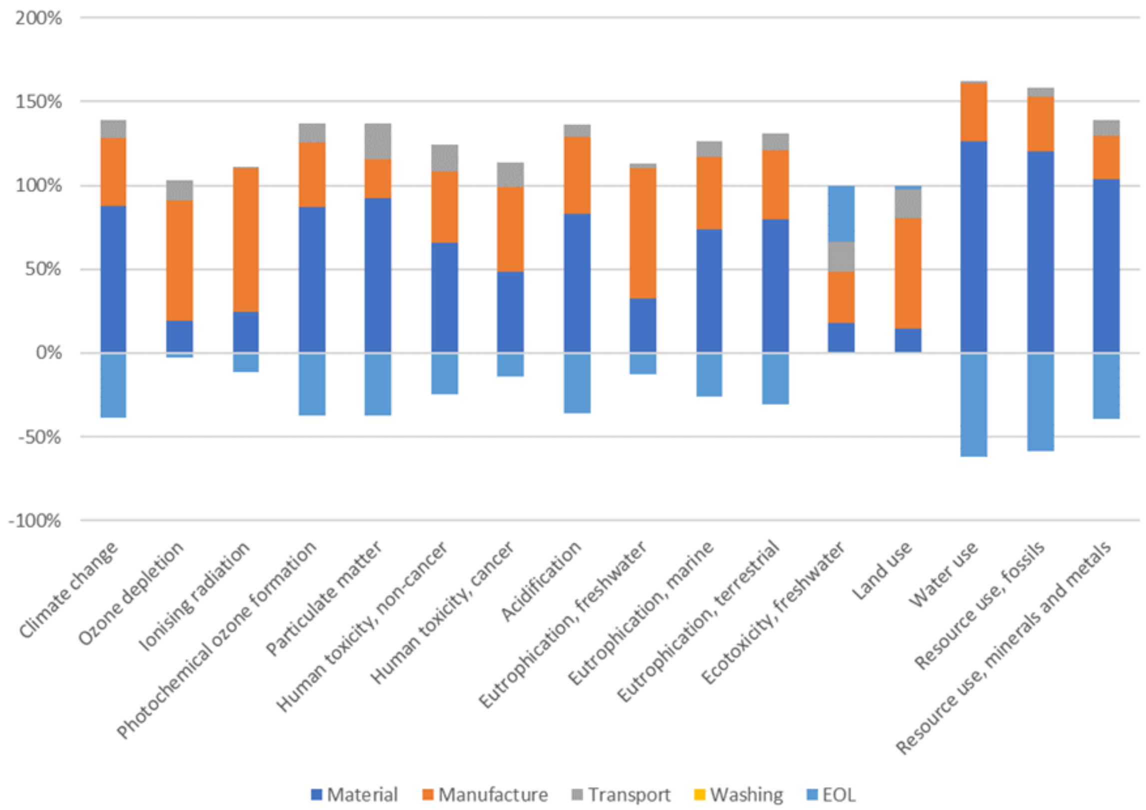


Figure 30: Single-use container: Environmental impact category results for a single-use container (assuming 100% recycling). Note that washing is not relevant in the single-use-case, but is shown in the key for colour consistency.

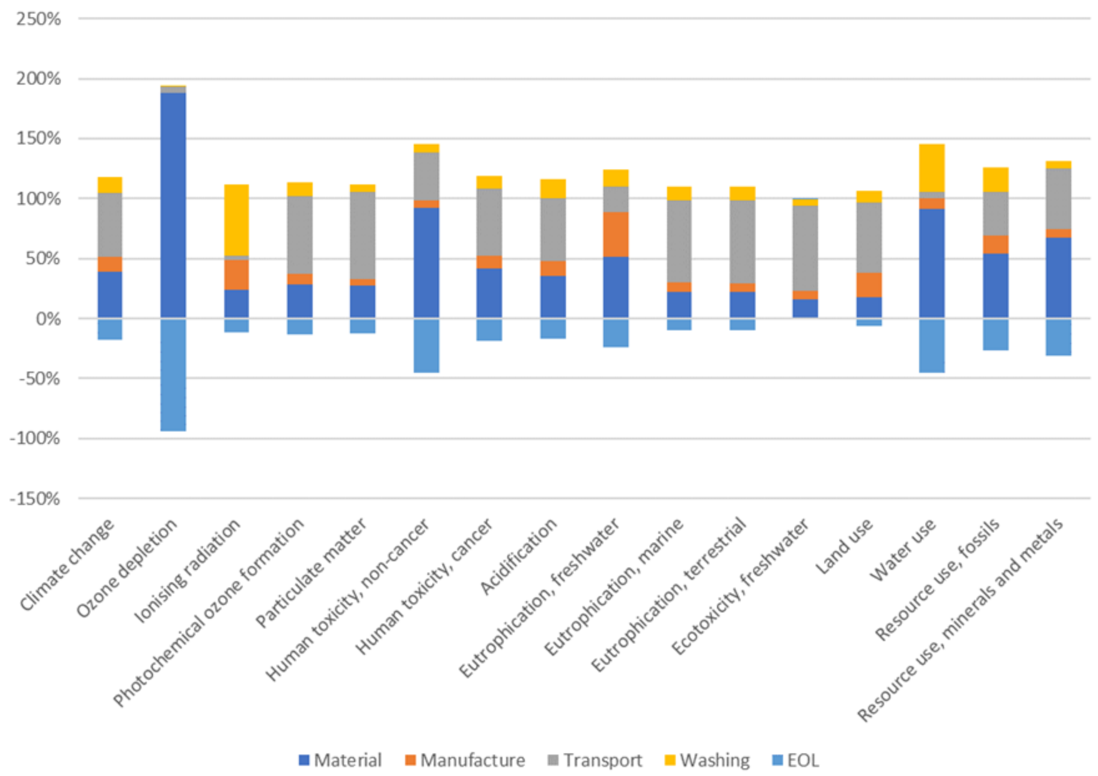


Figure 31: Reusable plastic container: Environmental impact category results for one reusable container (assuming 100% recycling)

3.3.3.2 Sensitivity analysis on Break-Even Point

After impact assessment, break-even analysis was undertaken for the three comparisons. This assessment aimed to identify:

- In the tray case, the number of uses of each type of reusable tray which gave comparable impacts.
- In the container case, the minimum number of uses required for a reusable container to have lower impact than single-use containers.
- In the combined case, the minimum number of uses required for the fully reusable system to have lower impact than the current system.

Break-even analysis results for the tray system are shown in Figure 32 to Figure 34. These graphs show the cumulative impact of the steel tray and plastic tray systems. This is based on delivering 40 meals per cycle, for the number of cycles indicated on the horizontal axis. It is necessarily to present the cumulative impacts as this comparison is of two reusable systems. These results are based on lifetimes of steel and plastic trays of 100 cycles and 50 cycles respectively. After this time, a new tray is manufactured, giving the "steps" visible in the graphs.

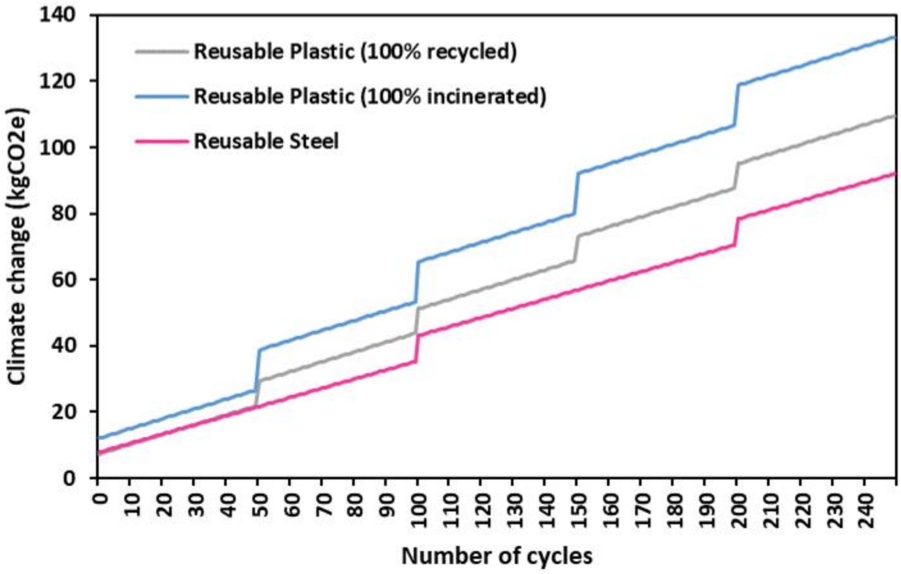


Figure 32: Greenhouse gas emissions break-even analysis results for reusable steel and reusable plastic trays, based on based on the EF 3.0 model for 40 meals per cycle (i.e. one steel tray or five plastic trays). Steel tray lifetime of 100 cycles, plastic tray lifetime of 50 cycles.

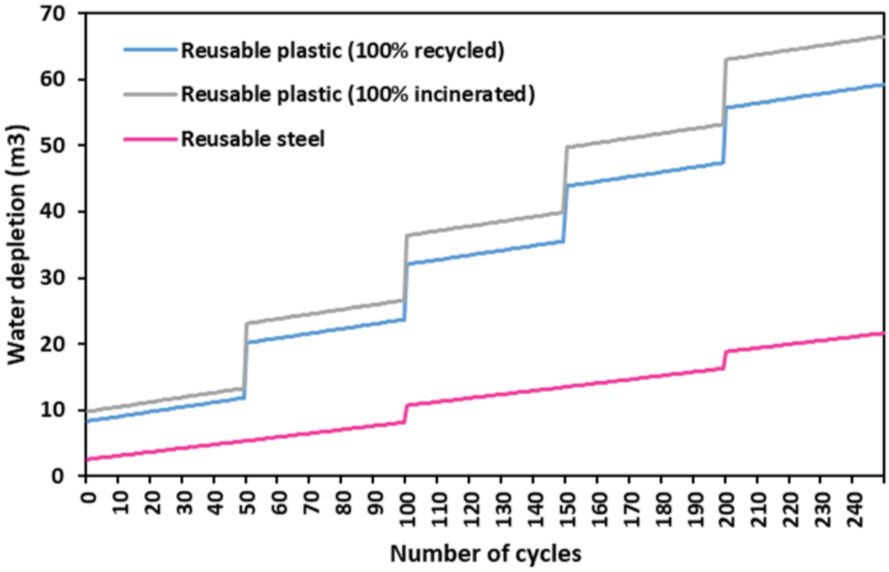


Figure 33: Water depletion break-even analysis results for reusable steel and reusable plastic trays, based on based on the EF 3.0 model for 40 meals per cycle (i.e. one steel tray or five plastic trays). Steel tray lifetime of 100 cycles, plastic tray lifetime of 50 cycles.

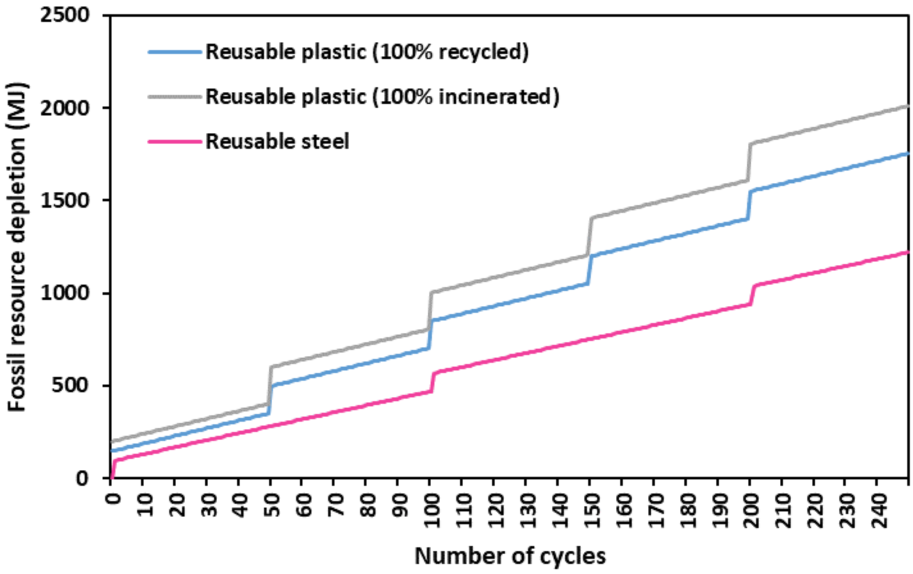


Figure 34: Fossil resource depletion break-even analysis results for reusable steel and reusable plastic trays, based on based on the EF 3.0 model for 40 meals per cycle (i.e. one steel tray or five plastic trays). Steel tray lifetime of 100 cycles, plastic tray lifetime of 50 cycles.

As illustrated in Figure 32 to Figure 34, the current reusable steel trays have lower impact per meal than plastic trays in all cases. This is due in part to the material efficiency provided by the steel trays' ability to deliver 40 meals per tray. The need for five plastic trays to reach the same capacity reduces the efficiency of the plastic tray system. Product lifetimes should be investigated further during the full LCA assessment phase of the project to ascertain whether the values used here are reasonable. In practice, steel trays are likely to last for many more than 100 cycles.

Break-even analysis results for the single-portion container system are shown in Figure 35 to Figure 36. These graphs show the cumulative impact of the single-use PP containers and the reusable PBT container with PP lid. Both contain one meal. These graphs assume the reusable container will last for the full number of cycles on the x axis.

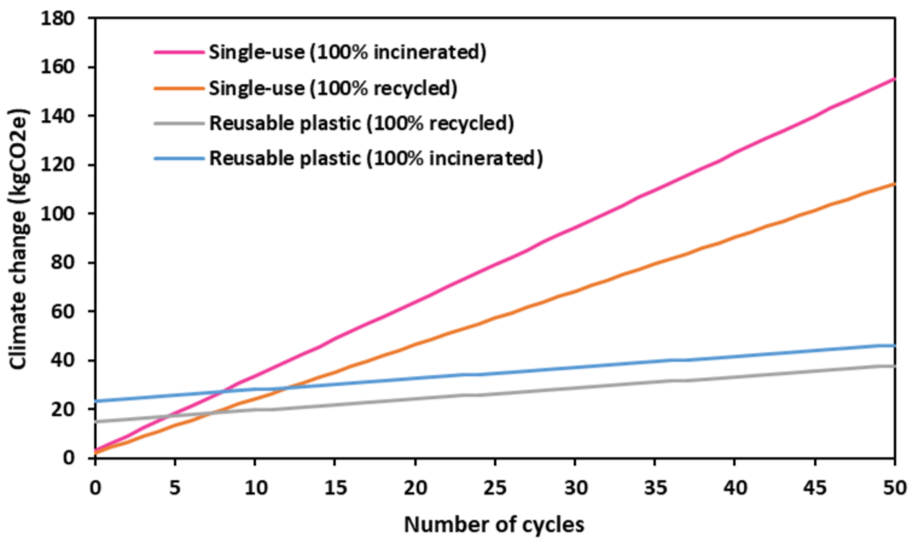


Figure 35: Greenhouse gas emissions break-even analysis results for reusable plastic and single-use plastic trays, based on based on the EF 3.0 model for 40 meals per cycle.

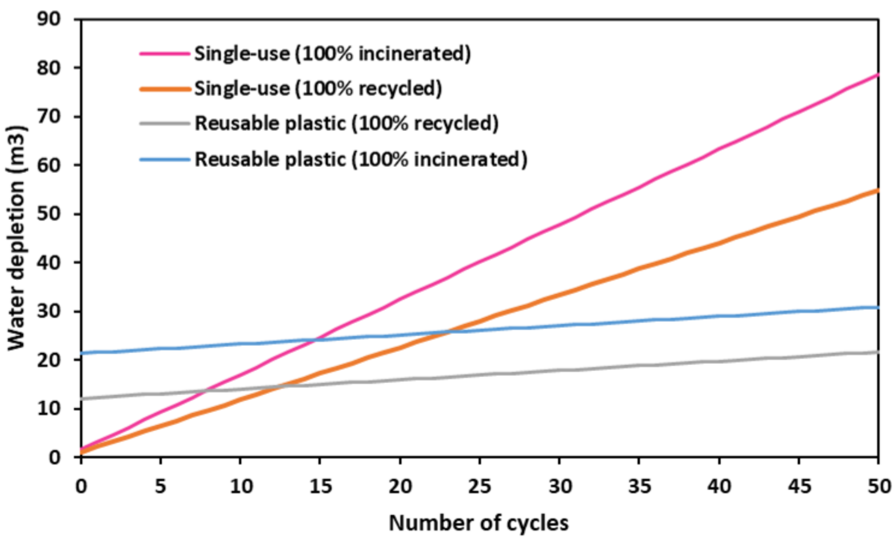


Figure 36: Water depletion break-even analysis results for reusable plastic and single-use plastic trays, based on based on the EF 3.0 model for 40 meals per cycle.

These results illustrate the significant impact of the single-use plastic container, particularly when larger numbers of cycles are considered. The break-even points, which indicate that a system of reusable containers is preferable to a system of single-use containers, occurs after 8 and 12 cycles when measured by impact in Climate change and Water use respectively if 100% recycling is assumed in both cases, and after 8 and 14 cycles if 100% incineration is assumed in both cases. The reusable system continues to perform better over larger cycle numbers, and after 50 cycles the single-use system has around 2 to 2.5 times greater greenhouse gas emissions.

Break-even analysis results for the combined systems including trays and containers are shown in Figure 37 and Figure 38. These combined systems represent the proportional allocation of meals packaged on trays and those packed in containers (80% trays and 20% containers). The two combined systems considered are:

- Steel trays and single-use single-portion plastic SUPP containers (the current system)
- Plastic RPP trays and reusable single-portion plastic RPP containers (the fully reusable system)

To compare all products, the two systems were compared for a shared reference system of 200 meals. In the current system, this requires 4 x steel trays (160 meals) + 40 single-use containers. In the fully reusable plastic system, this requires 20 x plastic trays (160 meals) + 40 reusable containers. Reusable plastic trays and containers are again assumed to have a lifetime of 50 cycles, and steel trays of 100 cycles. As discussed above, lifetimes have a significant impact on overall results and should be considered in detail during subsequent phases of the work. One further theoretical system is also shown. This system is made up of the lowest impact systems from the trays and containers cases, i.e. the steel trays with the reusable single-portion plastic containers. This system is shown for reference.

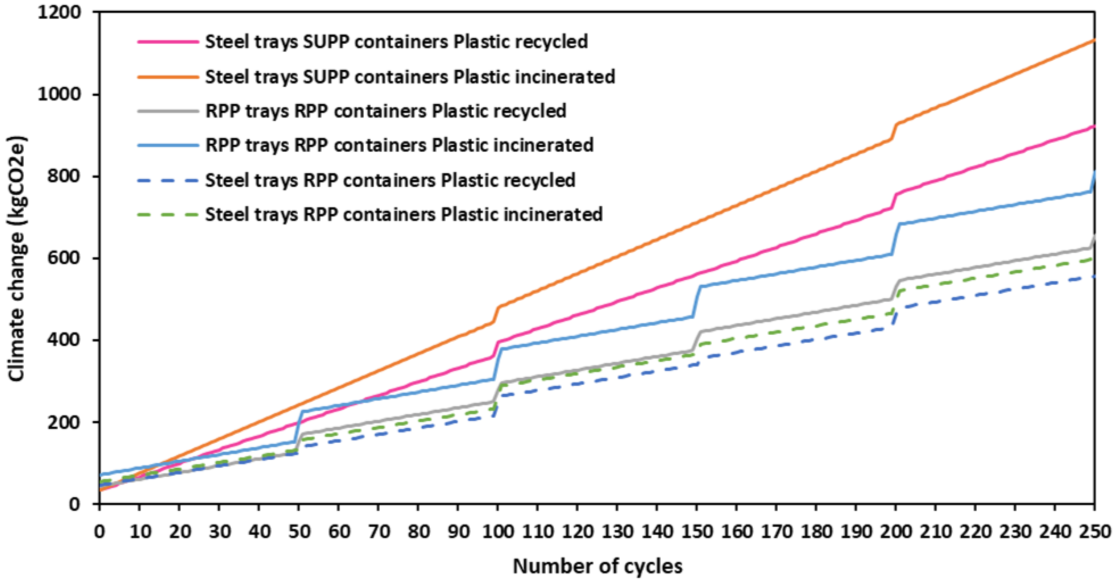


Figure 37: Greenhouse gas emissions break-even analysis results for combined systems, based on based on the EF 3.0 model for 200 meals per cycle (80% on trays, 20% in containers).

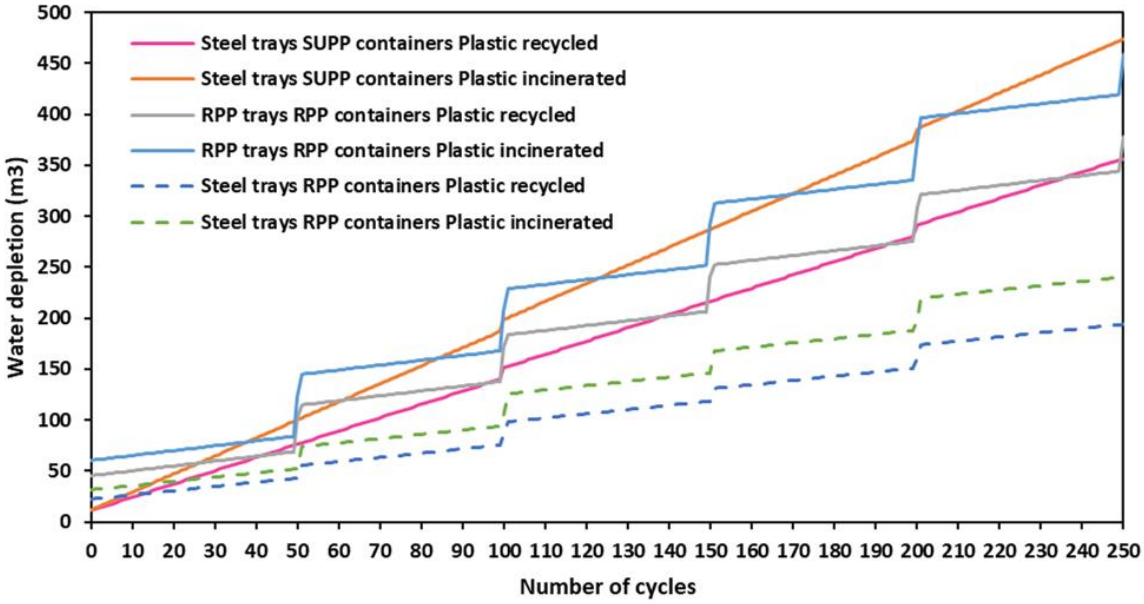


Figure 38: Water depletion break-even analysis results for combined systems, based on based on the EF 3.0 model for 200 meals per cycle (80% on trays, 20% in containers).

A clear conclusion is that the impact of the steel trays and single-use containers case is driven by the impact of the single-use containers. Though the steel trays have lower impact than the proposed RPP trays, when combined with the single-use containers the total impact of this system is greater than that of RPP trays and RPP containers in Climate Change and similar in water depletion. Again, end-of-life treatment has a significant impact, with recycling leading to lower total impact than incineration.
In general, the proposed system of reusable plastic trays and containers reduces the impact of serving meals relative to the current system, with this benefit maximised when material is recycled, and when plastic product lifetimes are as long as feasibly possible. The 'best' system, however, appears to be the combination of current reusable steel trays with proposed reusable plastic containers.

3.3.4 LCCA Cost Analysis

Figure 39 shows the steps of the Ausolan use-case value chain that are integrated in the LCCA study. Market purchase costs are used to describe the cost of the product used in both SUPP and RPP scenario. Indeed, the partners involved in this use-case do not transform the material but purchase it ready to be used.

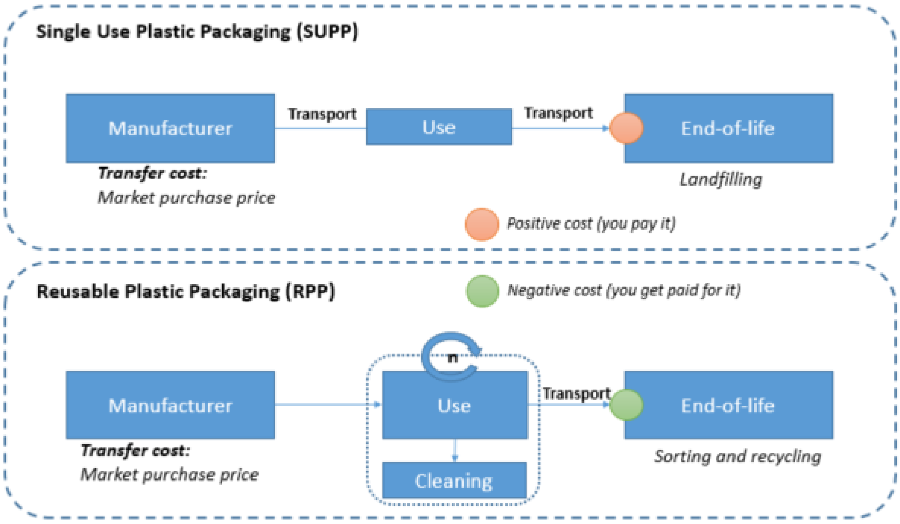


Figure 39: Study perimeter of catering tray use-case LCCA

3.3.4.1 Cost structure for SUPP

The costs for the SUPP scenario are given in Table 37. For this model, the product chosen for the single-use is the multi-portion tray (GPB285 Fedinsa [10]) purchased directly at a market price. The tray is considered as non-recyclable and then landfilled.

Table 37: Cost screening for the Ausolan use-case SUPP scenario

LCC		
Purchase price	0.742 €	per item
Transport	0.002 €	per item
EoL	0.015 €	per item
Total	**0.759 €**	per item

The total cost of the Ausolan SUPP solution is 0.759€/item.

3.3.4.2 Cost structure for Reusable Steel Packaging

The costs for the reusable steel tray and lid are given in Table 38. The product chosen for the reusable strategy is an inox steel tray with an inox lid. The EoL cost of inox steel is 950€/t.

Table 38: Cost screening for Ausolan's use-case reusable scenario

LCC		
Target number of use	100	
Purchase price	45.400 €	per item
Transport	0.088 €	per item
EoL	-1.982 €	per item
Cleaning (OPEX +CAPEX per product)	0.178 €	per cycle
Transport for cleaning	0.002 €	per cycle
Total fixed	**43.506 €**	per item
Total variable	0.180	per cycle

The cleaning step is assumed to be similar to that in the UZAJE use-case (3 million items cleaned per year and cost 0.18€ per cleaning iteration). This assumption will be removed later in the project when data will be collected on the cleaning step of this specific use-case.

The total cost of the Ausolan reusable solution (steel tray and lid) is (43.506 + n * 0.180) €/item.

The costs of the reusable plastic trays and containers have not yet been modelled due to lack of cost data on the production of the tray and container.

3.3.5 Conclusion on hotspots and design guidelines

The reusable steel and plastic trays show a large impact contribution due to transport. This is partly because the trays are used many times, meaning the impact of manufacture per use is low.
The reusable plastic tray shows greater impacts than the reusable steel tray. This is partly because it only holds 8 portions, compared to the 40 that a steel tray can container. Design of the reusable plastic tray should consider how to maximise the number of portions in each tray.

The reusable single-portion container show lower impacts that the single-use single-portion container. Lightweighting of the design will aid in lowering impacts further, as seen in other use-cases.

Thus far, the reusable steel trays plus reusable single-portion plastic containers appear to be the system with the lowest impact.

3.3.6 Data gaps

Data for washing of the various trays and containers has been estimated. A more accurate picture of how many can be washed at once is needed in each case. The number of times the steel and plastic reusable

trays and containers can be used for has been estimated. Accurate data on the reuse rate will be very important to fully assess the system in the Full Circularity Assessment.
Direct and indirect cost data are needed for the reusable plastic packaging scenarios (both tray and container) to enable the cost analysis to be conducted.

3.4 Dawn Meats use-case : Meat secondary food packaging

For this use-case, some data coming from use-case leaders became available during December 2023. However, the deficit of information compared to the other use-cases, including washing phase, End-of-Life treatment scenario or data related to the indirect cost for the LCCA, meant that screening of this case study could not be done within the deadlines of the Deliverable (due in February 2024).
The screening will still be performed to give Dawn Meats inputs on their packaging design and material choice, thus enabling to reach Milestone 7.

3.5 Uzaje use-case : On-the-spot food consumption container

3.5.1 Goal and Scope of the Study

The aim of this life cycle assessment is to assess the cradle-to-grave environmental impacts of a reusable container compared to the single-use baseline for a supermarket on the spot meal. The impact assessment aims to identify the main contributors of the reusable packaging. Then a break-even point (BEP) is evaluated for several changes on the system to identify the minimum number of uses for a reusable container to be considered as preferable as a disposable container.
For this use-case, both reusable and single-use packaging are made of a polypropylene tray and a polypropylene film (Table 29).
The chosen functional unit was: "Contain and enable refrigerated storage for 2 days and distribution to a supermarket food corner in France, so that 500mL of prepared dish can be consumed on site".
The corresponding reference flows are:

- One use of the reusable container (used 20 times);
- One disposable container.

Table 39: Average weight of the reusable and disposable containers (500 ml).

Samples	Packaging unit	Material	Weight (g)
	Reusable container + single-use film	PP	62,75
	Single-use container + film	PP	9,2

Figure 40 and Figure 41 depict a generic system boundary diagram for the reuse and disposable containers. The system consists of four stages: production and manufacturing use phase, waste collection and waste treatment (End-of-life).

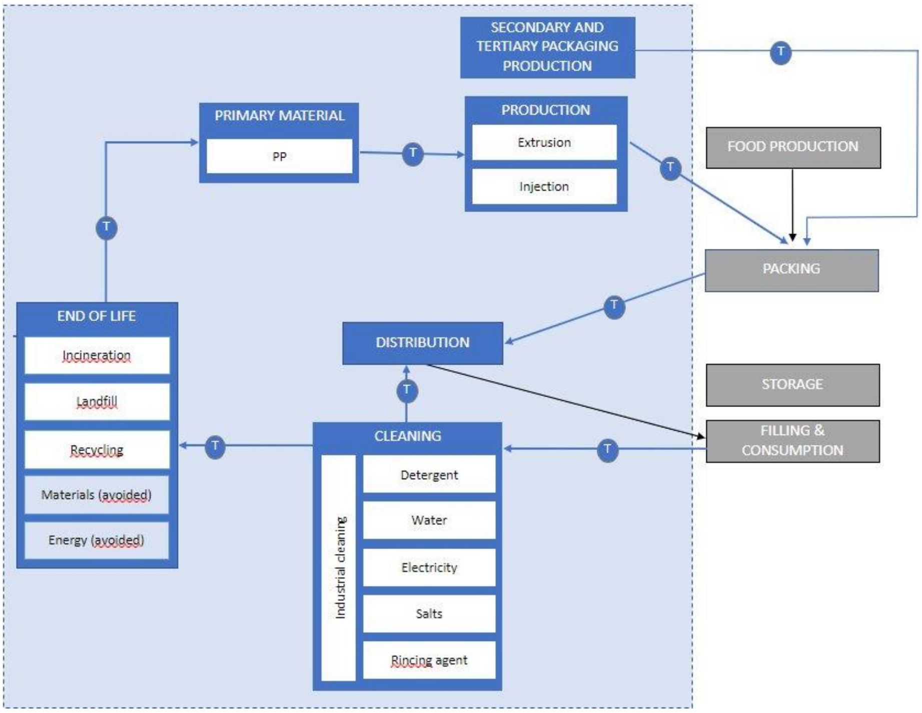


Figure 40: System boundary for life cycle assessment of a reusable container.

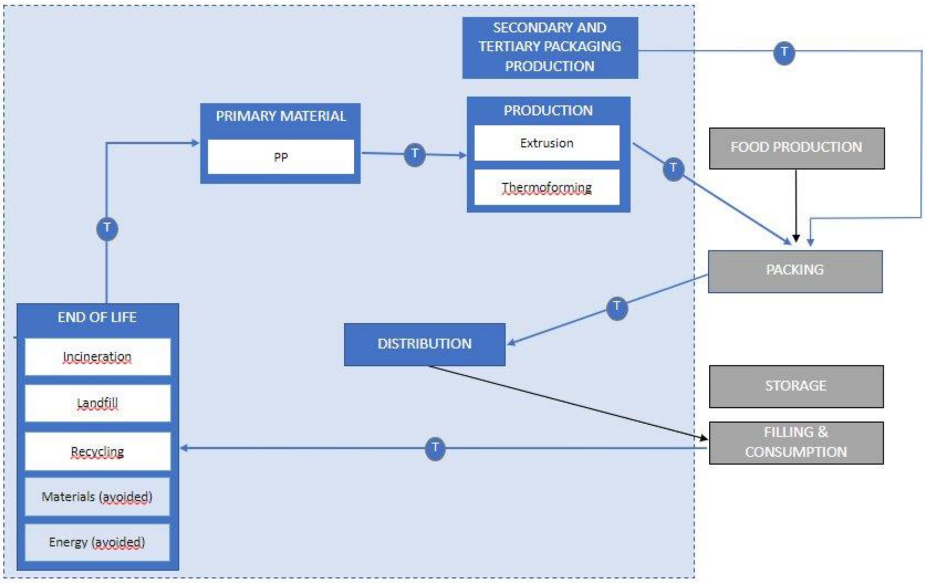


Figure 41: System boundary for life cycle assessment of a single-use container.

Raw materials are produced, then processed into containers (primary material and production phases). Then the containers are transported to a distribution centre. This transport step needs the manufacturing of secondary and tertiary packaging. The containers are transported from the distribution centre to a supermarket where they are filled, stored, consumed and stored to be sent for washing. At the washing facility, containers are washed on an industrial line and inspected before being sent back to the distribution centre. Damaged containers are sent as industrial and commercial wastes to end-of-life facilities, to be recycled, incinerated or landfilled in respect of the French waste scenario.

3.5.2 Life Cycle Inventory (LCI)

The life cycle inventory is given in Table 40 to Table 42. Inventory data was taken from several primary sources, with most of the secondary data coming from the Ecoinvent 3.9. database. For each container,

the main manufacturing processes were applied using representative processes from the Ecoinvent 3.9 database in SimaPro. These processes were modified if necessary to represent the correct country of manufacture and specific loss rate if given by the partners. When the material or manufacturing process was not known, global market data was used.
Transport distances from primary material production to packaging manufacturing are given by Knauf Industries. The other transport steps are calculated for a hypothetic distribution centre and supermarket around Paris, where the Uzaje washing facility is. For the washing stage, the data used is the average water, electricity and detergent consumption per day of the Uzaje washing facility, divided by the assumed washing rate per day of a packaging with those dimensions. Due to confidentiality, this part of the LCI is not shown in the report.
For plastic material recycling processes, data has been extrapolated from Franklin LCI study on PP, PET and HDPE recycling (6). The other materials and waste treatments use Ecoinvent 3.9 data. The reference scenario uses the end-of-life percentages and transport scenario of the ADEME methodology (3).

As the LCI tables are presented per reference flow, the values of steps happening once in the reusable packaging life cycle (material and packaging production, end-of-life, some transport…) are divided by the number of uses, estimated at 20.

Table 40: Life cycle inventory for production and manufacturing single-use and reusable containers (value per functional unit).

Activity	Primary production (Material)						Manufacturing			
	Material		Mass (g)	Recycled content	Country of origin	Model in SimaPro	Process	Country	Loss rate	Model in SimaPro
Reusable system	Container	PP	3,0375	0 %	Spain	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, U	Injection moulding	France	1 %	Injection moulding {FR}| injection moulding | Cut-off, U
	Film	PP	2	0 %	GLO	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U	Extrusion	GLO	2.4 %	Extrusion, plastic film {GLO}| market for extrusion, plastic film | Cut-off, U
	SP: Plastic bag	LDPE	0,019	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, S	Extrusion	France	2,4 %	Extrusion, plastic film {FR}| extrusion, plastic film | Cut-off, U
	SP: Card-board	Card-board	0,21	14,7 %	RER	Corrugated board box {RER}| market for corrugated board box | Cut-off, S	/	/	/	/
	SP: Reusable crate	PP	0,086	0 %	GLO	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, S	Injection	France	0,6 %	Injection moulding {FR}| injection moulding | Cut-off, U

	TP: Pallet	Wood	0,60	0 %	RER	EUR-flat pallet {RER}| market for EUR-flat pallet | Cut-off, S	/	/	/	/
	TP: Film	LDPE	0,057	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, S	Blow moulding	GLO	1 %	Blow moulding {GLO}| market for blow moulding | Cut-off, S
Single-use system	Container	PP	7,2	0 %	Spain	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, U	Extrusion	France	3,1%	Extrusion, co-extrusion {FR}| extrusion, co-extrusion of plastic sheets | Cut-off, U
							Thermoforming	France	5,4 %	Thermoforming of plastic sheets {FR}| thermoforming of plastic sheets | Cut-off, U
	Film	PP	2	0 %	GLO	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U	Extrusion	GLO	2.4 %	Extrusion, plastic film {GLO}| market for extrusion, plastic film | Cut-off, U
	SP: Plastic bag	LDPE	0,071	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, S	Extrusion	France	2,4 %	Extrusion, plastic film {FR}| extrusion, plastic film | Cut-off, U
	SP: Cardboard	Cardboard	0,85	14,7 %	RER	Corrugated board box {RER}| market for corrugated board box | Cut-off, S	/	/	/	/
	TP: Pallet	Wood	0,089	0 %	RER	EUR-flat pallet {RER}| market for EUR-flat pallet | Cut-off, S	/	/	/	/
	TP: Film	LDPE	0,0085	0 %	GLO	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, S	Blow moulding	GLO	1 %	Blow moulding {GLO}| market for blow moulding | Cut-off, S

Table 41: Life cycle inventory for transportation of single-use and reusable containers.

Activity	Transportation					
	Name	Type	Departure region	Arrival region	Value (kg.km)	Model in SimaPro
Reusable container	Primary material to injection plant	Road	Spain	Dreux, France	3,7	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Injection plant to distribution centre	Road	Dreux, France	Ile-de-France, France	0,28	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Distribution centre to supermarket	Road	Ile-de-France, France	Paris, France	1,3	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U
	Supermarket to washing facility	Road	Paris, France	Ile-de-France, France	1,5	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U
	Washing facility to distribution centre	Road	Ile-de-France, France	Ile-de-France, France	0,97	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U
	Waste collection	Road	French average		0,00095	Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U
	Transfer to sorting facility	Road	French average		0,1565	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
	Transfer to recycling facility	Road	French average		1,35	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
Single-use container	Primary material to extrusion plant	Road	Spain	Torcé, France	9,4	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Extrusion plant to thermoforming plant	Road	Torcé, France	Nantes, France	1,3	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Thermoforming plant to distribution centre	Road	Nantes, France	Ile-de-France, France	2,8	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
	Distribution centre to supermarket	Road	Ile-de-France, France	Paris, France	0,14	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U
	Waste collection	Road	French average		0,00027	Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U
	Transfer to sorting facility	Road	French average		0,46	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
	Transfer to recycling facility	Road	French average		3,9	Transport, freight, lorry >32 metric ton, EURO5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

Table 42: Life cycle inventory for End-of-Life scenarios

Material	End-of-life percentage	End-of-life scenario	Model in SimaPro	
Polypropylene	26,5 %	Recycling	Input process	Recycling of PP based on Franklin, 2018 (6)
			Avoided product	Polypropylene, granulate {RoW}| polypropylene production, granulate | Cut-off, U
	21,3 %	Incineration (energy recovery)	Input process	Waste polypropylene {CH}| treatment of waste polypropylene, municipal incineration | Cut-off, U
			Avoided product	Heat, district or industrial, natural gas {FR}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Heat, district or industrial, other than natural gas {FR}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U Electricity, medium voltage {FR}| market for electricity, medium voltage | Cut-off, S
	52,2 %	Landfill	Input process	Waste polypropylene {CH}| treatment of waste polypropylene, sanitary landfill | Cut-off, S
Cardboard	98,5 %	Recycling	Input process	White lined chipboard carton {RER}| white lined chipboard carton production | Cut-off, S
			Avoided product	Solid bleached and unbleached board carton {RER}| solid bleached and unbleached board carton production | Cut-off, S
	0,4 %	Incineration (energy recovery)	Input process	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, S - Copied from Ecoinvent Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	1,1 %	Landfill	Input process	Waste paperboard {CH}| treatment of waste paperboard, sanitary landfill | Cut-off, S
LDPE	26,5 %	Recycling	Input process	Recycling of HDPE based on Franklin, 2018 (6)
			Avoided product	Polyethylene, low density, granulate {RoW}| polyethylene production, low density, granulate | Cut-off, S
	21,3 %	Incineration (energy recovery)	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, S - Copied from Ecoinvent Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	52,2 %	Landfill	Input process	Waste polyethylene {CH}| treatment of waste polyethylene, sanitary landfill | Cut-off, S
Wood	29 %	Incineration (energy recovery)	Input process	Waste wood, untreated {CH}| treatment of waste wood, untreated, municipal incineration | Cut-off, S
			Avoided product	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, S - Copied from Ecoinvent Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, S
	71 %	Landfill	Input process	Waste wood, untreated {CH}| treatment of waste wood, untreated, sanitary landfill | Cut-off, S

3.5.3 LCA Results and Sensitivity Analyses

3.5.3.1 Comparative assessment

The comparative results are given Figure 42 between the reusable packaging used 20 times and the single-use packaging. Concerning the two indicators that will be mostly studied in this part, Climate change and Water use, the reusable packaging causes at least 15% less impact than the single-use one for 20 uses. The reusable packaging causes more impact on three indicators: Ozone depletion, Ionizing radiation and Freshwater ecotoxicity.

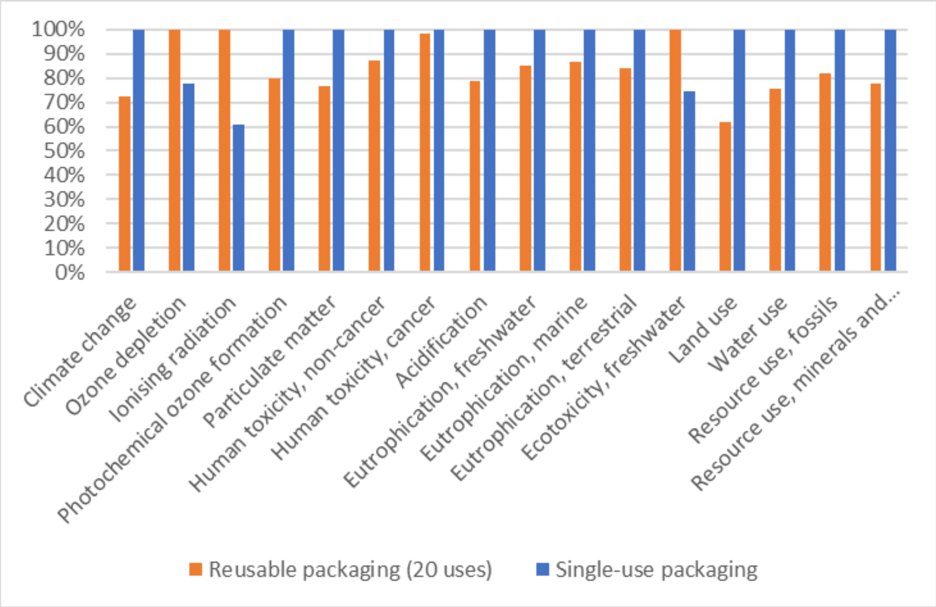


Figure 42: Comparative LCA between reusable and single-use packaging

3.5.3.2 Analysis of contributors

Analysis on the contributions of the life cycle stages for the reusable system for one and 20 uses are shown respectively in Figure 43 and Figure 44. For only one use, the main impact is from the material (predominantly polypropylene production) for all indicators. For land use, secondary and tertiary packaging production also contribute, as they are mainly made from biosourced materials, cardboard and wood. Transport and washing are negligible.

When used 20 times, the reusable system logically contributes less to the life cycle impact for every indicator, as its production impact is divided by 20. Washing becomes a significant contributor. The impact on climate change, ionising radiation and fossil resource use is mainly due to electricity consumption. The contribution on ozone depletion and mineral resource use is due to detergent production. Transport and EoL remain negligible.

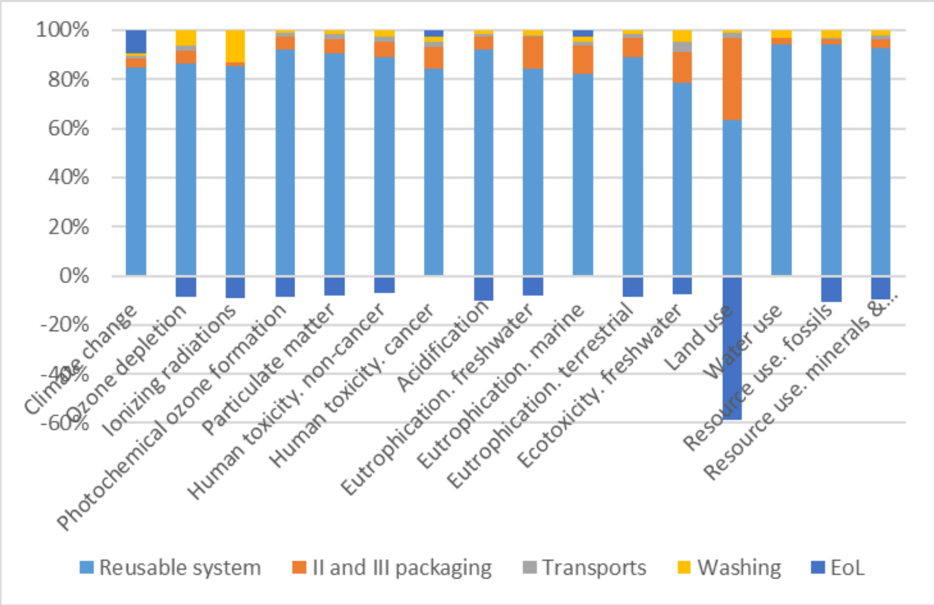


Figure 43: Life cycle contributors for the RPP system (1 use)

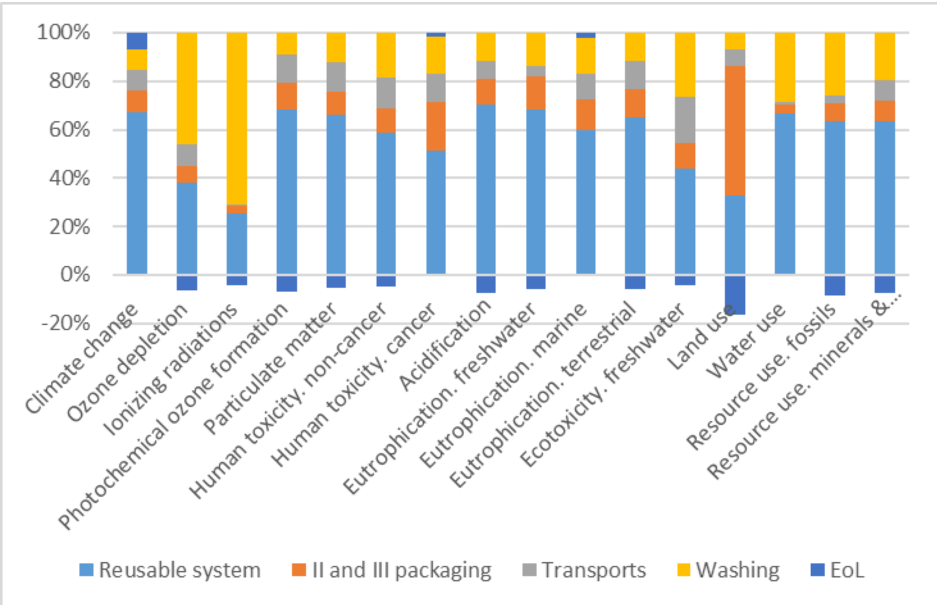


Figure 44: Life cycle contributors for the RPP system (20 uses)

For the single-use system, most of the impacts shown Figure 45 are due to the production of the single-use container. For land use, the main contributor is the secondary and tertiary packaging production and their End-of-Life, as they are mainly made from biosourced materials, cardboard and wood.

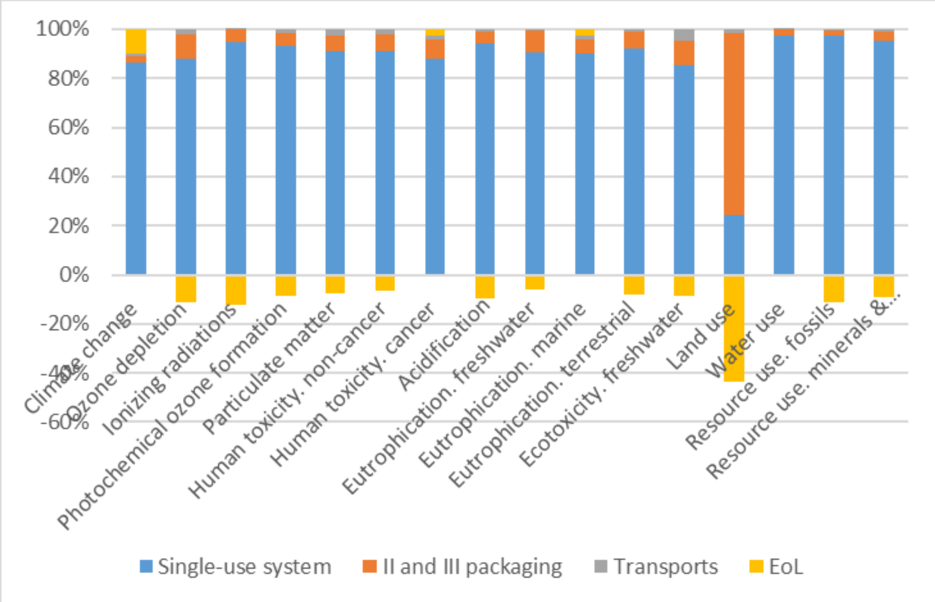


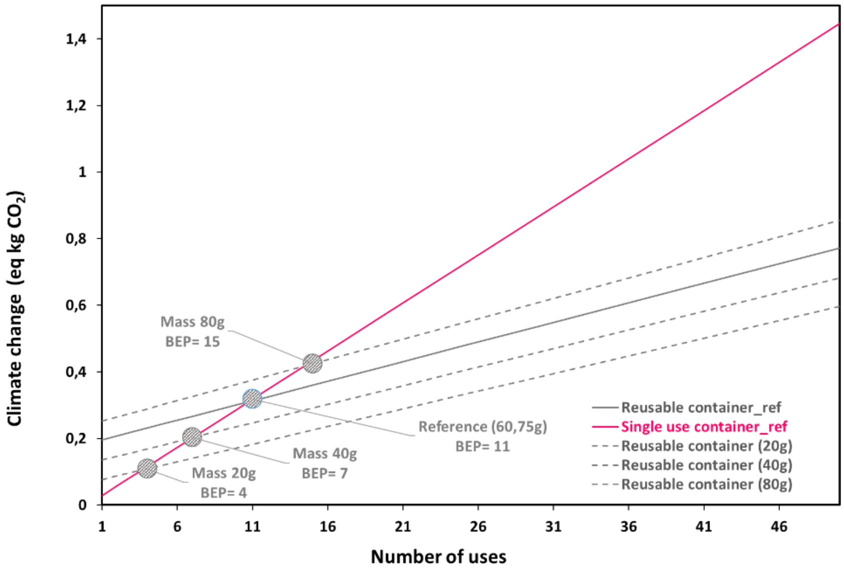
Figure 45: Life cycle contributors for the SUPP system

3.5.3.3 Sensitivity analysis on Break-Even Point

3.5.3.3.1 Container Mass

As the reusable container design may change during the project, to make it more resistant to the reuse loop, it is interesting to see the impact of weight change on the BEP to help WP1 choose the best combination of mechanically attainable yet with low environmental impact. To do so, the baseline scenario of a 60.75 g container is compared to a 20 g, 40 g and 80 g container scenario.

It can be seen in Figure 46 that the reduction ratio is the same between container mass and BEP, i.e. when the container mass goes from 60 g to 20 g, the BEP for Climate change and Water use is approximately divided by 3.



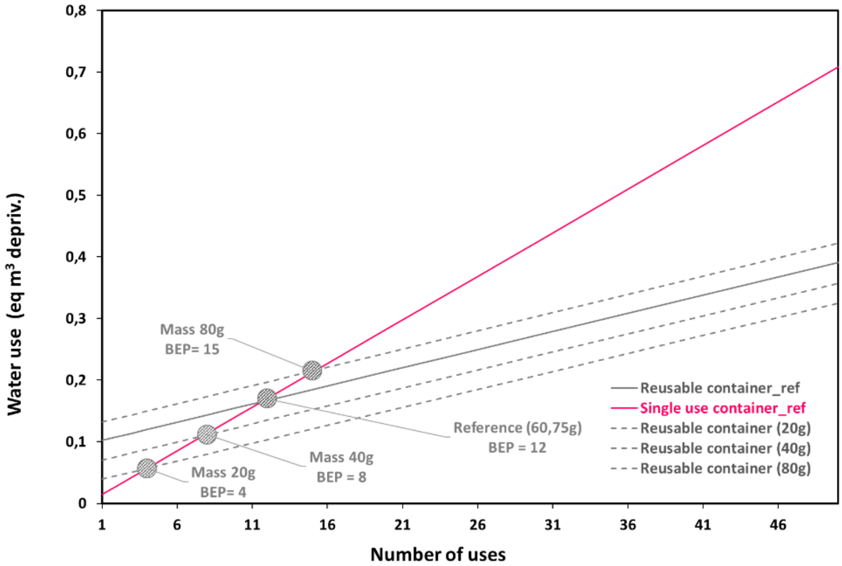
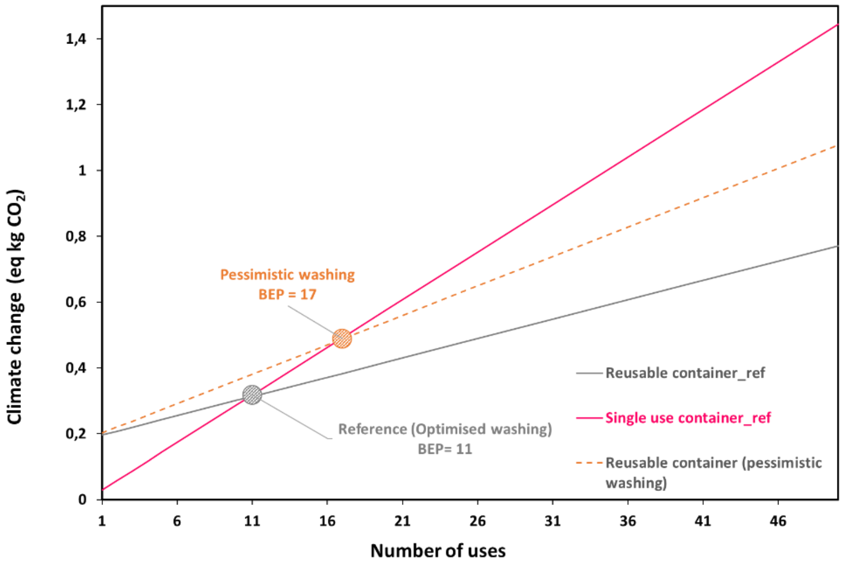


Figure 46: Climate change & Water use BEP evolution depending on container mass

3.5.3.3.2 Washing consumptions

During the model of washing step, it has been identified by the partner that there is a risk that the consumption become higher if the machines use is not optimised. The risk has been evaluated at multiplying water use by 2.5 and electricity consumption by 6.

Figure 47 shows that these assumptions would make the BEP go from 11 to 17 uses for Climate Change and more drastically from 12 to 29 uses for Water use.



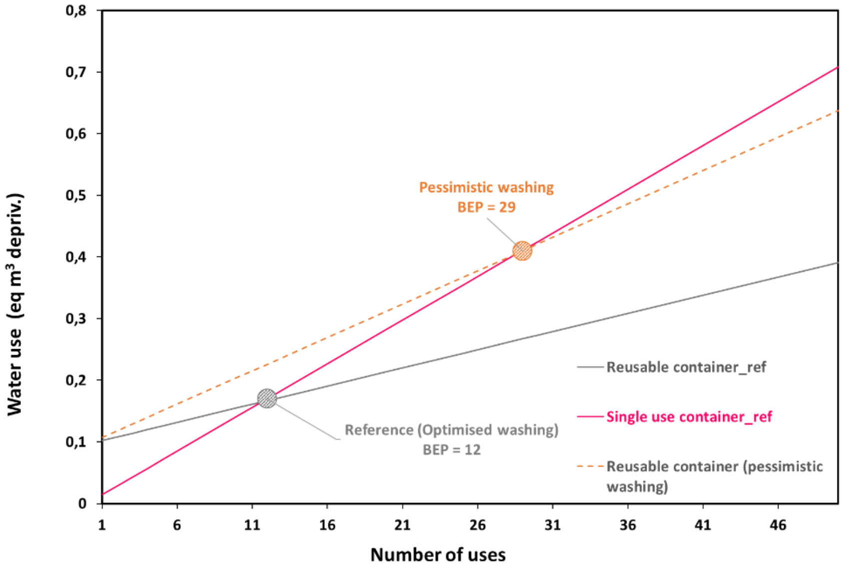


Figure 47: Climate change & Water use BEP evolution depending on washing consumptions

3.5.3.3.3 Transport distances

The transport steps do not show a big contribution to the impacts, due to the use-case happening only in the North-West of France and the reuse loop staying inside of Ile-de-France. A sensitivity analysis is then made to study the impact on the BEP of multiplying transport distances by five. This magnification only raises the BEP from 11 to 14 uses on Climate change, as seen in Figure 48. The transport distance change has no impact on the Water use BEP.

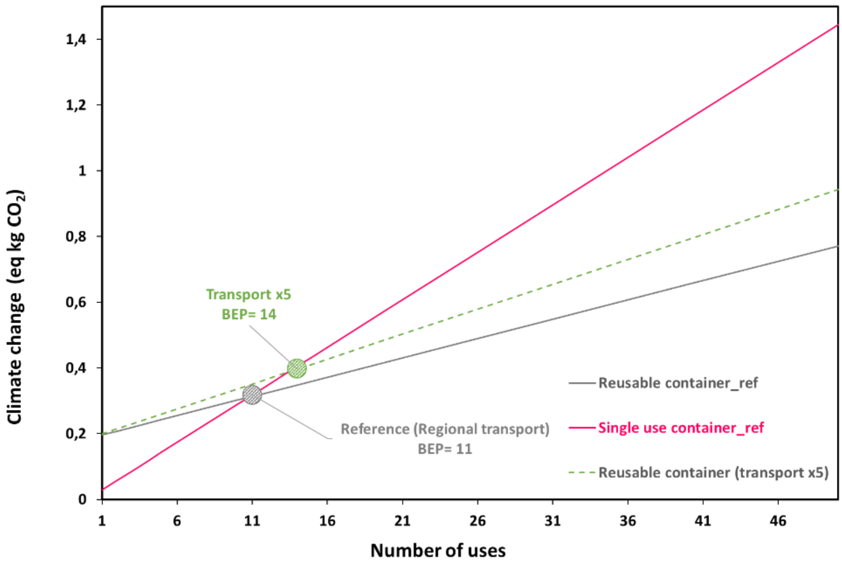


Figure 48: Climate change evolution depending on transport distances

3.5.3.3.4 End-of-Life scenario

The baseline EoL scenario considered is the French one for Industrial and Commercial packaging. For the reusable container, the recycling percentage of a rigid plastic packaging is 26.5%. It is not sure if the container developed in the project will be able to be integrated in the current recycling chain. The aim of the project is also to create closed loop recycling chains, maximising recycling rates. Thus, it is important to assess the potential impact of the extreme EoL scenarios: a 100% recycling rate and a 100% incineration rate.

As shown in Figure 49, non-recyclable packaging would have to be used approximately twice as much as that which is recyclable to reach the BEP on Climate change. Increasing the recycling rate from 26.5%

to 100% has a small impact on the Climate change BEP. The End-of-Life scenario change has no impact on Water use BEP evolution.

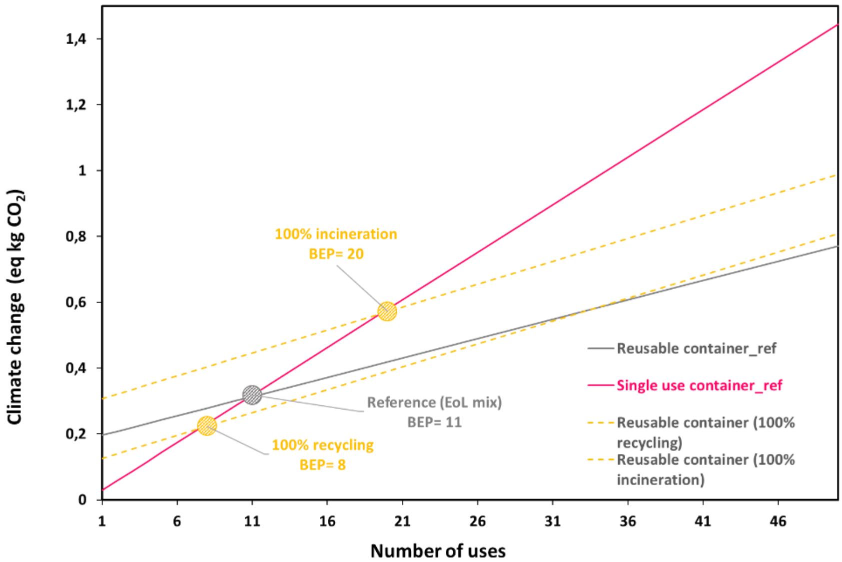
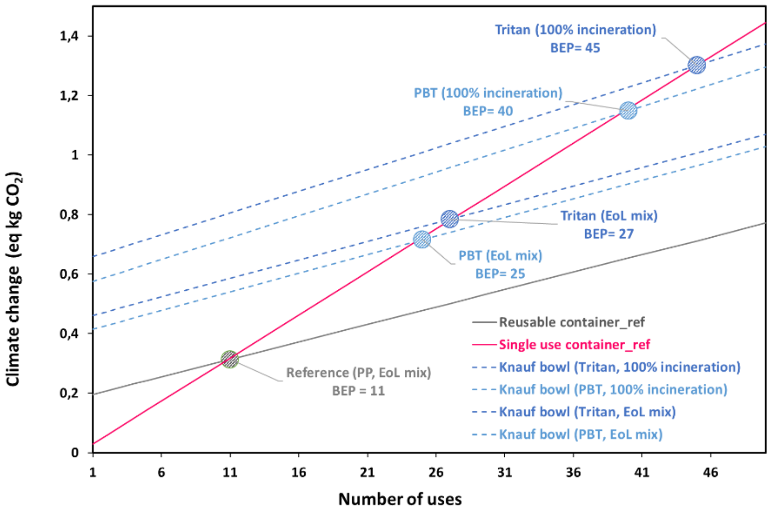


Figure 49: Climate change BEP evolution depending on packaging EoL

3.5.3.3.5 Reusable container material

As for the packaging mass, the material chosen by WP3 is prone to changing during the rest of the project. In this use-case, the baseline material, polypropylene, is the one currently used by Knauf Industries for their reusable packaging line. However, WP3 aims to test prototypes made of Tritan™ copolymer and PBT in the next steps of the project. The impact of these three materials on the BEP, according to their respective density and considering a baseline 100% incineration rate for PBT and Tritan containers as they are not recyclable for now, is shown in Figure 50. For Climate change, switching to PBT or Tritan requires to approximately quadruple the number of uses of the container to reach the same BEP, and approximately double it if the technical recycling rate is 26.5%.
For Water use, Tritan BEP is lower than PP and even twice as low if recycled. For PBT, whatever the EoL scenario is, the BEP is five times higher than that for PP.



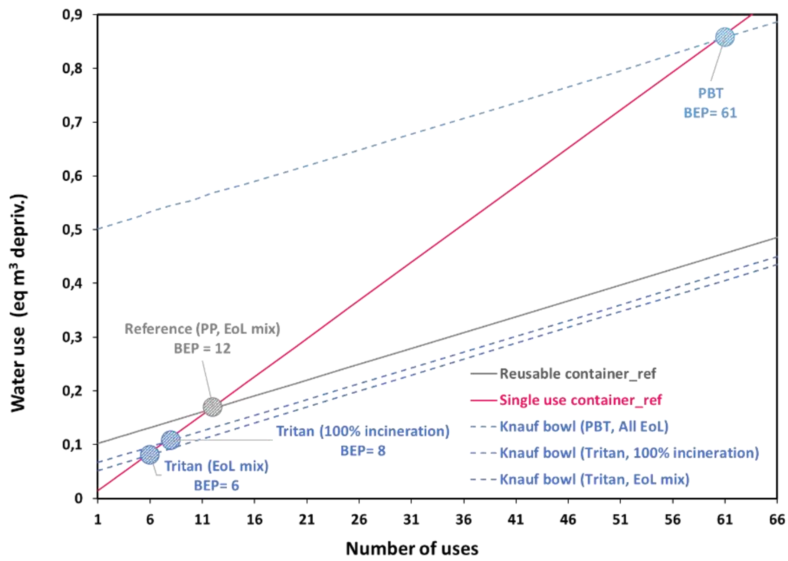
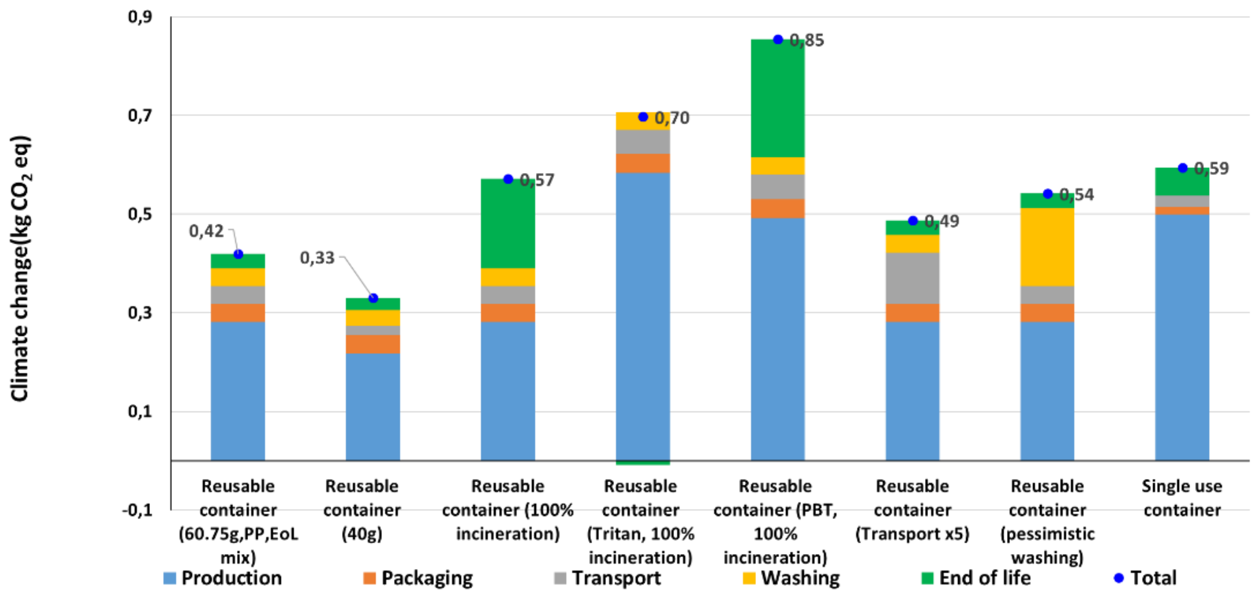


Figure 50: Climate change & Water use BEP evolution depending on container material

In conclusion, Figure 51 shows the impact of above-studied sensitivity analyses for a container used 20 times, as in the reference flow chosen, compared to 20 single-use containers. It shows that for Water use, reusable container impact stays below single-use for every scenario except if material is changed for PBT, and if washing water consumption is not optimised. For Climate change, end-of-life scenario and material change can make the reusable container have a bigger impact than the single-use one.



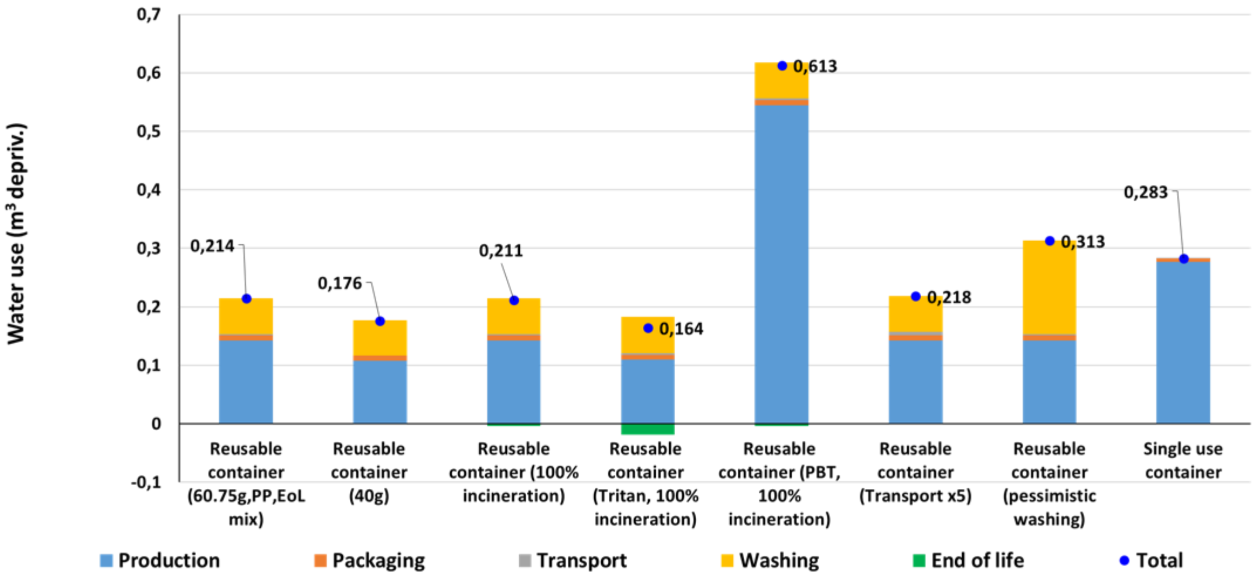


Figure 51: Results per hypothesis for a container used 20 times, compared to 20 single-use containers

3.5.4 LCCA cost analysis

Figure 52 shows the steps of the use-case value chain that are integrated in the LCCA study. Market purchase costs are used to describe the cost of the product used in both SUPP and RPP scenario. Indeed, the partners involved in this use-case do not transform the material but purchase it ready to be used. In addition, both products are PP based and then recycled at end-of-life.

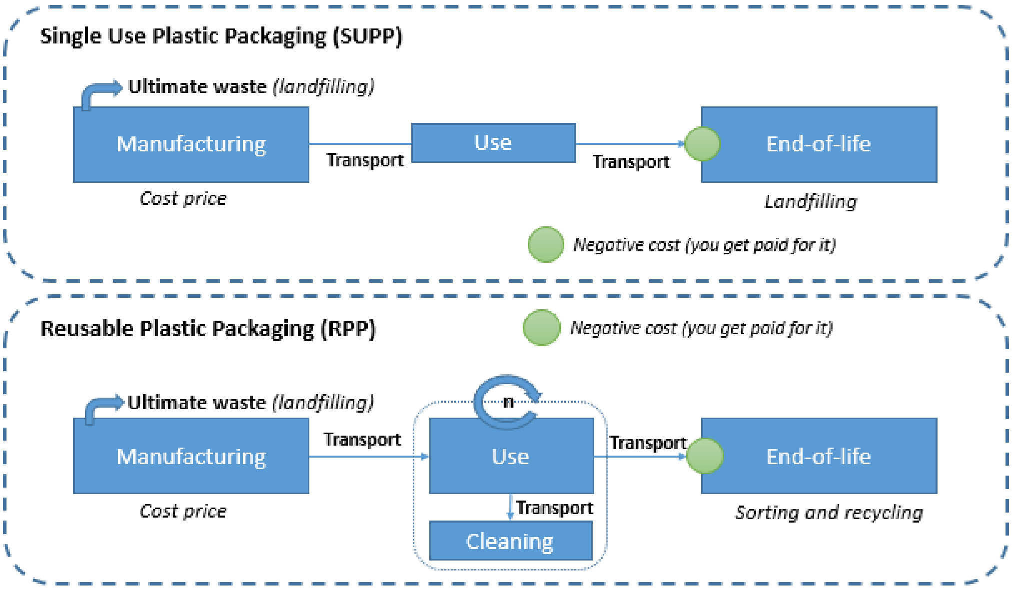


Figure 52: Study perimeter of on-the-spot use-case LCCA

3.5.4.1 Cost structure for SUPP

The costs for the SUPP scenario are given in Table 43. For this model, the product chosen for the single-use is a PP tray and a PP film directly at a market price. The tray and film are considered recyclable in the PP waste stream. The EoL cost of PP is 680€/t.

Table 43: Cost screening for Uzaje's use-case SUPP scenario

LCC		
Purchase price	0.060 €	per item
Transport	0.001 €	per item
EoL	-0.018 €	per item
Total	0.043 €	per item

The total cost of the Uzaje SUPP solution is 0.043€/item.

3.5.4.2 Cost structure for RPP

The costs for the RPP scenario are given in Table 44.
The Uzaje cleaning step is given for 3 millions of items cleaned per year. Transport is 400km there and back.

Table 44: Cost screening for Uzaje's use-case RPP scenario

LCC		
Purchase price	0.800 €	per item
Transport	0.002 €	per item
EoL	-0.043 €	per item
Cleaning (OPEX +CAPEX per product)	0.178 €	per cycle
Transport for cleaning	0.002 €	per cycle
Total fixed	0.759 €	per item
Total variable	0.180 €	per cycle

The total cost of the Uzaje RPP solution is (0.759 + n * 0.180) €/item.

3.5.4.3 Break-even point

At this stage of the project there is no breakeven point as the cleaning step is more expensive that the purchase of the single-use packaging. Those numbers will have to be validated as the different models are optimized.

3.5.5 Conclusion on hotspots and design guidelines

The main identified hotspots of this screening study on climate change, water consumption and total cost of the reusable packaging are:

- Primary material: PP production, even more if the material is changed to Tritan or PBT;
- Washing phase: actual consumptions make the reusable packaging more expensive than the single-use, and if they raise, more impactful on Water use;
- End-of-Life: If the material is changed to PBT or Tritan without a proper integration into the current recycling schemes, a 100% incineration scenario makes the BEP almost unreachable.

The corresponding guidelines are:

- Work on the packaging mass reduction at identical functionalities, especially with a material change to PBT or Tritan;
- Reduce the consumptions of the washing phase;
- Carry out a precise analysis of consumer behaviour to make the return rate as high as possible;
- Make a recyclable packaging, but reaching a higher recycling rate than the average French percentage does not make impact smaller, so a close loop recycling scheme is not mandatory on an LCA point of view.

3.5.6 Data gaps

For LCA, the washing data has to be improved to correspond to the specific packaging used in this use-case. Data from other washing facilities can also be collected to get an average French data. Transports steps will also be more precise when data from large scale demonstration actors will be gathered. Real mass and precise material data are missing for this screening study. For example, if PBT is the final material chosen, real data will have to be created. The EoL scenario of those new materials must also be more precise, based on scientific prospective data. Finally, the real reuse rate, using the formula in the PEF and the ADEME methodology, is missing. For now, it is only the number of washing cycles the packaging can resist, but it may be lower considering other parameters like return rate that will be collected during the large scale demonstration phase of the project.
For the LCCA, the following data are missing:

- For the SUPP test-case:
    - CAPEX, maintenance and labour or purchase cost
- For the RPP test-case:
    - CAPEX, maintenance and labour or purchase cost.

4 Work performed on SLCA

4.1 Methodology chosen

The selected methodology for Social Life Cycle Assessment (SLCA) studies, as detailed in the previous deliverable D7.1 « Definition of goal & scope, assessment methodology », was influenced by the forthcoming ISO standard, which aligns with the United Nations Environment Programme's (UNEP) "Guidelines for Social Life Cycle Assessment of Products and Organizations" published in 2020 (13). While the UNEP guidelines lacked some detailed and practical information, the Product Social Impact Assessment (PSIA) handbook (11) and the World Business Council for Sustainable Development (WBCSD)(12) methodological guides provided additional support for conducting SLCA. Opting for simplicity, especially for screening studies, the project chose to follow the WBCSD guidelines while adapting them to specific case studies within the UNEP/SETAC framework.
Regarding impact categories, the project chose to focus on 11 mandatory subcategories/social topics outlined in the WBCSD guidelines, ensuring predefined reference scales and data sources for simplicity and consistency. Additional indicators are selected based on relevance to case studies, with a focus on developing appropriate reference scales and impact indicators. Tools such as the Risk Mapping Tool of the Social Hotspots Database will aid in defining the assessment scope and impact categories.
In summary, the project steps for S-LCA studies closely follow those laid out for LCA in ISO 14040, and include identifying relevant social topics, defining impact indicators and reference scales, collecting data, evaluating impacts, and interpreting results.

4.2 Adjustments for screenings

For task 7.4, the challenge was to determine what could be qualified as a "screening" study in SLCA. There is no a clearly defined screening version of S-LCA. Due to the constraints of time, conducting a comprehensive S-LCA within the designated period for task 7.4 was not feasible. Consequently, we adapted our approach to produce results with following planned activities:

- Providing preliminary results using the SHDB (Social Hotspots Database).
- Identifying and selecting relevant social topics for the comprehensive circularity assessment
- Defining the reference scales to be associated with each social topic.
- Developing a data collection sheet to serve as an exchange platform with BUDDIE-PACK partners.
- Collecting Corporate Social Responsibility documents from the partners and analyse their commonalities and differences.

These steps aim to lay the groundwork for the full assessment and ensure alignment with project objectives.

4.3 Screening study

4.3.1 Preliminary results with SHDB database

The Social Hotspot Database (SHDB) is a database created in 2009 by NewEarth (USA), mainly following the UNEP guidelines. This database is used to identify a first level of risk (hotspots) via the collection of generic data. It covers 140 countries and 57 economic sectors. The main sources for data are the World

Health Organization (WHO), the International Labor Organisation (ILO), the U.S Dept of State, the World Bank Development Indicators, the UNICEF, the UNDP Humain Development Report and more.
For the project, we had temporary access to the SHDB's Risk Mapping Tool, an online tool using SHDB's data. This allowed us to conduct a brief hotspot analysis focusing on the countries with the highest risk of negative impacts. We also used the results to define a preliminary list of relevant social indicators. Identified hotspots and relevant social indicators are given in next sections of the report.

4.3.1.1 SHDB categories and data collection method

Data available in S-LCA are covering a given number of countries and sectors. To determine the countries and sectors to evaluate through the SHDB, the first step was to identify the life cycle stages of a generic plastic product suitable for assessing social performance, the main selection criteria being the completeness of the SHDB database. The chosen stages were Raw Materials manufacturing stage, which includes Crude oil extraction, Oil refining, Cracking/Granulate production, and Manufacturing stage. Table 45 shows how correspondence was found between life cycle stage and SHDB sectors.

Table 45: Sources for plastics life cycle stage market analysis and corresponding SHDB category

Life Cycle Stage	Atlas economic complexity	Resource Trade	SHDB
Crude oil extraction	Petroleum oils, crude	Crude oil	Oil
Oil refining	Petroleum oils, refined	Refined oil and oil products	Coal, Petroleum products
Cracking/Granulates production	Plastics	-	Chemical, rubber, plastic products
	Polymers of ethylene	-	Chemical, rubber, plastic products
	Polymers of propylene	-	Chemical, rubber, plastic products
Manufacturing	-	-	Manufactures

The second step was to determine which countries have the largest market shares for each of these lifecycle phases. To achieve this, we used the Growth Lab database, accessible on the Atlas Economic Complexity website (14), and the Resource Trade data (15). The selected countries per life cycle stage are detailed in Table 46. In the case of the manufacturing stage, both our BUDDIE-PACK partners' countries and the principal Western European countries were considered for the selection.

Table 46: Countries studied per plastics life cycle stage

Crude oil extraction	Oil refining	Cracking/granulates production	Manufacturing
United Arab Emirates	USA	China	Germany
Saudi Arabia	United Arab Emirates	Germany	France
Russia	Russia	USA	Spain
USA	Netherlands	South Korea	Italy
Canada	India	Japan	United Kingdom
Iraq	Singapore	Netherland	Belgium
Nigeria	China	Italy	Netherland
Norway	South Korea	Belgium	Ireland

Angola	Malaysia	France	
		Taiwan	
		Saudi Arabia	
		Iran	
		Canada	
		Thailand	
		United Arab Emirates	

The third step was to establish an equivalence between the social topics provided by the WBCSD, the UNEP and the SHDB. However, not all social topics aligned perfectly, leading to choices being made on a best-fit basis. The resulting equivalences are outlined in Table 47.

Table 47: Social topics equivalence between different methods

WBCSD/UNEP Category	SHDB Category
Freedom of association, collective bargaining, right to strike	Freedom of association, collective bargaining, right to strike
Child labour	Child labour
	Children out of school
Fair wages	Wage assessments
	Workers in poverty
No forced labour, human trafficking and slavery	Forced labour
	Migrant labour
Appropriate working hours	Excessive working time
Workers occupational health risks	Occupational toxics & hazards
	Occupational injuries & fatalities
	Human health issues - NCD
	Human health issues - CD
	Labor laws & conventions

WBCSD/UNEP Category	SHDB Category
Social/Employer Security and benefits	Social benefits
Access to Basic Needs for human rights and dignity Or Access to material resources	Access to improved source of drinking water
	Access to improved source of sanitation
	Access to electricity
	Access to health care
Safe and healthy living conditions	High conflict zones
	Corruption
	Property rights
Respect for indigenous rights	Indigenous rights
Job creation	Unemployment
Equal opportunities Or No discrimination	Discrimination & equal opportunity
	Gender equality

The final step involved utilizing the Risk Mapping Tool to gather results for each country, SHDB category, and social topic. These results are displayed by the Risk Mapping Tool on a reference scale ranging from 1 to 4, with 1 representing very low risk and 4 indicating very high risk. The market shares of each country are provided in percentages. All data were compiled into an Excel spreadsheet. An example is given in

Table 48, for the "Oil" SHDB category concerning the "No forced labour, human trafficking, and slavery" social topic.

Table 48: Example of reference scale results made for the Oil SHDB category

WBCSD Category	SHDB Category	UAE *(19.17%)*	Saudi Arabia *(11.35%)*	Russia *(9.32%)*	USA *(6.77%)*	Canada *(6.64%)*	Iraq *(5.84%)*	Nigeria *(3.47%)*	Norway *(2.94%)*	Angola *(2.25%)*
No forced labour, human trafficking and slavery	Forced labour	3	2	4	1	1	4	3	1	3
	Migrant labour	3	3	3	3	2	4	3	2	3

Due to the incompleteness of the SHDB, certain data were unavailable which brings to data gaps. For such situations, we assigned a provisional social risk score of 2.5, representing an average value on the reference scale.

4.3.1.2 Hotspot identification

The previously collected data, using the Risk Mapping Tool, enabled us to carry out a brief hotspot analysis. The objective was to identify "High risk countries" in terms of supply of primary plastic materials. These findings will be shared with BUDDIE-PACK partners who can utilize them to challenge and evaluate their supplier value chains for a better social performance.

The hotspot analysis involved calculating the average social risk for each country, shown in Table 49, without applying any weighting to lifecycle phases. If a country is involved in several lifecycle phases, like Russia (Crude oil extraction and Oil refining, see Table36) the highest estimated risk is retained.

The colour code is as follows:

- Green: risk < 2, Low social risk
- Yellow: 3 > risk > 2, Medium social risk
- Red: risk > 3, Very high social risk

Table 49: Average social risk according to Risk Mapping Tool

Country	Social risk
Norway	1.12
Germany	1.35
Netherland	1.37
Belgium	1.41
Canada	1.45
France	1.52
Japan	1.65
Italy	1.70
Poland	1.78
South Korea	1.82
USA	1.91
Taiwan	2.1
Russia	2.21
Saudi Arabia	2.23
United Arab Emirates	2.27

China	2.33
Malaysia	2.36
Turkey	2.46
Singapore	2.5
Iran	2.54
India	2.71
Iraq	2.75
Nigeria	3.18
Angola	3.26

An initial review of these preliminary results reveals the following insights:

- Every European (apart from Russia) and North American countries present a low social risk.
- Japan and South Korea, in Asia, also have a low social risk.
- Nigeria & Angola, the only two African countries, have the highest social risk. Together, these two countries own less than 6% of the market share for crude oil.
- Countries of the Middle East and of South Asia present a medium risk.

To get some perspective and to comprehend to results better, it is important to know for which social topics the risk is the highest. Here is a list of social risks rated 3 or 4 for the countries with highest market share or the highest average risks.

- **Angola & Nigeria:** Child labour, Workers in poverty, Discrimination/Gender equality, Workers occupational health risks, Access to basic needs for human rights and dignity, Safe and healthy living conditions (high conflict zones and corruption), Legal system and Democracy/Freedom of speech.
- **United Arab Emirates & Saudi Arabia**: Freedom of association/collective bargaining/right to strike, Migrant Labor, Gender equality, Working hours, Property rights and Democracy/freedom of speech.
- **USA:** Freedom of association/collective bargaining/right to strike, Migrant labour, Social/employer security and benefits, Indigenous rights
- **Russia:** Freedom of association/collective bargaining/right to strike, Migrant labour, Workers occupational health risks, Safe and healthy living conditions (high conflict zones and corruption), Legal system and Democracy/freedom of speech.
- **China:** Freedom of association/collective bargaining/right to strike, Child labour, Forced labour, Working hours, Workers occupational health risks, Safe and healthy living conditions (high conflict zones and corruption), Legal system and Democracy/freedom of speech.

The relevant (impactful) social topics will be studied further in the following section.

4.3.1.3 Social topics preselection

The hotspot analysis allowed us to establish a preselection of 7 social topics using the preliminary results. The method was the following:

1. Calculate the average risk (on a scale of 1 to 4) for every social topic of the SHDB on the pro-rata of the country's production volume (in %). An example is shown in Table 50 for the indicator "Migrant Labour". We multiply a country's risk by its share of the total production and obtain an average risk value[1].

[1] Note: when no data was available, a 2.5 average risk was chosen.

We obtained an average social risk, for every social topic, per life cycle stage.

Table 50: Example of average risk calculation according to production share for Migrant labour indicator

Country	China	Germany	USA	South Korea	Japan	Netherland	Italy	Belgium	France	Taiwan	**TOTAL**
Production share	25.49 %	16.80%	16.03 %	8.22 %	6.99 %	6.06%	5.44 %	5.09%	4.95%	4.92%	**100%**
Migrant Labor	2	2	3	2	2	2	3	2	2	3	**2.3**

2. Calculate the average risk of the social topics across every life cycle stage. We obtained a list of 25 social topics with the associated average risk.
3. Define a quantified average risk threshold. Arbitrarily, we chose a threshold of 2.0, leading to the selection of 7 social topics with a superior average risk.
4. Use the equivalence table presented in Table 37 to translate the relevant SHDB topics into the WBCSD social topics. This methodology gave us the list of social topics given in Table 51.

Table 51: Relevant social topics and stakeholder categories chosen

Stakeholder category	Social topics	Average social risk
Workers	Freedom of association, collective bargaining and labour relations	2.74
	No forced labour, human trafficking and slavery	2.59
	Workers occupational health risks	2.41
	Social/employer security and benefits	2.23
	Appropriate working hours	2.18
	Equal opportunities/No discrimination	2.10
Local Communities	Safe and healthy living conditions	2.55

4.3.2 Social topics for the comprehensive circularity assessment

The selected pertinent set of social topics were taken from the WBCSD recommendations for mandatory social topics. We decided to expand our scope with additional indicators that are recommended by project's practitioners and some found as very relevant to the project's use-cases. We also removed low relevance indicators from the mandatory WBCSD list to allow greater focus on high-risk areas. Furthermore, during the comprehensive assessment, the CSR documents of the partners were examined to evaluate the alignment of their reporting methods with the selected social impact indicators. In the subsequent section, we detail the chosen "relevant" social topics, their indicators (including reference scales), and provide justification for our selection.

4.3.2.1 Additional relevant social topics

The study using the SHDB Risk Mapping Tool highlighted 7 relevant social topics for 2 stakeholder categories.
To be as relevant and exhaustive as possible, we consulted the mandatory social topics described in the WBCSD. 11 mandatory topics are prescribed in total; fair wages, freedom of association, forced labour, occupational health risk, safety management systems for workers, employability, access to basic needs, job creation, healthy living conditions, and consumer health and safety; all of which are included in the assessment. Beyond initial selection of social topics, a further set of 14 optional topics are presented.

Fair wages: this social topic was assessed during the screening study. Two indicators are used in the SHDB to quantify the risk on this indicator. The "wage assessments" indicator had one of the lowest average risks (1.22) and the "workers in poverty" was close to the threshold for the preselection (1.97). However, we feel like having a specific social criterion for "Fair Wages" is unnecessary. Instead, we propose using "Fair wage" as a measuring indicator for freedom of association, collective bargaining and labour relations.

Safety management system: This is assumed to cover only the workers occupational safety and health; therefore, it is incorporated within workers occupational health risk indicator. The examination of safety management systems allows for additional insights into the most likely future trajectory of occupational health risk. It also exhibits a significant overlap with the SHDB "labour laws and conventions" category, offering a potentially applicable scoring scale. Aspects of the WELL health-safety rating project are included, covering the heath resources, emergency preparedness and general workplace environmental factors.

Skills, knowledge and employability: Within this indicator the professional development of workers is considered. This is deemed important to measure the degree of support provided by the organisation to support employees career progression. In today climate, upskilling is a significant socio-economic benefit to workers, and more broadly, the local community. Criteria used to assess this indicator include training requirements, access to skill management programs, and lifelong learning opportunities.

Access to basic needs for human rights and dignity: This indicator is primarily used to assess the organisations efforts to identify and actively mitigate any risks to the wellbeing of the local community. This primarily the assessment of this criteria is based on the evaluation and official reporting procedures of the organisation. In addition, higher performance is achieved by organisations that transparently communicate social benefits available to their workers.

Job creation: Job creation is a relatively common indicator within S-LCA. However, when examining the social impact of disruptive products, such as re-usable packaging, a net value must be evaluated. The net value of job creation in this case is therefore equal to the jobs generated in the production and recycling lifecycle phases, minus the jobs displaced in the single-use value chain. Evaluation of job creation in this way is critical in determining the true impact on society considering both the positive and negative impacts of the project.

Impact on consumer health and safety: Significant differences are seen between the use/consumer lifecycle phases for reusable and single-use food packaging on this topic. This is a consequence of soiled containers being cleaned and re-used multiple times, introducing additional opportunities for health and safety related impacts such as contamination. Consequently, additional focus should be placed upon consumer impact. Consumer health and safety is to be included as an indicator, quantifying the risk of detrimental impacts associated with re-usable products. This will initially have to focus on the short-term effects of the new value chain, due to a lack of long-term consumer impact data.

Feedback mechanism: The opportunity for consumers to relay their experiences, positive or negative, of a new product is a key metric for social sustainability. In addition, feedback mechanisms can be combined with the evaluation of consumer product experience, generating a cohesive and meaningful insight to the product's use phase performance and potential product or service improvements.

4.3.2.2 A focus on Child Labour

Within the WBCSD guidelines, and other practitioner guidance documents, child labour is specified as a mandatory social topic. However, it was suspected during the early stages of the screening study that the Europe oriented use-cases within the BUDDIE-PACK project would exhibit very low risk within this topic. Consequently, a study was conducted to quantify the risk of child labour utilisation on a national level. The results of this screening study are then used to determine whether the topic is included in the full study.

The general method examined two key factors to examine the risk of child labour; current prevalence, and vulnerability. Current prevalence is included to consider the current utilisation of child labour within countries, using the classification criteria laid out in Table 51. However, this does not evaluate the risk of these practices becoming more common in the near future. To assess this second factor, a vulnerability score is incorporated. Vulnerability is difficult to accurately quantify as it cannot be directly measured as with prevalence. Consequently, the Walk Free Foundation's (WFF) method is employed, evaluating a number of risk stimulators in procedures verified through audit by Ernst and Young (Walk Free Foundation, 2018 (17)).

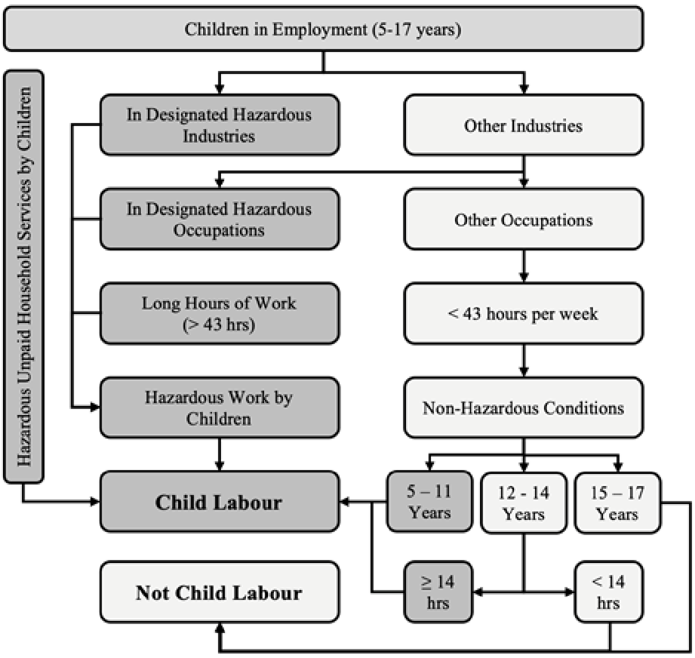


Figure 53: Flow diagram showing the classification of what constitutes child labour. Adapted from UNICEF and ILO (International Labour Organization and United Nations Children's Fund, 2021 (16)).

The full details of the calculation procedure can be found in Annex 1. However, in the interest of conciseness, a summary of the results is shown in Figure 54. The map detail risk levels for each country, showing that child labour is of most concern in Central and Western Africa. In contrast to this fact, Europe exhibits very low risk, suggesting that the topic is of little relevance. Scoring is based on a 0-1 scale in which zero indicates high risk, and one suggests no risk.

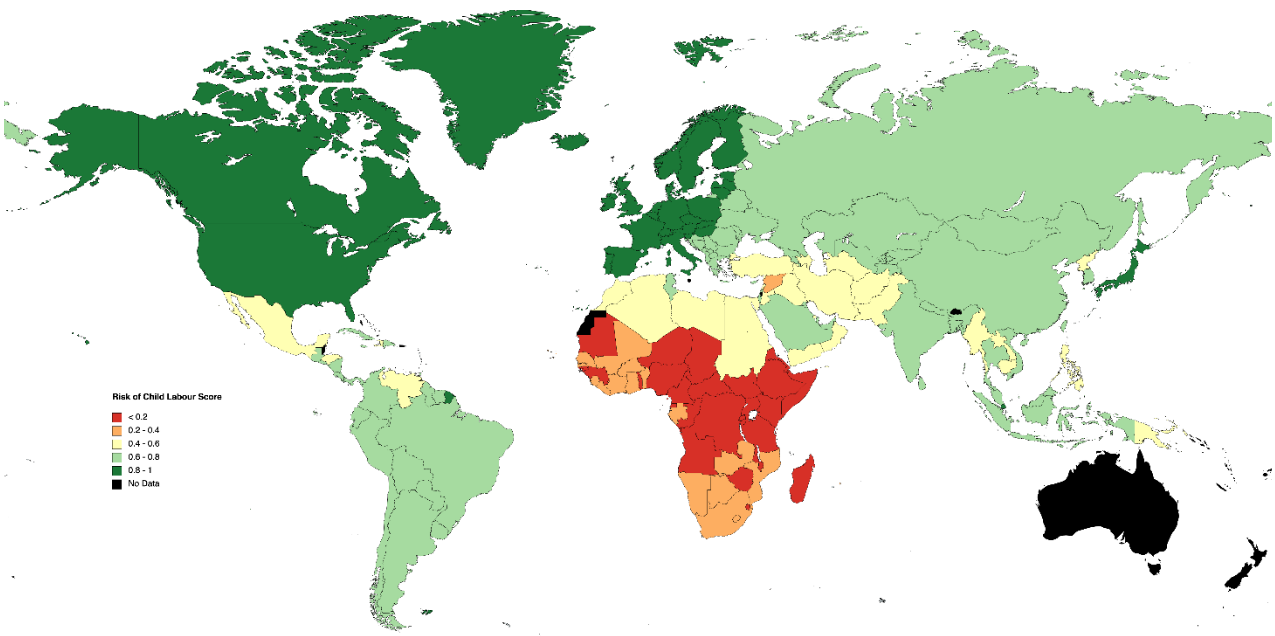


Figure 54: Overview of the national risk of child labour utilisation. Where low numerical scores indicate high risk.

Furthering this analysis, Figure 55 examines the countries directly involved in manufacturing the products considered within BUDDIE-PACK. All relevant nations achieve a score greater than 0.8, with a large majority residing above 0.88. Consequently, this ordinarily mandatory topic can be dismissed since it adds little in terms of assessment insights. Furthermore, this allows for the dedication of practitioner's time to the more relevant additional topics discussed previously.

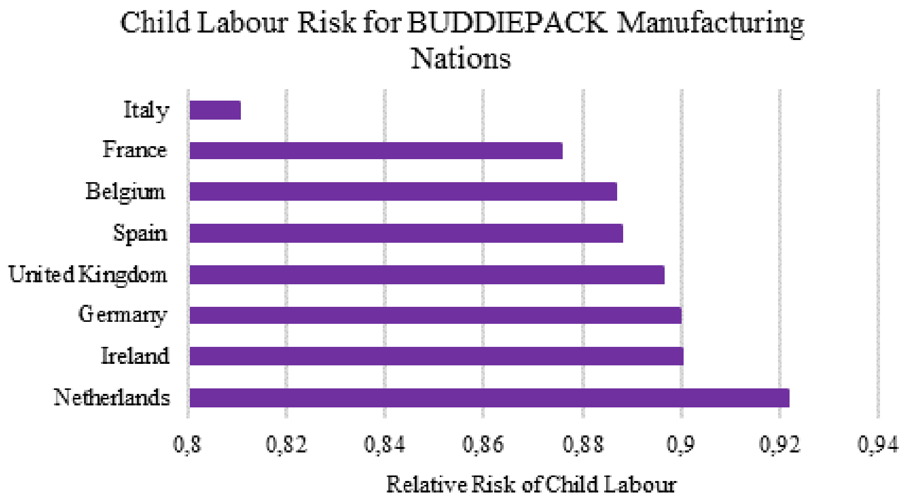


Figure 55: Quantified risk of child labour utilisation within the BUDDIE-PACK manufacturing countries.

4.3.3 Reference scale construction

In S-LCA, two main approaches are available:

- A reference scale approach is used when the project goal and scope focus on the characterising the magnitude of social risk associated with a product. Reference scales, while less granular, provide a structured and systematic approach to evaluating social impact; helping to inform decision-making, benchmarking, and communication of a product's social sustainability profile. The scales are especially applicable in the context of corporate social responsibility and supply chain management, where stakeholders are increasingly concerned about the social impacts of products and processes.
- Conversely, an impact pathway approach can be adopted for goals and scopes aiming to predict, through casual chains, more specific social consequences associated with a product system.

The main difference between the approaches is that the reference scale assumes a causal relationship between the activity and potential social impacts, whereas the impact pathway approach utilises cause-effect relationships.

Within the BUDDIE-PACK project, the reference scale approach will be used. This is better suited to the predicted data availability. Furthermore, the developed reference scales can be tailored to the European application by considering the associated best, and industry standard, practices. Adoption of the impact pathway approach would require much more specific data that is unlikely to be readily available from partners or wider value chain actors.

For many of the selected impact categories and indicators, reference scales are available from the SHDB or WBCSD. Five-point scales are primarily used, providing a manageable number of scoring levels, while maintaining a reasonable degree of granularity. Where the SHDB's existing scales are absent or misaligned with our selected indicators, bespoke scales must be produced. It is proposed that the generation of reference scales be approached in two possible ways, depending on the targeted indicator.

The first way is comparison to the average industry or sector performance in this category (Suitable for indicators such as fair wages). This would deliver a benchmark value against which the assessed product can be evaluated (shown in the figure below). Negative scoring scale points can be set at X and Y % less than the industry average, with positive points at X and Y % above this average.

2	Health performance > x% better than industry average.
1	Health performance>y% better than industry average.
0	Health performance at industry average.
-1	Health performance >y% worse than industry average.
-2	Health performance> x% worse than industry average.

The second way to generating novel reference scales is the specification of application specific criteria. As a value chain or product attains more of these criteria, its achieved score increases (Suitable for indicators such as safe and healthy living conditions). This approach is the most common characterisation method within S-LCA and is recommended by the WBCSD (example scale and criteria for consumer health and safety is shown below).

Scale-based	(a) The level of contribution of the product to consumers' health and safety, excluding intended basic functions.
	(b) The product is risk assessed for consumer use and the outcome is communicated to the general public.
	(c) There is a procedure in place in the event of the recall of an unsafe product.
	(d) The product is labelled for safe handling and disposal.
	(e) The product is labelled on a voluntary basis for safe handling.
	(f) The product increases risk of disease, accident or injury.
2	a,b,c,d,e
1	a,b,c,d
0	b,c
-1	a
-2	f

Data availability, capacity for insight generation, and relevance are important considerations for the selection of one of these two possible ways. Selection of an industry average or criteria-based approach should be made on a case-by-case basis. For the project, a xxx approach was decided. Due to the comparative nature of the assessment within the project, the same bespoke reference scale criteria will be applied to each of the use-cases. Scoring against the same criteria both simplifies the S-LCA process, as well as delivering a greater understanding of performance differentials across the use-cases.

To deploy the reference scale approach in the project, we have developed a set of reference scales for every selected social indicator that are applicable to all BUDDIE-PACK use-cases and that are tailored to the assessment of reusable plastic packaging. A five-point scale (-2 --> +2) is selected, as recommended in the WBCSD guidelines. The full set of reference scales will be confirmed within the full assessment; however, an example for the assessment of consumer health and safety indicator is shown in Figure 56. The reference scale description includes its recommended or expected data sources, alphabetically labelled assessment criteria can be seen on the bottom right-hand side, and the subsequent scoring requirements shown on the bottom left.

Stakeholder category	Consumer
Social topic	Consumer Health and Safety

Indicator description	Consumer health and safety refers to the consumers' rights to be protected against products andservices that may be hazardous to health or life (ISO 26000, 2008). Customers (end users) expectproducts and services to perform their intended functions satisfactorily and not pose a risk totheir health and safety. Moreover, consumers have to the right to "early warnings when unsafeproducts are on the market or are subject to a ban or recall" (OECD, 2020). This subcategory helps to identify the existence and scope of systematic efforts to address consumer health and safety across the organizations involved in the life cycle of a product and/or service.
Data sources	Interviews or questionnaire filled out by management and human resources.

2	a, b, c, d, & e achieved
1	b, c, d, & e achieved
0	d & e achieved
-1	e achieved
-2	a, b, c, d, & e not achieved

a	Adopt measures that prevent products from becoming unsafe through improper handling or storage while in the care of consumers.
b	The organization goes beyond minimum safety requirements where there is evidence that higher requirements would achieve significantly better protection
c	Presence of management measures to assess consumer health and safety
d	Convey vital safety information to consumers (using symbols wherever possible), preferably those that have been internationally agreed, in addition to the textual information;
e	Provide products and services that, under normal and reasonably foreseeable conditions of use, are safe for the users, other people, their property, and the environment.

Figure 56: Example of reference scale evaluation for the assessment of consumer health and safety

4.3.4 Data collection document

A data collection document has been generated to aid communication between the S-LCA practitioners and the partner companies. This covers all of the indicators selected for the full S-LCA (restated in Table 52 for ease of reading) and support the application of the reference scales developed for the assessment. Partners will be required to fill in the data collection sheet, stating which criteria they achieve to assess (with supporting evidence where possible), and which they do not. This information will then be used to characterise their social sustainability performance against the defined scales.

Table 52: Summary of the stakeholder categories and impact indicators assessed within the S-LCA

Stakeholder Category	Impact Indicator
Workers	Freedom of association
	Risk of forced labour
	Workers occupational health risks
	Security and benefits
	Appropriate working hours
	Equal opportunities
	Fair Wages
	Safety Management Systems
Local Communities	Safe and healthy living conditions
	Skills, Knowledge & Employability

	Job Creation
	Access to Basic Needs
Consumers	Feedback Mechanism
	Consumer Health & Safety

The data collection sheet has been designed to ensure that the partners do not know which criteria are required to achieve a certain score, this was done with the aim making the assessment more methodologically robust. To this end, the reference scale scoring procedure is not shared with partners In the event that partners are unable to answer one or more of the criteria, meetings will be organised to support the reporting process and ensure maximized data collection and highest possible percentage of evaluated social criteria. Data gaps may present themselves during the sull S-LCA, these will be handled through the use of proxy data if possible; where this occurs a representative value for the industry will be used based on open literature.

Once all criteria have been evaluated for each impact indicator, the final social indicator values / score can be evaluated using the reference scales. The overall results will be reported in terms of the –2 to +2 scores for each use-case and indicator (format shown in Table 53), where the achieved scores are presented in notation form in lieu of the final assessment results.

Table 53: Format of the results table to be used in the compiling of final reference scale-based S-LCA data from partners.

Use-case	Indicator 1	Indicator 2	Indicator 3	Indicator 4
A	A1	A2	A3	A4
B	B1	B2	B3	B4
C	C1	C2	C3	C4
D	D1	D2	C4	D4

4.3.4 Work plan for the full assessment

Firstly, the selection of impact indicators requires additional justification and scrutineering around the cut-off procedure utilised. Impact categories were screened using a five-point scale, examining each lifecycle phase and country of operation on a pro-rata basis (low numerical scores represent a favourable performance). The average score for each indicator was calculated (as detailed previously), and a threshold value of 2 applied. Several indicators lie around a score of 2.0, requiring that we revisit and validate the selection of both the cut-off position and number of decimal places to be used.

WBCSD and SHDB reference scales are to be evaluated for alignment to the selected indicators for the full assessment. Where suitable reference scales are available, they will be adopted for the full S-LCA assessment. In cases where no reference scale is available, a sectoral average or criteria-based approach must be selected, and the scoring criteria laid out.

With the reference scales fully defined, the required data for the S-LCA inventory can be specified. This subsequently allows for the propagation of data collection sheets. These will be distributed to partners, aiming to gather data that will enable the more accurate and bespoke full S-LCA. With the data collected in this standardised form, practitioners will translate it to the relevant reference scales. Once complete, the social topic results for each use-case can be calculated.

Conclusion

The screening LCAs enable identifying the main contributors over the life cycle of reusable packaging developed in the project. From this contributor analysis on all indicators of EF3.0, sensitivity analyses conducted on Climate change and Water use study the impact of varying their value over the Break-Even Point.

In conclusion, the screening studies make it possible to identify effective eco-design guidelines, but also the hypotheses that need to be explored in further detail because they have a major impact on the conclusion of the study. They can therefore be used to identify the data gaps that need to be filled before a complete and representative LCA can be carried out for the system under study.

The LCCAs analyse the main contributing life cycle steps over the total cost of the packaging, and if possible give the BEP of the baseline scenario. There is a deviation in comparison to the work envisioned in Deliverable 7.1, but the data gaps have been identified and the studies will continue after Deliverable 7.2 submission.

The screening S-LCA has successfully identified the relevant social topics for the full assessment of BUDDIE-PACK use-cases. These cover a range of stakeholder categories ranging from workers to local communities and consumers. These are largely aligned with the WBCSD, and UNEP and SETAC guidelines. However, a mandatory social topic (child labour) was removed due to lack of relevance. Within this screening study generic data from literature and databases was used to assess representative sectors and countries of operation; risk hot spots were subsequently identified.

With the hotspots identified the approach to impact characterisation within the full S-LCA was selected. Owing to several data related considerations, a reference scale approach is identified as the most appropriate. The developed reference scales, in conjunction with the partners co-operation and CSR documentation should enable a complete assessment of the use-cases with minimal need for assumptions of data imputations.

In conclusion, this deliverable shows the potential impact of the reusable solutions developed in the project, as data coming from the other Work packages arrived at the end of the screening tasks. Many assumptions have been taken concerning decisive parameters of systems (packaging mass and End-of-Life, washing consumptions…). These data gaps will be filled throughout the rest of the project with inputs from large-scale demonstration of each use-case and methodological improvements from the screenings to the full assessment identified (real reuse rate calculation, transport allocation…).

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Annexes

Annex 1: Study of Child labour indicator integration in S-LCA

Methodology

In order to assess the relevance of child labour within the BUDDIE-PACK S-LCA, estimated risk is examined on a national level owing to data availability issues. If Europe, the primary base for manufacturing operations, exhibits low risk, a full assessment of the indicator would be superfluous. To this end, literature data is used to generate a country specific early-stage characterisation model. In this, a quantification of the risk of child labour utilisation within generic value chains is targeted, acting as a proxy for BUDDIE-PACK value chains in the absence of more specific data.

Due to data limitations, the resulting risk characterisation is not sector specific. However, as a red-flag based justification for indicator inclusion, this is deemed acceptable. National level risk will be based on both the on-going estimated prevalence of child labour, and the vulnerability of the population to future occurrences. This decision is taken in order to account for trends in governmental action and broader societal pressures. Simplistic evaluation of only current prevalence offers limited insights, with no consideration of other stimulating or de-stimulating factors; this will be shown through an example in the following section.

Method (Characterisation of Child Labour Risk)

To attain an accurate risk indication for child labour, it must first be defined. Clear classification requirements are laid out by United Nations Children's Fund (UNICEF) and the International Labour Organization (ILO), resulting in Figure 39. This considers varied factors such as hazard levels, age, and work duration (International Labour Organization and United Nations Children's Fund, 2021), providing a widely accepted framework.

With a clear and quantifiable definition achieved, risk characterisation can be approached. At this stage data availability around child labour proves problematic. Difficulties primarily arise in in the form of lacking geographic resolution. Rather than at the national level, data is presented in terms of the following UN SDG regions;

- Sub-Saharan Africa
- Central and Southern Asia
- Eastern and South-Eastern Asia
- Northern Africa and Western Asia
- Latin America and the Caribbean
- Europe and North America

This clearly reduces the granularity attained. However, it was previously proposed that vulnerability be utilised to improve insights; but, in this setting it also aids geographic resolution. The incorporation of the vulnerability score allows for upwards or downwards adjustment of the base prevalence data, accounting for intra-UN SDG region variation, and future risk.

First examining the prevalence data, all identified child labour between the ages of 5-17 is included. UNICEF independently report the prevalence of both hazardous and non-hazardous child labour as a percentage of the relevant population. For the purposes of SIA characterisation method development, both of these types are of significance. Additionally, the reported values are mutually exclusive, permitting their additive aggregation through Equation 1 without risk of double counting.

$$NCL_i + HCL_i = OPCL_i$$

Equation 1 – Aggregation of child labour prevalence data for UN SDG regions; Where, NCL_i is the % of children in non-hazardous child labour in country i, HCL_i is the % of children in hazardous child labour in country i, and $OPCL_i$ is the country's overall prevalence of child labour.

The generated overall child labour prevalence (OCLP) values can then be normalised using Equation 2. As seen with forced labour prevalence this occurs on a max zero basis, both reversing scoring directionality and ensuring a requirement of 0% child labour prevalence for a perfect score of 1.

$$1 - \frac{OPCL_i}{OPCL_{Max}} = NPCL_i$$

Equation 2 – Normalisation of overall child labour prevalence (OPCL). Where, $OPCL_{Max}$ is the highest observed prevalence, $OPCL_i$ is the overall prevalence in country i, and $NCLP_i$ is the normalised prevalence of child labour for country i.

With the normalised child labour prevalence (NCLP) determined for each UN SDG region, their constituent countries are assumed to mirror this value. At this stage vulnerability top child labour can be incorporated. This is not directly assessed by UNICEF or its partner organisations. Consequently, the national vulnerability scores for forced labour are used as a proxy. This is deemed a reasonable assumption given a clear commonality between stimulating factors.

Vulnerability is difficult to accurately quantify as it cannot be directly measured as with prevalence. Consequently, the Walk Free Foundation's (WFF) method is employed, evaluating a number of risk stimulators in procedures verified through audit by Ernst and Young (Walk Free Foundation, 2018 (17)). An initial group of 35 risk stimulators were checked for collinearity, removing those with a significant correlation; defined as those with variance inflation factors (VIF) greater than 10 and tolerance below 1.

A total of 23 stimulators meet these requirements, necessitating grouping into clusters through principal component analysis (PCA). The result is five main factors that more approachably characterise a populations vulnerability to forced labour. An expert working group was then consulted to assign weights to the five factors. The result is the use of eigenvalues, indicating the amount of variance explained by a certain factor, as weightings (Walk Free Foundation, 2018). The factors possessing greater eigenvalues, and thus variance, explain a greater proportion of the overall model; commanding greater weights. This process delivers the following factors and associated weights (detailed in brackets):

1. Governance Issues (5.76)
2. Lack of Basic Needs (3.422)
3. Inequality (2.233)
4. Disenfranchised Groups (2.092)
5. Effects of Conflict (1.938)

With the five factors fully defined, weighted, and evaluated for 167 countries, the raw national scores can be calculated. This yields country specific eigenvalue weighted values (EWV) through Equation 3.

$$\frac{(F_{1_i} \times 5.76) + (F_{2_i} \times 3.422) + (F_{3_i} \times 2.233) + (F_{4_i} \times 2.092) + (F_{5_i} \times 1.938)}{0.01 \times 5 \times 5.76 \times 3.422 \times 2.233 \times 2.092 \times 1.938} = EWV_i$$

Equation 3 – Calculation of the eigenvalue weighted value for country i. Where, indicates the avarage value of factor x for country i.

This EWV delivers an overall vulnerability score for each country, incorporating the 23 identified stimulating factors. However, this must be normalised, using Equation 4, to facilitate further use.

$$\frac{100 - \left(1 - \frac{99(EWV_i - EWV_{Min})}{EWV_{Max} - EWV_{Min}}\right)}{100} = NVFL_i$$

Equation 4 – Calculation of the normalised vulnerability to forced labour for country i.

The final indicator value can therefore be determined using Equation 5, resulting in the national scoring profile seen in Figure 54.

$$0.5(NPCL_i + NVFL_i) = Risk\ of\ Child\ Labour$$

Equation 5 – Final indicator calculaktion for the risk of child labour. Where, $NPCL_i$ is the normalised prevalence of child labour in country i, and $NVFL_i$ is the normalised vulnerability to forced labour in country i.

Results of Characterisation

The results of this child labour risk model can be used to identify potential geographical hotpots in which more due diligence should be exercised. This data can be used to pragmatically evaluate the relevance of a child labour indicator within a full product SIA. When averaging national scores over the UN SDG regions, as assessed by UNICEF (International Labour Organization and United Nations Children's Fund, 2021 (16)), the following normalised values are obtained.

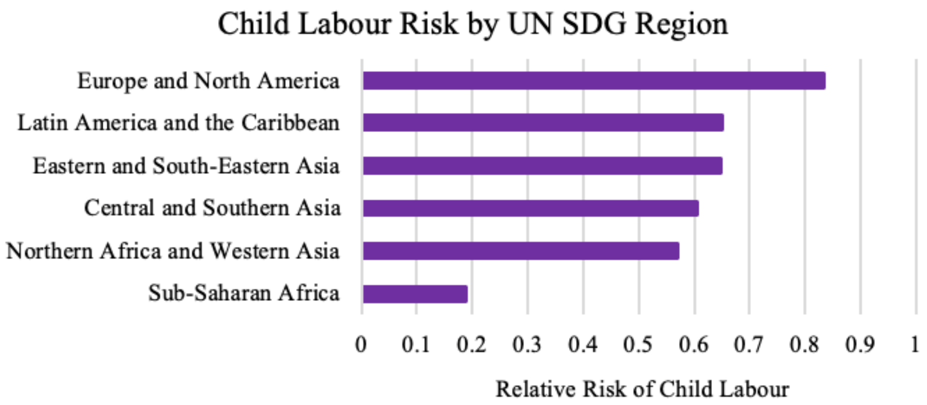

Figure 57: Normalised risk of child labour for the six UN SDG regions assessed by UNICEF's child labour report.

Given that a higher normalised performance score indicates a lower risk of child labour utilisation, Europe and North America is revealed as the best performing region (score: 0.8357). In contrast, Sub-Saharan Africa exhibits the worst performance, achieving a score of 0.1885. The remaining four regions show largely similar levels of risk, all falling within a range of 0.024.

With the increased granularity achieved through the incorporation of the WFF's vulnerability scoring (Walk Free Foundation, 2018 (17)), Europe and North America can be further partitioned. Averaging the national level scores for Europe gives a value of 0.8331, with North America scoring 0.8867. Such positive estimation of European performance in the child labour indicator is buttressed by a score of 1 (best possible) against the Social Hotspot Database's (SHDB) existing reference scale.

To evaluate the risk within the context of this specific supply chain, the countries associated with the manufacturing steps are examined. This list of countries includes;

- The Netherlands (0.9213)
- Ireland (0.9001)
- Germany (0.8997)
- The United Kingdom (0.8962)
- Spain (0.8879)
- Belgium (0.8866)
- France (0.8756)
- Italy (0.8104)

Consultation reveals that Western European countries, those in which manufacturing is based, all fall within the highest scoring category. This format does reveal the lack of coverage in Oceania, a consequence of the UNICEF data being incomplete.

In summary, the data generated through this early-stage characterisation model shows that the consideration of child labour does not constitute a meaningful value addition in Europe based assessments. Consequently, it is proposed that child labour be dropped for the BUDDIE-PACK SIA in favour of the evaluation of other more relevant indicators.