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

Starting date of the project: 01/09/2022
Duration: 42 months

= Deliverable: D7.3 =

Set of circularity indicators as proxy for environmental impact for RPP

Methodology document

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DISCLAIMER

Executive Summary

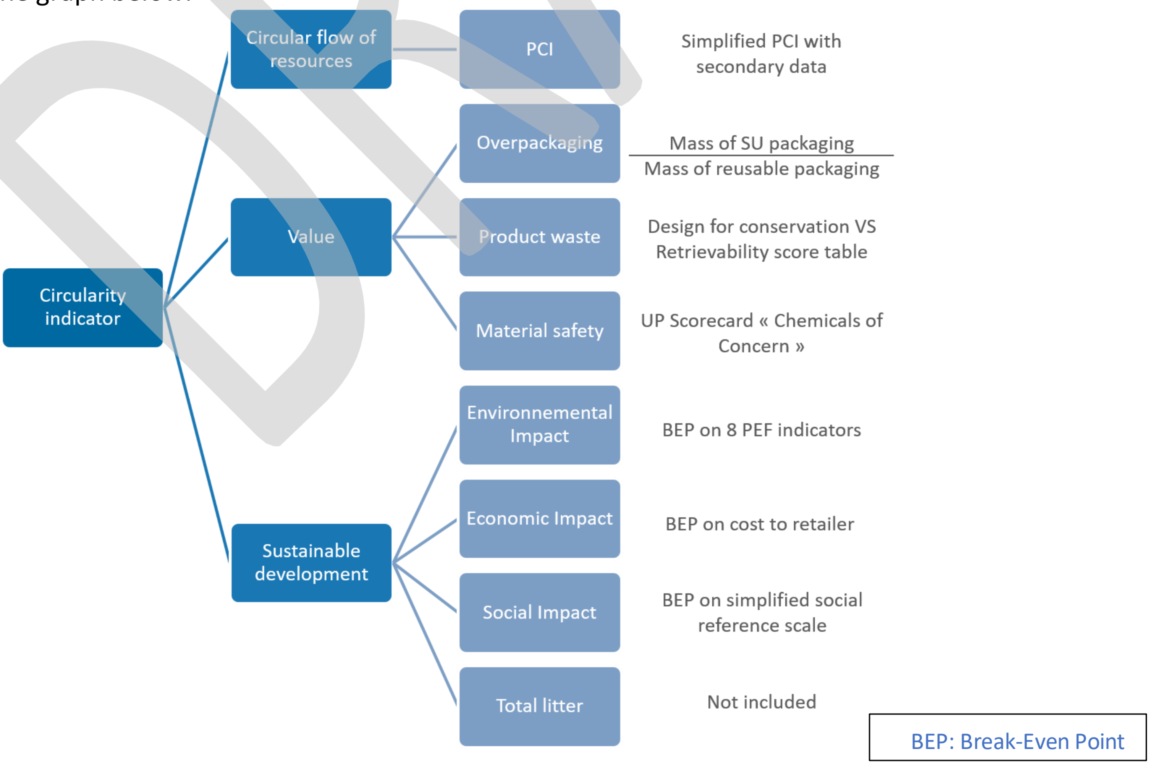
This document is part of Deliverable 7.3: Circularity indicators. The indicators are calculated in an Excel tool, and this document explains the methodology and data used behind it.

The categorisation of circularity indicators proposed by Saidani et al., 2019 has been used to describe the indicator developed with the criteria in the table below.

Categories (criteria)	Value
Levels	Micro
Loops	Reuse, Recycle
Performance	Intrinsic and impact
Perspective	Potential
Usages	Decision making
Transversality	Sector-specific
Dimension	Multiple
Units	Quantitative & qualitative
Format	Computational tool
Sources	Multiple

The tool considers all life cycle steps of reusable packaging, using a cradle-to-cradle approach.

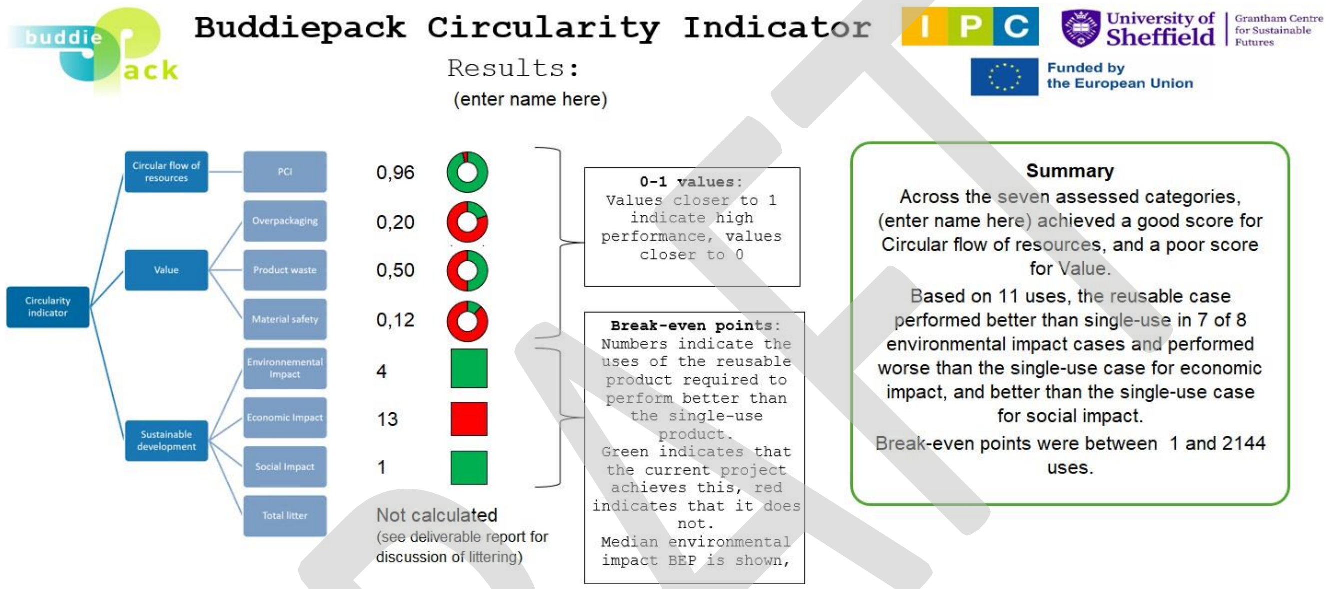
The aim of the circularity indicator is to give a simplified evaluation on the adequacy of the reusable packaging with circular economy definition. To do so, the tool proposes a circularity indicator structure that fits the ISO 59004 definition of circular economy (i.e. an economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development), based on the triad of Circular flow of resources, Value and Sustainable development.
The three subsections of the tool are considered through a series of indicators in Parts 4, 5 and 6, that are summarised in the graph below.



The next section of the document explains the global structure and interface of the tool. The structure of the defined circular tool is as follow:

- Life cycle information
- One PCI spreadsheet
- One Value spreadsheet
- One Sustainability spreadsheet
- One Result spreadsheet
- Databases spreadsheets (not visible from user)

The Result spreadsheet, shown below, does not show an aggregation of the results as a single score, as they combine 0-1 scale and Break-Even Point formats.



The circular tool developed with the methodology described in this deliverable provides a simplified point of view on the compatibility of reusable packaging with the circular economy definition.
It asks as little information as possible to the packaging user to give a simple, comprehensive and clear view of where the reusable packaging has a better or worse circular impact than comparable single-use packaging.
As a consequence, it can be used by companies looking to switch from single-use to reusable packaging, or by packaging manufacturing companies to help their eco-design roadmap. In an improved version, the circular tool could be a decision-making tool at a larger scale, for instance by helping a company or a region state to determine if a reusable packaging is better than a single-use packaging. Further improvements, that couldn't be done during the one year-development, have already been identified for Circular flow of resource, Material Safety, Product waste, Environmental and economic impact, and Littering assessment.

The current version will be tested during the final months of BUDDIE-PACK project, and results of its application (with feedbacks from industrials) will be implement in Deliverable 7.4: Full circularity assessment.

Acronym description

BEP	Break-Even Point
CE	Circular Economy
CFF	Circular Footprint Formula
CoC	Chemicals of Concern
EFSA	European Food Safety Authority
EPR	Extended Producer Responsibility
LCA	Life Cycle Assessment
GA	Grant Agreement
MCI	Material Circularity Indicator
NIAS	Non Intended Added Substances
NMP	Nano and Micro Plastics
PEF	Product Environmental Footprint
PCI	Product Circularity Indicator
PPWR	Packaging and Packaging Waste Regulation
WP	Work Package

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1. Introduction

This document is part of Deliverable 7.3: Circularity indicators. The indicators are calculated in an Excel tool, and this document explains the methodology and data used behind it.

The aim of the circularity indicator is to give a simplified evaluation on the adequacy of the reusable packaging with circular economy definition. To do so, the first part of this document proposes a circularity indicator structure that fits the ISO 59004 definition of circular economy. A definition of the tool goal and scope is then defined. The three subsections (Circular Flow of resources, Value and Sustainable development) are considered through a series of indicators in Parts 4, 5 and 6.
The next section of the document explains the global structure and interface of the tool.
Finally, the implementation of the circularity indicator in an industrial context is reviewed with an explanation of future intended use of the developed tool, possible improvements, and feedback from project's industrial partners.

2. Adequation to ISO 59004 definition

According to ISO 59004 [1] and ISO 59020 [2], circular economy is defined as:

An economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development.

The definition is valid for all applications and therefore valid for reusable packaging systems. From this definition, three key aspects of circular economy can be extracted: Circular flow of resources, value or economy, and sustainable development. These concepts can be considered individually and ultimately used to evaluate the circularity of a system, as described in the following sections.

2.1. Circular flow of resources

A circular flow is defined by ISO 59004 as *"a systematic cycling of the provision and use of resources within multiple technical or biological cycles"*. This includes all the methods to break down the linear flow of resources ending in landfill.

2.2. Value or economy

The notion of value is somewhat more open to interpretation in the standard. Value is defined in ISO 59004 as *"gain(s) or benefit(s) from satisfying needs and expectations, in relation to the use and conservation of resources"*. The standard also states that value is relative to, and determined by, the perception of those interested parties able to capture it. It can be financial or non-financial (e.g. social, environmental, other gains or benefits), and is dynamic over time. Value currently tends to be assimilated to an economic or functional value.

2.3. Sustainable development

Sustainable development is defined by ISO 59004 as "*a development that meets the environmental, social and economic needs of the present without compromising the ability of future generations to meet their own needs"*. In order to truly evaluate the sustainability of a system, each of the three pillars, i.e. environmental, social and economic, must be considered and analysed.

To ensure alignment with the ISO 59004 definition of circular economy, the circularity tool structure shown in Figure 1is proposed. 8 subindicators are stored in the three categories (Circular flow of resources, Value and Sustainable development).

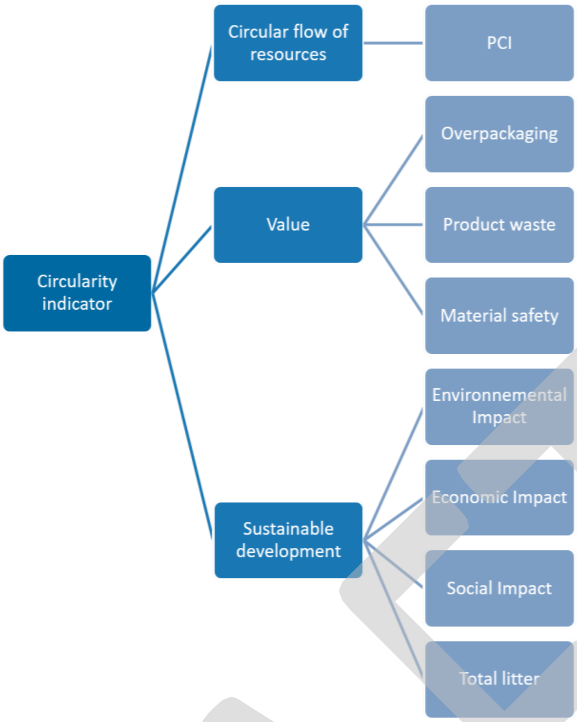

Figure 1: Circularity indicator structure based on ISO 59004 definition

3. Circularity indicator categorisation

It is important to categorise the developed circularity indicator, to let the user know for which packaging application it is more suitable. Based on the categorisation proposed by Saidani et al. [3], the tool developed can be described with the criteria in Table 1.

Table 1: Circularity indicator description based on Saidani et al. categorisation

Categories (criteria)	Value	Justification
Levels	Micro	Product specific
Loops	Reuse, Recycle	
Performance	Intrinsic and impact	PCI measures the inherent circularity whereas the env., eco. & social consequence of switching from single-use to reuse is calculated
Perspective	Potential	ex-ante evaluation to explore whether proposed CE transitions have potential to bring about the intended CE effects
Usages	Decision making	Helps taking action to chose or design a reusable packaging
Transversality	Sector-specific	Applicable to the packaging sector
Dimension	Multiple	
Units	Quantitative & qualitative	Qualitative except for environmental & economic impacts
Format	Computational tool	Excel sheet
Sources	Multiple	Co-developed by an industrial and an academia, with literature and project data

The tool considers all life cycle steps of reusable packaging, using a cradle-to-cradle approach. The steps per metric are indicated in Table 2.

Table 2: Relevant life cycle steps and indicators for each phase: Material, Manufacturing, Use (including reuse), and EOL

	Indicator \ Life cycle step	**Material**	**Manufacturing**	**Use**	**EOL**
Circular flow of resources	**Product Circularity Indicator (PCI)**	x		x	x
Value	**Over-Packaging**		x		
	Food waste • Retrievability • Design for conservation	x	x	x	
	Material safety • UP Scorecard “Chemicals of Concern”	x		x	
Sustainable Development	**Environnemental impact** BEP on: • Acidification • Climate Change • Eutrophication, freshwater • Particulate matter • Photochemical ozone formation • Resource use, fossils • Resource use, minerals and metals • Water use	x	x	x	x
	Social impact • BEP	x	x	x	x
	Economic impact • BEP	x	x	x	x

4. Calculation: Circular Flow of Resources

The Circular Flow of Resources section of the Circular Economy definition will be assessed in this structure through the use of a modified version of the Product Circularity Indicator (PCI) [4]. The PCI provides a quantification of the circularity of a product. The PCI method uses a wider dataset than the MCI method [5], with 37 input values required per product. Some are direct inputs required from the user, while some are calculated from these direct inputs. In order to use the PCI, both primary data and secondary data were required. Table 3 illustrates the variables used to calculate the PCI, highlighting those which are calculated from other input values and therefore require no user inputs, and those which use secondary data. Primary data should be used for the remaining variables, since these are heavily influenced by specific product-level data.

Table 3: PCI input variables and primary / secondary data selection

Description	**Title**	**Unit**	**Calculated (no user input)**	**Secondary data usable**
Fraction of reused components	Fu	*%*		
Fraction Recycled content of material	Fr	*%*		yes
Total mass	M	*kg, T*		
Efficiency of component production	Ecp	*%*		yes
Efficiency of raw material production	Efp	*%*		yes
Efficiency of recycled material production	Efrp	*%*		yes
Efficiency of material separation	Ems	*%*		yes

Fraction of recovered material losses: component production	Ccp	*%*		yes
Fraction of recovered material loss: raw material production	Cfp	*%*		yes
Fraction of end-of-use products collected for re-use	Cu	*%*		
Fraction of end-of-use products collected for recycling	Cr, CR	*%*		
The available or used life of the product (years), for the product evaluated	L	*y*		
The expected life of the product (in years) based on a market study or industry standard / average.	Ld	*y*		yes
The intensity of use available or used (uses per year)	I	*nb/y*		
The intensity of use expected (uses per year)	Id	*nb/y*		yes
Material quality factor used in the product (if known)	Qin	*0 - 1*		
Material quality factor derived from the product (if known)	Qout	*0 - 1*		
Actual number of uses during the product lifetime	U	nb	yes	-
Expected number of uses of the product during lifetime	Ud	nb	yes	-
Virgin material	V	kg, T	yes	-
Waste from feedstock production	Wfp	kg, T	yes	-
Waste from component production	Wcp	kg, T	yes	-
Uncollected EoL product	Wu	kg, T	yes	-
Waste from material separation	Wms	kg, T	yes	-
Waste from recycled feedstock production	Wrfp	kg, T	yes	-
Unrecoverable waste	W	kg, T	yes	-
Waste for component production	Rcp	kg, T	yes	-
Waste from EOL	Reol	kg, T	yes	-
Recycled material used for feedstock production	Rin	kg, T	yes	-
Recycled material recovered	Rout	kg, T	yes	-
Recycled material (net exchange)	R	kg, T	yes	-
Reused components (net exchange)	C	kg, T	yes	-
Amount of virgin feedstock in the linear system	V_{linear}	kg, T	yes	-
Amount of waste in the linear system	W_{linear}	kg, T	yes	-
Linear flow index	LFI	kg, T	yes	-
Linear flow index (material quality known)	LFI	kg, T	yes	-
Utility factor (L/Ld)(I/Id) or (L/Ld)(U/Ud)	X		yes	-

Calculation methods for the above identified variables are given in Annex 1.

5. Calculation: Value

The Value section of the Circular Economy definition will be assessed in this structure through the use of a range of separate indicators. These indicators are taken from a variety of sources and when combined enable to calculate an overall indicator for the Value section. The aim is to qualify the high performance requirements in a reusable packaging, that is to say a long lasting packaging with a design that preserves the food while keeping the consumer safe.

5.1. Over-Packaging

Overpackaging is defined by the Institute of Packaging Professionals as "a condition where the methods and materials used to package an item exceed the requirements for adequate containment, protection, transport, and sale" [6].

In France, the AGEC law (2020) [7] sets a national strategy for the reduction, reuse, re-employment and recycling of single-use plastic packaging. These measures include the mobilisation of extended producer responsibility channels (EPR) and their eco-modulations, the adaptation of rules on the marketing and distribution of packaging and the use of any economic tools.

The Producer Responsibility Organisation Citeo, mandated for the consumer packaging extended producer responsibility, is responsible of applying this part of the AGEC law by giving bonuses or maluses (penalties) associated with e.g overpackaging situations [8], as described below.

Proportional bonus:

- Reducing the weight of packaging at source: Bonus proportional to the weight reduction in the packaging on annual contribution to this packaging unit.

Malus (penalty) 10%:

- Small drinks (plastic bottles, cartons or flasks with a capacity of 0.5L or less). Cans and glass bottles are not affected by this penalty, whatever their capacity.
- Bundling of packaging units as part of a one-off or permanent promotion: regardless of the material, if this bundling does not provide a protective function (product integrity) or transport products (logistics).

From those examples, there are consequently several ways to assess overpackaging:

- Weight of packaging
- Empty space in packaging
- Small volumes packed
- Elements that do not provide a protective function

Reusable packaging generally already reduces material per use compared to a single-use packaging. However, to increase their lifetime through durability, they are usually heavier than the single-use alternatives, even if the content doesn't need such protection against shocks and falls. This can also affect the environmental or economic performance compared to single-use. To translate these factors into a simple parameter, the formula proposed is the weight ratio between the single-use packaging and the reusable one. This will give a result between 0 and 1. When the weight of reusable packaging tends towards the weight of the single-use packaging, the score will tend towards 1.

5.2. Product waste

Two key parameters required to give an overview of the capacity of a packaging to limit product waste are product preservation and conservation, and product retrievability.

Product preservation and conservation is the primary function of a packaging. It is essential to address, in order to properly evaluate packaging functional value and lifetime. The aim is to assess whether the packaging has a design which enables enhanced product preservation. For a reusable packaging, the focus is on its ability to be hermetically sealed and resealed between uses.

"Spoonability" is also a parameter taken into account when designing a new food packaging. The term defines how easy it is to empty a pack of its contents without leaving any leftovers. However there is no defined method or abacus on how to calculate Spoonability. A simplified method to assess whether packaging is designed to maximize this parameter is therefore proposed. As the tool is designed to apply to packaging of all types (i.e. not only food packaging), this has been termed Retrievability.

The two parameters are calculated on a scale from 1 to 3 and combined to give a total score for Product waste from 0 to 1, is given in Table 4.

- Retrievability:
  - Level 1: The pack is smoothly shaped and allows all or almost all of the product to be removed.
  - Level 2: The pack has some sharp edges or corners where product cannot be removed from, but is generally smoothly shaped.
  - Level 3: The pack has sharp edges and corners which mean a large amount of product cannot be easily removed and remains in the packaging.
- Design for conservation:
  - Level 1: The pack reseals and protects the product as well after opening as the original unopened packaging / The packaging is closed with a single-use film and is resealable.
  - Level 2: The pack reseals but protects the product less well than the original unopened packaging.
  - Level 3: The pack does not reseal.

Table 4: Product waste score calculation method

		Design for conservation		
		Level 1	Level 2	Level 3
Retrievability	Level 1	1	0.75	0.5
	Level 2	0.75	0.5	0.25
	Level 3	0.5	0.25	0

5.3. Material safety

As defined by EFSA, a material safety assessment is the evaluation of a material's composition, migration, and toxicological profile to ensure it does not pose health risks when used in food contact.
To keep the tool simplified, it focused on the two main safety risks associated with plastic packaging use [9] :

- Substances release
- Microplastic release

5.3.1. Risk of substances release

This indicator is sourced from the UP Scorecard method version 1.0 (2025) [10]. The UP Scorecard method includes a metric called Chemicals of Concern (CoC), which is calculated by combining two scores:

- Presence Score: The intentional presence of chemicals of concern and verification of these claims. Calculated with a matrix associating the Compliance Level and the Disclosure Level.
- Migration Potential Score: The potential for any present chemicals of concern including NIAS to migrate from the product into food and the environment. This is based on the inertness of the food contact materials (Inertness Score) and interactions the food can have with the materials (Food and Material Interaction Score).

$$Migration\ Potential\ Score = \frac{Inertness\ Score + Food\ and\ Material\ Interaction\ Score}{2}$$

The total CoC score is the addition of the Presence Score and the Migration Potential Score. If there are several elements in the packaging, the CoC scores are weighted and averaged.

In the UP Scorecard method, the weighted score W is used to calculate a linear value within the range of 1 to 100, using the following formula: $1 + 99 * (20 - W) / (20 - 2)$.
The proposition in BUDDIE-PACK circularity indicator is to change the formula, to have a value within the range of 0 to 1 (to harmonize with other metrics), using the following formula: $(20 - W) / (20 - 2)$.

The full method is presented in Annex 2.

The UP Scorecard provides a useful screening tool to flag potentially chemicals of concern present in food contact materials. However, its application comes with several significant limitations. First, the tool is not truly discriminant across polymers, since most plastics receive similar scores for "*Material inertness*", limiting its value for material comparison. In addition, the identification of substances – especially NIAS – remains extremely challenging. Finally, the methodology is hazard-based and does not account for actual exposure, *i.e.,* the migration levels measured under real-use conditions. This limitation can be partially mitigated by the work conducted in WP5, which focuses on the safety assessment of reusable plastics packaging. By generating an accurate inventory of substances present, including IAS and NIAS, WP5 provides the detailed input needed to refine the UP Scorecard scoring. Additionally, migration study through experimentation testing or mathematical modelling can provide direct evidence of substances release. Together, these approaches enhance the reliability of the UP Scorecard and ensures a more accurate calculation of the circularity indicator for reusable plastics.

5.3.2. Discussion on Microplastic release

Microplastic release is one of the biggest environment and health threats caused by plastics packaging. There is currently a lack of knowledge on all aspects needed to quantify their impact on humans and ecosystems, such as:

- Inventory
- Fate
- Exposure
- Effect

The MariLCA project, amongst others, is working on filling those gaps. A significant piece of work is also being done in this area as part of the BUDDIE-PACK project. In 2023 the MariLCA project published a set of Characterization Factors for Microplastics Impacts in Life Cycle Assessment, to assess physical effects on biota from emissions to aquatic compartments [11]. This work addresses the steps within the green border in Figure 2.

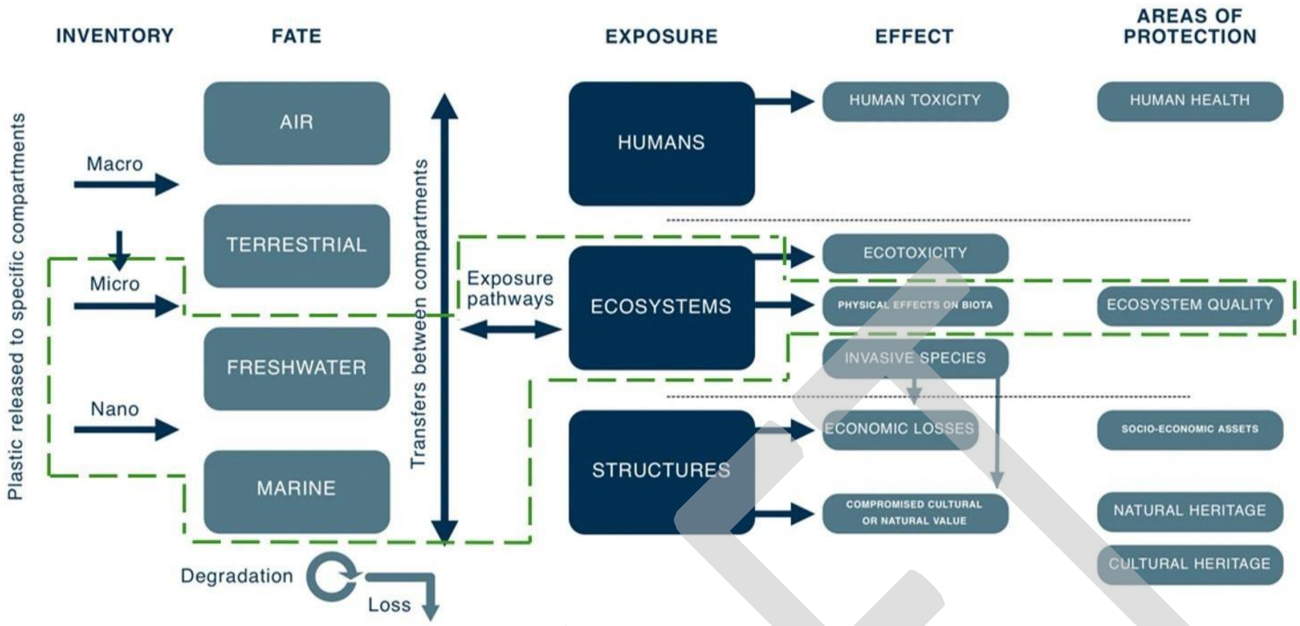

Figure 2: Simplified MarILCA framework with the scope of the developed CFs highlighted in green

The MariLCA project also aims to tackle the other compartments shown in this figure: macroplastic inventory, air & terrestrial fate, transfer between fate compartments, human toxicity and ecotoxicity, and impact on structures. However, it does not work on microplastic production leading to those impacts, depending on the type of resin, process, use steps, end-of-life, etc.

Work by IPC & ENSAM [12] highlights that industrial activities contribute significantly to microplastics, over and above losses of plastic granules. Several sectors have been identified as sources of nano- and microplastic (NMP) discharges, including mechanical plastics recycling, the textile industry, petrochemicals, incineration of plastic waste, and ultrafiltration treatment of drinking water. The mechanisms behind NMPs include mechanical wear of plastics and aerosol formation during heating. The analysis highlights the importance of better understanding the interactions between materials, processes and intrinsic polymer properties to better assess and prevent the formation of NMPs in industrial processes. Through comparison of properties with industrial data, IPC has developed a tool which allows risk of formation and potential release mechanisms to be understood, and provides guidance to companies setting up a new line or looking for ways to understand and limit the formation of NMPs.

In conclusion, several initiatives exist in order to quantify microplastics production probability and impacts, but they remain limited to a specific area of study, thus making it hard to clearly bring out the relation between microplastic production through all plastic packaging life cycle steps and their potential impact on humans and ecosystems.

Work package 5 of the BUDDIE-PACK project addresses this gap by providing experimental, quantitative data on MPs released from reusable plastic packaging (RPP) under realistic washing and aging conditions. Results show that MP release is very limited, with no significant difference between new and aged materials. Detailed analyses of the wash water include particle size distribution, morphology (fibers versus fragments), and polymer composition. These findings indicate that RPP represents a low-risk source of MP compared to other environmental sources such as air and soil. Incorporating such empirical data into circularity and lifecycle assessment tools could strengthen their predictive power and provide evidence-based guidance for safe and sustainable reuse of plastic packaging, complementing the more predictive or sector-specific approaches currently available.

6. Calculation: Sustainable development

The Sustainable development section of the Circular Economy definition will be assessed in this structure through the use of three indicators: Environmental impact, Social impact and Economic impact. Each is described in the following section.

6.1. Environmental impact

6.1.1. Indicators selection

Eight environmental impact indicators were selected. Indicators were selected from the Product Environmental Footprint (PEF) method [13]. Indicators were selected with the PEF method, by normalising and weighting the results from the screening results for all use cases coming from Deliverable 7.2 of BUDDIE-PACK. The method selects the normalised and weighted indicators that account in total for more than 80% of the single score. The selected indicators are:

- Acidification
- Climate Change
- Eutrophication, freshwater
- Particulate matter
- Photochemical ozone formation
- Resource use, fossils
- Resource use, minerals and metals
- Water use

Results for these eight indicators across the five BUDDIE-PACK use cases and average result are shown in Figure 3.

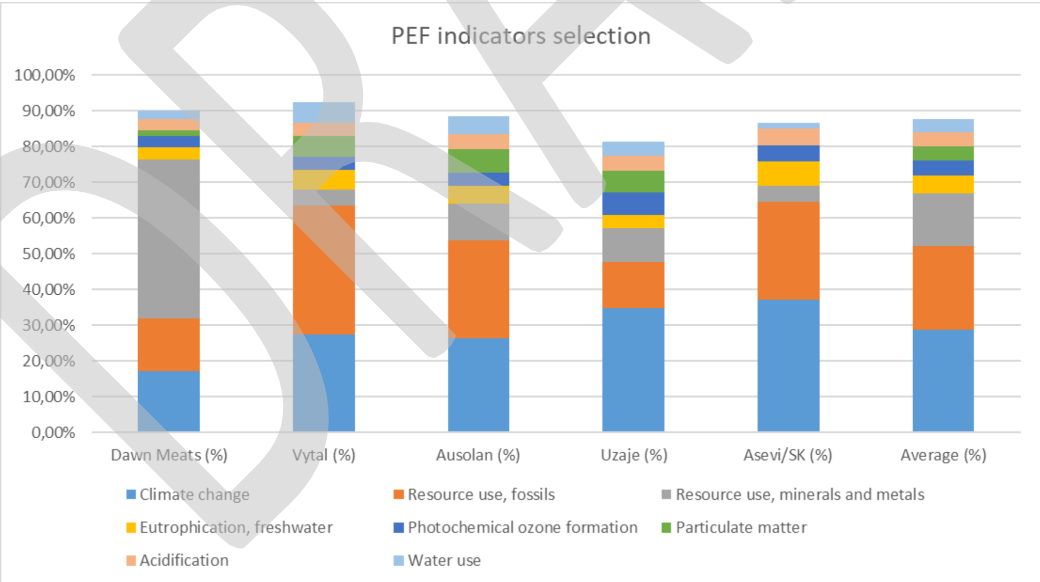

Figure 3: PEF indicator selection for environmental impact

Inventory indicators, i.e indicators that add flows and don't transform them into impacts, can also be good outputs for the user, easier to understand as they don't use characterisation factors. It can be for instance Cumulative Energy Demand, water consumption or litter production. We consider that Cumulative Energy Demand and Water consumption are not necessary, as those flows are respectfully included in Resource use, fossils and Water use indicators. Litter production is tackled Part 6.4.

6.1.2. Input data and database

As the aim of the circularity indicator is to compare the impact of the reusable packaging with that of a single-use packaging, there is a need to model both. In order to keep the indicator "simplified", generic single-use packaging designs are proposed for each use case. To lower quality discrepancies, a restricted selection of use cases is chosen. The single-use packaging modeled in the project full assessment (Deliverable 7.4) are added to the database. The reusable packaging use cases proposed in the indicator for comparison are:

- Detergent bottle
- Supermarket catering container
- Takeaway food container
- Canteen tray
- Meat secondary packaging

The first step consists therefore of selecting the use case, then the corresponding generic packaging available in the database. The single-use packaging options considered are available in Annex 4.

For the reusable packaging modelling, the following information is asked to the user:

- Packaging volume
- Country of use
- For each component (3 maximum): weight, material, RPM rate, process
- Transport for reuse
- Cleaning processes (2 maximum)
- End-of-life collection and scenario, or by default the one of country of use

Secondary data from Ecoinvent 3.9.1 [14] is used for most of the materials, processes and transport processes. Literature data is used for PBT and Tritan materials. Environmental impact data for washing is based on the KIDV LCA tool for reusable packaging V2.0 [15]. Recycling data comes from Franklin life cycle inventories document [16].

Using this data, the database developed in the tool then gives the environmental impact of selected materials, processes, washing, etc. according to the EF3.1 characterisation factors for the selected impact categories, presented in Table 7 [17].

Table 5: EF3.0 characterisation factors for the 8 environmental indicators selected

Impact category	Indicator	Unit	Characterisation methods	Robustness
Climate change	Global Warming Potential	kg CO_2 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
Acidification	Accumulated Exceedance (AE)	mol H+ 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

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
Water use	User deprivation potential (deprivation weighted water consumption)	m^3 deprived	Available WAter REmaining (AWARE) model (Boulay et al., 2018; UNEP 2016)	III

The impact and benefits of end-of-life are modelled with the use of the CFF formula from the PEF [13] (Figure 4).

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

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

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

Figure 4: 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. This is also the case 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.

6.1.3. Modelling of impacts

The model of the packaging life cycle can be summarised by Figure 5.

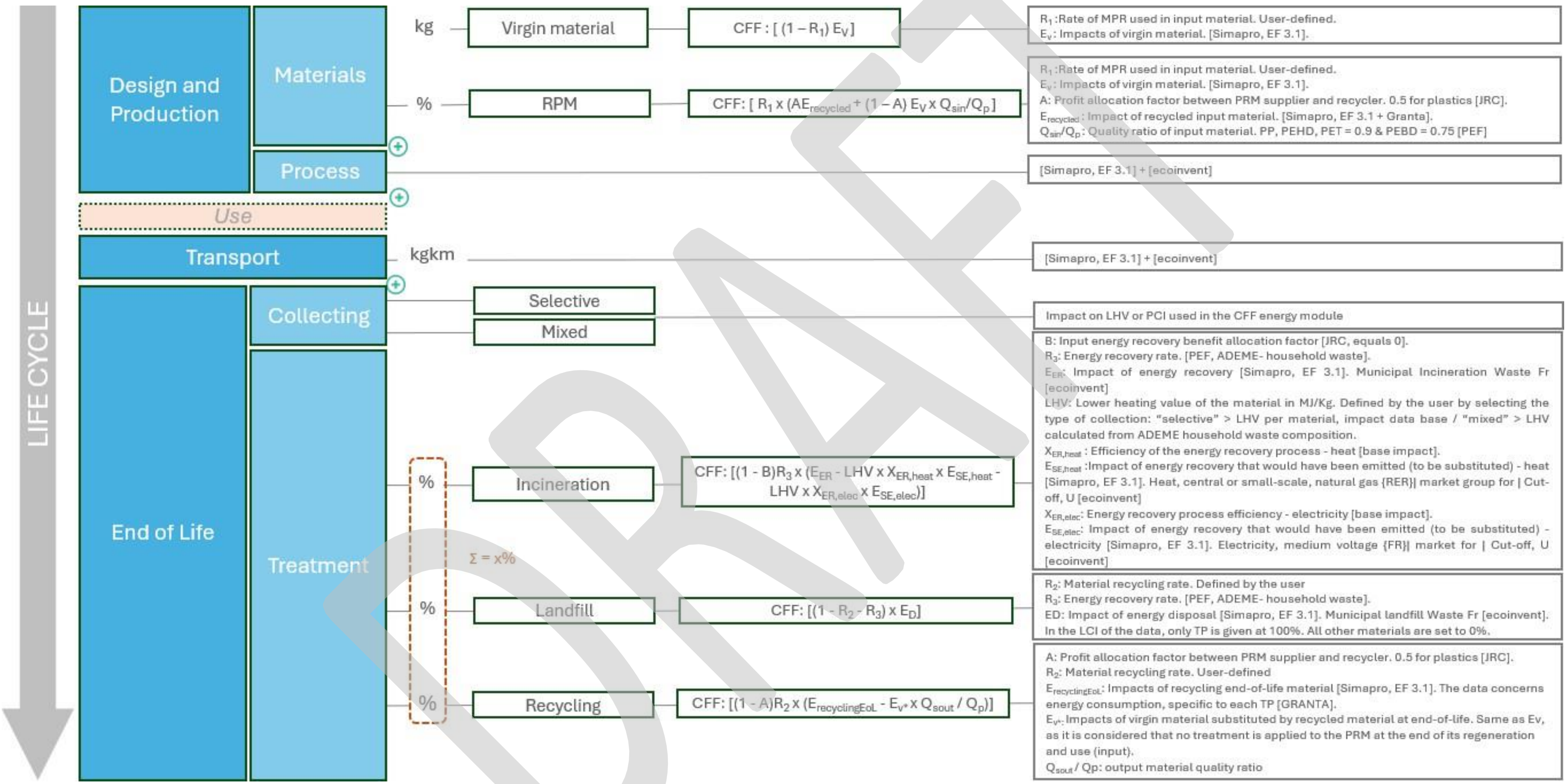

Figure 5: Structure for the calculation of the environmental approach

6.1.4. Output

The output data given by the indicator is the Break Even Point (BEP) i.e. the number of uses necessary to make the reusable packaging better than the single-use one.

It is calculated by finding for each indicator n, the number of reuses in the reusable case, for which:

Single use impact > (Design &Production/n) + Cleaning + Transport + (End-of-life/n)

Consequently, there are 8 BEPs as there are 8 indicators studied.
To simplify the indicator, it was decided to show one BEP value as part of initial results, but to allow the user to easily access individual BEPs. The choice of which single value best represents the range of BEPs is complex. Cases can be made for to show the BEP which is least beneficial for reusable packaging, that which is the most beneficial, or an average. In order to present a conservative result whilst not misleading the reader, it was decided to use the median value. A breakdown of BEPs is also provided.
Due to the washing step in the reusable case, the BEP is significantly higher on Photochemical ozone formation. The screening studies in Deliverable 7.2 not having this kind of result, it is considered that the washing data can be outdated. Hence, the median value enables to have a more consistent global result than the medium value.

6.2. Economic impact

Cost to the producing company, and cost to the consumer, are important economic indicators. Identifying the most suitable specific indicators without requiring large amounts of primary data is challenging. Costs are incurred at each stage of the life cycle (as identified in Figure 8 including materials, manufacturing, transport, end-of-life treatment, and washing in the reuse case. However, in many cases, cost data for specific stages is commercially sensitive and this data is not available. Cost to the retailer was therefore selected as a representative value.

In the single-use case, the product cost to the retailer can be used to give the total cost of all life cycle stages up to the use stage, as well as the manufacturer's profit, but excluding retailer profit. End-of-life treatment is not included in this cost. In the reusable case, the product cost to the retailer includes all life cycle stages apart from end-of-life treatment and washing.

Using product cost to the retailer as the basis for economic data avoids challenges of sensitive data, but requires additional data in both cases. Per use costs, where n represents the number of reuses in the reusable case, are modelled by:

Single-use case: Cost to retailer + End-of-life cost

Reusable case: (Cost to retailer/n) + Washing cost + (End-of-life cost/n)

6.2.1. End-of-life cost

End-of-life differs between single-use and reusable cases: the single-use case is handled by the customer, whereas in general the reusable case will be handled by the manufacturer or some other system operator. . Because of this, end-of-life costs are resolved differently. In the single-use case, this cost has historically been met by local governments. However, as producer responsibility schemes become more common, these costs are now being met by product manufacturers, and consequently are included in the initial cost to the retailer. In the reusable case, if products are returned to the manufacturer or system operator for disposal, these costs are also met by this company and are therefore also likely to be included in the initial cost to the retailer.

End-of-life costs are therefore likely, in both single-use and reusable cases, to be incorporated in the initial cost to retailer.

6.2.2. Washing cost

Data from a study by Zero Waste Europe (*The economics of reuse systems*, published in 2023 [18]) suggests standardised washing costs of €0.10 for bowls and €0.05 for bottles in Europe. These values include transport to and from washing facilities, and can be used as a baseline for calculation when commercially sensitive data is not available.

6.2.3. Cost calculation

Cost to the retailer will be used as an indicator of the material and manufacturing costs, including end-of-life, and standard washing cost data will be added in the reusable case. If the number of reuses is known, the system with the lowest cost can be calculated directly, or if the number of reuses is not known, a break-even point in terms of reuse number can be calculated.

Calculation

Costs per use:

$$\text{Single-use case cost} = Cs$$
$$\text{Reusable case cost} = (Cr/n) + Wr$$

Break-even point:

$$n = Cr / (Cs - Wr)$$

Where:
Cr = Cost to retailer (reusable): user input
Cs = Cost to retailer (single-use): user input

Wr = Washing cost (reusable, per wash): Standard data (bowls: €0.10, bottles: €0.05)
n = Number of reuses at break-even point

6.3. Social impact

According to UNEP / SETAC guidelines [19], and as discussed at length in deliverable 7.2, Social Impact Assessment can be undertaken by considering a series of stakeholder categories and impact subcategories. Guidance recommends six overarching stakeholder categories. Following the social impact assessment scoping study undertaken as part of BUDDIE-PACK project (see Deliverable 7.2), three key relevant stakeholder groups and 13 relevant impact subcategories were identified. These are shown in Table 6.

Table 6: Relevant stakeholder groups and indicator subcategories identified during BUDDIE-PACK Social Impact Assessment screening phase

Stakeholder category	Indicators
Workers	Freedom of association, collective bargaining, labour relations
	No forced labour, human trafficking and slavery
	Management of workers' individual health
	Social / Employer Security and benefits
	Appropriate working hours
	No Discrimination / Equal Opportunities
	Fair Wages
	Safety Management Systems

Local communities	Health and safety of local community's living conditions
	Skills, Knowledge, & Employability
	Access to basic needs for human right to dignity
Consumer	Impact on consumer Health and Safety
	Feedback Mechanism

Social Impact Assessment relies on specific supply chain data, making meaningful conclusions challenging in the absence of primary data. Due to this, simplified indicators of social impact are not easily achievable. However, it is possible to consider differences between the supply chains of reusable and single-use packaging. To produce a simplified indicator, the key difference is the number of required manufacturing and end-of-life processes. In the single-use case, one manufacturing and one end-of-life process are required per product use, whereas in the reusable case, one manufacturing and one end-of-life process provide several product uses. However, the reusable case also requires washing processes, which the single-use case does not. For a reusable product with a lifetime of *n* uses, the impact <u>per use</u> for the two supply chains can be simplified as follows:

Single-use: Manufacture + Transport + Use + EOL
Reusable: (Manufacture + Transport + EOL)/n + Use + Washing

In order to allow a social impact comparison, it is therefore necessary to understand the relative social impact of manufacture, transport, use and end-of-life treatment of single-use products in comparison to the manufacture, transport, use, washing and end-of-life treatment of reusable products. The use phase is identical in both cases. The calculation principles of the comparative social indicator is explained hereafter.

6.3.1. Materials and manufacture

The social impact of manufacture of reusable and single-use products is, in general, expected to be the same. Manufacturing locations and the companies undertaking large scale manufacturing are the same and, in an induced way, the social impact is same. Only materials differ. This difference is not considered in the simplified indicator.

6.3.2. Transport

The social impact of transport from manufacture to distribution locations is expected to be the same for reusable and single-use cases. Transport distances may differ, but in social impact terms this is not relevant.

6.3.3. Washing

The washing phase only applies to reusable packaging, meaning a specific social impact applies to this stage. It was assumed that washing takes place close to use locations.

6.3.4. End-of-life treatment

Single use and reusable packaging are likely to be recycled or disposed of in municipal waste treatment, itself likely to be landfilling or incineration. Though different materials may be used in single-use and reusable cases, the same class of material is expected, so there is no discernible difference in the likelihood of recycling or municipal treatment. This makes the social impact indiscernible between the two cases.

6.3.5. Social indicator calculation

Single-use packaging requires more manufacture, transport and end-of-life processes per use, so if these have significant social impact potential then the single-use packaging is likely to have a greater social impact. Reusable requires washing processes, so if the social impact potential of washing is high, reusable packaging is likely to have a greater social impact.

Based on the 13 social impact subcategories and highlighted in Table 9, a simplified assessment system is used to provide a social impact score for each of the three stakeholder categories. For consistency with the range used in the UNEP / SETAC [19] social impact assessment guidelines, scores of +2, 0 or –2 will be selected. The user will provide a score for each stakeholder group in each life cycle stage (Manufacture, Transport, End-of-life treatment, and Washing). Score descriptions are given in Table 9.

Table 7: Simplified scoring for Social impact assessment based on three relevant stakeholder groups

	Workers	**Local communities**	**Consumer**
+2	The organisation actively works with unions, are free to terminate employment, work fair hours are free from discrimination. The organisation actively works to improve health and safety and enhance social security.	Organisation takes proactive action to improve community health and safety, measured and monitored skills and employability programmes are offered, and organisation takes action to address community needs and improve dignity.	Consumer safety is actively addressed and measures are in place to prevent products becoming unsafe in use, and organisation responds to consumer feedback
0	Workers have the right to join unions, international labour and working hours laws are followed, health and safety risks are considered but not necessarily addressed, and a minimum standard of social security is provided.	Organisation takes appropriate measures and does not harm community health, skills training is available, and some initiatives exist to address human right to dignity.	Products and services are safe for people, property and environment under normal conditions. Organisation has a mechanism for consumer feedback.
-2	Unions are not enabled or engaged with, evidence of forced labour may exist, health and safety and social security laws are not considered or are violated, and discrimination occurs.	Appropriate measures are not taken and harm may occur, no community engagement is undertaken, no measures in place to address human dignity and community needs.	Products and services are not necessarily safe for people, property and environment under normal conditions. No mechanism for consumer feedback.

Scores for the three stakeholder groups are combined to give a total score for each life cycle stage (for example, if the Manufacturing stage for a single-use product was scored +2 in the Workers category, 0 in the Local community category and +2 in the Consumer category, the total score would be +4). The process is repeated for Transport, End-of-life and Washing stages to give a score for each.

Assuming as discussed above that manufacturing, transport and end-of-life treatment scenarios are likely to be similar in the reusable and single-use case, a social impact break-even point can be calculated using these scores. If the impacts of Manufacture, Transport, Use, Washing and End-of-life treatment are represented as M, T, U, W and E respectively, and n is the number of reuses, a break even point occurs when:

$W=(n-1)/n\ (M + T + E)$
(excluding U, which is present in both cases)

At this point, the single-use and reusable cases have the same overall impact.

If $W > (n-1)/n\ (M + T + E)$, the reusable case is likely to have a higher overall social impact
If $W < (n-1)/n\ (M + T + E)$, the single-use case is likely to have a higher overall social impact

6.4. Total littering

A range of definitions of littering exist, but most agree that a key element is the intentional or unintentional disposal of a product in a different location to the intended disposal location. Littering is a complex issue, and as with any risk is fundamentally a product of the likelihood of occurrence and the impact of occurrence. The calculation of likehood and impact of littering are detailed hereafter.

6.4.1. Likelihood of littering

The likelihood of littering is the subject of a greater body of work than the impact of litter.In some literature, likehood of littering is referred to as the "risk of littering", however risk is the product of likelihood and impact, so where literature referred to risk but was clearly describing likelihood, this has been taken into account.

A significant proportion of literature on the likelihood of littering is in the comparison of conventional and bio-based plastics (e.g. [20] [21]). It has been previously suggested that bio-based plastic packaging encourages or validates littering, which has led to a number of publications in this sector. Recently, a review by Hanson et al[i] [22] suggested that this is not the case, and highlighted the size of the product as a more relevant indicator for the likelihood of littering. They concluded that littering is "*primarily driven by convenience and situational factors rather than material properties".* If we base on this assumption, it appears likely that reusable products would be littered less than single-use products, with the possible exception cases where a financial incentive to return the product exists.

6.4.2. Impact of littering

There is limited data on the impact of littering. Much of the work which has been undertaken in this field relates to the impact of litter on marine and ocean environments (such as the MariLCA project [11] and work on coastal impact of litter [23]).Often studies focus on the impact of microplastics. In most cases, studies do not consider differences in impact due to different materials, or consider only large material classes (e.g. plastic). This means that comparison between different plastic materials is not possible, and therefore makes any comparison of the difference in impact of littering between single-use and reusable packaging impossible.

6.4.3. Littering assessment

Due to this lack of supporting data, it is not possible to include a full assessment of the comparative risk of littering in single-use and reusable cases in this work and littering was not included in the assessment tool. However, the likelihood of littering can be considered in a qualitative sense. A range of other factors influence the likelihood of packaging becoming litter, for which insufficient data exists to undertake qualitative assessment. For example, the impact of financial incentives, the values of individuals engaging in reuse, or the increased mass of reusable products relative to single use products. Littering is an area in which further work is required before quantitative conclusions can be made.

Littering can occur at various stages in the product life cycle, for example during distribution, use, or end-of-life phases. In general, distribution stages are well managed and it may be assumed that littering is negligible during this stage. The use and end-of-life stages appear to be the most likely sources of littering. In the single-use product case, one end-of-life stage is required per use, so the likelihood of litter occurring is the sum of the likelihood at each of those two stages. In the reusable case, multiple use stages take place before one end-of-life stage, so the likelihood per use is the use stage plus the end-of-life stage likelihood divided by the number of uses. This suggests that if the end-of-life stage is a major source of littering, then the single-use product is more likely to become litter than the reusable product. However, if littering is most likely to be produced during the use phase, the likelihood of littering, per packaging product, is similar in single-use and reusable cases. Assuming that reusable packaging achieves more than one use and therefore leads to less packaging products being produced, it appears likely that reusable packaging would reduce the likelihood of littering.

7. Circularity indicator calculation tool structure

7.1. Tool interface

As explained previously, the method described in this document will be translated in an Excel based Circular indicator calculation tool (Circular tool). The structure of the defined circular tool will be as follow:

- Life cycle information
- One PCI spreadsheet
- One Value spreadsheet
- One Sustainability spreadsheet
- One Result spreadsheet
- Databases spreadsheets (not visible from user)

The aim is that the first spreadsheet captures most of the necessary information, which is then used for the environmental and economic impact calculations. This will be supplemented by additional parameters in the other spreadsheets to calculate the other indicators.

7.2. Results presentation

It has been decided that each score would be presented separately, as aggregation would blur the message. Moreover, not all indicators have the same unit and scale: the BEP for environmental, social and economic impact each give a number of uses from 1 to infinite, whereas the other scores have a scale from 0 to 1. The interface, shown Figure 6, is still readable with an automatic summary of results.

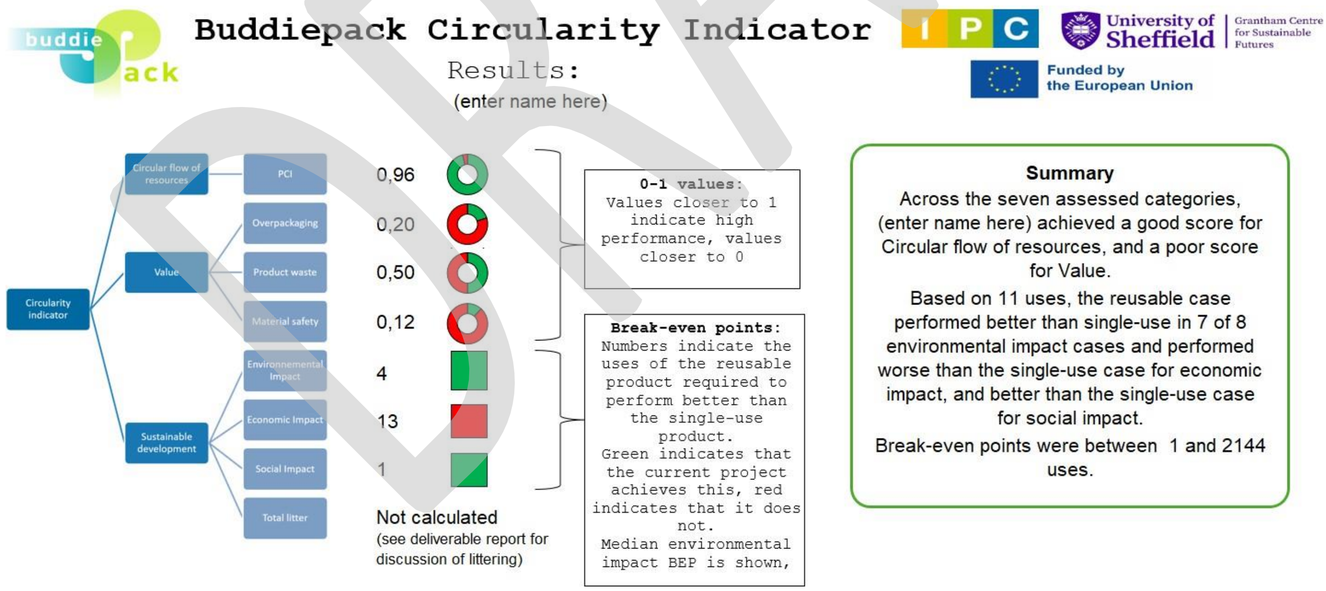

Figure 6: Results presentation interface in Excel tool

As explained Part 6.1.4, the results tab also displays the environmental BEP for each indicator, below the general results presentation.

8. Implement circular indicators at industrials

8.1. Intended use

The circular tool developed with the methodology described in this deliverable provides a simplified point of view on the compatibility of reusable packaging with the circular economy definition.
It asks as little information as possible to the packaging user to give a simple, comprehensive and clear view of where the reusable packaging has a better or worse circular impact than comparable single-use packaging.
As a consequence, it can be used by companies looking to switch from single-use to reusable packaging, or by packaging manufacturing companies to help their eco-design roadmap.

Identified gaps in the circular tool and corresponding methodology are given in the next paragraph. In an improved version, the circular tool could be a decision-making tool at a larger scale, for instance by helping a company or a region state to determine if a reusable packaging is better than a single-use packaging. The current version will be tested during the final months of BUDDIE-PACK project, and results of its application (with feedbacks from industrials) will be implement in Deliverable 7.4: Full circularity assessment.

8.2. Looking ahead

This circular indicator has been developed over a period of one year, and many choices have been made to keep it as simple as possible and ensure delivery on time. Hence, there is room for improvement in order to be more robust and applicable to all use cases. The identified gaps are discussed in the following sections.

8.2.1. Circular flow of resources: comprehensiveness versus simplicity

Circularity indicators demand a challenging balance of comprehensiveness and simplicity. Particularly in the circular flow of resources section, an indicator could easily become sufficiently complex to calculate that it would bring limited benefit in comparison to undertaking full impact assessments. As described in Section 3.3, the method described in this study includes some simplification to avoid this, whilst maintaining a comprehensive assessment. It uses the PCI completed by identified values which can be calculated with secondary data as they correspond with sufficiently limited impact.

8.2.2. Material safety: better understanding of microplastics and substances impact on health

As stated in paragraph 3.4.3, gaps remain concerning material safety in the knowledge of microplastic generation and impact. This gap is of high importance, as resolving this will enable more comprehensive comparison of plastics to other materials used for packaging.

8.2.3. Product waste: narrowed product perimeter

The product waste matrix of the circular tool combines the Retrievability and Design for conservation scores. As the conservation performance of a packaging product depends on many parameters (such as barrier properties, sealing, mechanical/scratch/temperature resistance, stability, and others) it is difficult to summarize these in a matrix, especially when the criteria change from one application to another.
By focusing on the closing performance, our matrix is applicable to all BUDDIE-PACK use cases. However, these results show only one aspect of design for conservation, that is relevant only for food, cosmetics and liquid products applications.
The further development would be to propose a matrix for each type of case study.

8.2.4. Environmental & economic impacts

- Included life cycle steps

To keep the life cycle model simple, it has been decided to exclude transports from the perimeter. They require a lot of information and have been proved as not the largest contributors to the BEP. The consumer transport to collect and return packaging however, may have a significant impact on the reusable packaging life cycle. However, this aspect of transport is heavily dependent on consumer behaviour, which has not been studied enough to develop robust assumptions.

- Number of included single use alternatives

For now, the number of single-use alternatives is limited to the BUDDIE-PACK case studies. The initial plan was to base the single-use packaging dataset on AGRIBALYSE database [24], a reference database on the environmental impact of agricultural and food products in France. The new impact factors for version 3.2 of the AGRIBALYSE database were published in May 2025. They include the results from PACK-AGB project [25], that aimed to model the most used packaging per product type, instead of using a proxy. The project covered 1286 products over the approximately 2400 available products in AGRIBALYSE database. However, the 'software' versions are currently being implemented in OpenLCA and Simapro, so it is difficult to export the packaging specific data to use them in the tool.
A potential future area for improvement may be the implementation of these packaging data in the circular indicator tool. However, it must be kept in mind that economic data is required to include these aspects. While economic data exists for some products, in some sectors (such as cleaning products or cosmetics), this can be more challenging to access.

8.2.5. Total littering

As stated in the section 3.5.4, risk of littering is made up of likelihood and impact. Whilst some work exists on likelihood of littering, the relevant body of work on the impact of littering is very limited. Consequently, it is not currently possible to define a total risk of littering, but only to discuss qualitatively the potential likelihood of littering. This is an area which would benefit greatly from further work.

9. References

(1) International Organization for Standardization (2024). ISO 59004:2024, Circular economy - Vocabulary, principles and guidance for implementation.

(2) International Organization for Standardization (2024). ISO 59020:2024, Circular economy - Measuring and assessing circularity performance.

(3) Michael Saidani, Bernard Yannou, Yann Leroy, François Cluzel, Alissa Kendall, A taxonomy of circular economy indicators, Journal of Cleaner Production, Volume 207, 2019, Pages 542-559, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.10.014.

(4) Bracquené, E., Dewulf, W., Duflou, J.R., 2020. Measuring the performance of more circular complex product supply chains. Resour. Conserv. Recycl. https://doi.org/10.1016/j.resconrec.2019.104608.

(5) Measuring Circularity, E. M. F. (2019). Circularity Indicators - An approach to measuring circularity - Methodology. 1–64. http://www.ellenmacarthurfoundation.org/circularity-indicators/.

(6) Soroka, W. *Illustrated Glossary of Packaging Terminology* (Second ed.). Institute of Packaging Professionals.

(7) LOI n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire. NOR: TREP1902395L. JORF n°0035 du 11 février 2020

(8) CITEO. Le tarif 2025 pour la réduction, le réemploi et le recyclage des emballages ménagers.

(9) Muncke, J., Touvier, M., Trasande, L. *et al.* Health impacts of exposure to synthetic chemicals in food. *Nat Med* **31**, 1431–1443 (2025). https://doi.org/10.1038/s41591-025-03697-5

(10) Single-Use Material Decelerator (SUM'D) and Scope 3 Consulting (2025). UP Scorecard (Version 1.0) Methodology.

(11) Elena Corella-Puertas, Carla Hajjar, Jérôme Lavoie, Anne-Marie Boulay, MarILCA characterization factors for microplastic impacts in life cycle assessment: Physical effects on biota from emissions to aquatic environments, Journal of Cleaner Production, Volume 418, 2023, 138197, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2023.138197.

(12) RECORD, AMVALOR, IPC, Rejets de micro-et-nanoplastiques dans les milieux lors des process industriels - état des connaissances et développement d'une approche méthodologique pour l'évaluation qualitative du risque d'émission de NMPs, 2025, 142 pages, n° 23-0174/1A.

(13) European Commission. Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations.

(14) Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230.

(15) Partners for Innovation, Utrecht University, KIDV. 2020. Calculation Tool Reusable Packaging. (16)Franklin Associates, A.D.o.R.G.E., 2018. Life cycle impacts for post consumer recycled resins: PET, HDPE, and PP. https://plasticsrecycling. org/images/apr/2018-APR-Recycled-Resin-Report.pdf

(17) Andreasi Bassi S., Biganzoli F., Ferrara N., Amadei A., Valente A., Sala S., Ardente F., Updated characterisation and normalisation factors for the Environmental Footprint 3.1 method. Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/798894, JRC130796.

(18) Zero Waste Europe, 2023. The economics of reuse systems. https://zerowasteeurope.eu/wp-content/uploads/2023/06/2023-SB-ZWE-The-economics-of-reuse-systems.pdf

(19) United Nations Environment Programme (2020). Guidelines for Social Life Cycle Assessment of Products and Organisations 2020. https://wedocs.unep.org/20.500.11822/34554.

(20) Webler, T., & Jakubowski, K. Attitudes, Beliefs, and Behaviors about Cigarette-Butt Littering among College-Aged Adults in the United States. International Journal of Environmental Research and Public Health. 2022. 19(13). 8085

(21) Dilkes-Hoffman, L., Lant, P., Ross, H., Pratt, S., and Laycock, B. Do biodegradable plastics increase public acceptance of littering? Environ. Res. Commun. 2024. 6. 121002

(22) Polly-Ann Hanson, Gail Shuttleworth, Adrian Higson, Jen Vanderhoven. Do Biodegradable Plastics Encourage Littering? BB-REG-NET project, May 2025

(23) Diana Ita-Nagy, Ian Vázquez-Rowe, Ramzy Kahhat. Developing a methodology to quantify mismanaged plastic waste entering the ocean in coastal countries, Journal of Industrial Ecology, 2022 https://onlinelibrary.wiley.com/doi/10.1111/jiec.13349

(24) Cornelus, Mélissa; Auberger, Julie; Rimbaud, Audrey; Ceccaldi, Mathilde, 2024, "AGRIBALYSE® version 3.2", https://doi.org/10.57745/XTENSJ, Recherche Data Gouv, V11

(25) Colombin Margaux; Audoye Pauline; Farrant Laura; Allain David; Anneraud Charlotte; Bosque Fabrice; Besnier Antoine; Bozec Arnaud; Colin Catherine; Falchetti-Cartier Axel; Hugrel Charlotte; Leroy François; Girard Pierrick; Gloz Justine; Guichard Clara; Librere Sarah; Morel Lucie; Penavayre Sophie; Rouault Anthony; Vialatte Cyntia, 2024, "Projet Pack-AGRIBALYSE", https://doi.org/10.57745/ZTZUQR, Recherche Data Gouv, V3

10. Annexes

10.1. Annex 1: PCI calculation method and secondary data

Calculated variables

An expanded version of the table presented in Section 3.3 is given below, including the equations used to calculate variables which are not entered as direct inputs.

Table 10.1. PCI variables, titles, units and calculation methods

Description	Title	Unit	Calculation (where calculated)
Fraction of reused components	Fu	*%*	
Fraction Recycled content of material	Fr	*%*	
Total mass	M	*kg, T*	
Efficiency of component production	Ecp	*%*	
Efficiency of raw material production	Efp	*%*	
Efficiency of recycled material production	Efrp	*%*	
Efficiency of material separation	Ems	*%*	
Fraction of recovered material losses: component production	Ccp	*%*	
Fraction of recovered material loss: raw material production	Cfp	*%*	
Fraction of end-of-use products collected for re-use	Cu	*%*	
Fraction of end-of-use products collected for recycling	Cr, CR	*%*	
The available or used life of the product (years), for the product evaluated	L	*y*	
The expected life of the product (in years) based on a market study or industry standard / average.	Ld	*y*	
The intensity of use available or used (uses per year)	I	*nb/y*	
The intensity of use expected (uses per year)	Id	*nb/y*	
Material quality factor used in the product (if known)	Qin	*0 - 1*	
Material quality factor derived from the product (if known)	Qout	*0 - 1*	
Actual number of uses during the product lifetime	U	nb	L . I
Expected number of uses of the product during lifetime	Ud	nb	Ld . Id
Virgin material	V	kg, T	(((1 - Fu) . M) / (Ecp . Efp)) . (1 - Fr)
Waste from feedstock production	Wfp	kg, T	(((1 - Fu) . M) / (Ecp . Efp)) . (1 - Efp) . (1 - Cfp)
Waste from component production	Wcp	kg, T	(((1 - Fu) . M) / Ecp) . (1 - Ecp) . (1 - Ccp)
Uncollected EoL product	Wu	kg, T	M . (1 - Cr - Cu)
Waste from material separation	Wms	kg, T	M . (1 - Ems) . Cr
Waste from recycled feedstock production	Wrfp	kg, T	M . Ems . Cr . (1 - Erfp)
Unrecoverable waste	W	kg, T	Wfp + Wcp + Wu + Wms + Wrfp
Waste from feedstock production	Rfp	kg, T	(1 - Ecp) . Ccp . ((1 - Fu) . M) / Ecp)
Waste for component production	Rcp	kg, T	(1 - Efp) . Cfp . ((1 - Fu) . M)
Waste from EOL	Reol	kg, T	Efrp . Ems . Cr . M
Recycled material used for feedstock production	Rin	kg, T	Fr . ((1 - Fu) . M) / (Efp . Ecp)

Recycled material recovered	Rout	kg, T	Rfp + Rcp + Reol
Recycled material (net exchange)	R	kg, T	|Rin - Rout|
Reused components (net exchange)	C	kg, T	|M . (Fu - Cu)|
Amount of virgin feedstock in the linear system	V_{linear}	kg, T	M / (Ecp . Efp)
Amount of waste in the linear system	W_{linear}	kg, T	M / (Ecp . Efp)
Linear flow index	LFI	kg, T	(V + W + 1/2 . |R| + 1/2 . |C|) / (Vlinear + Wlinear)
Linear flow index (material quality known)	LFI	kg, T	(V + W + Qin. Rin - Qout . Rout) / (Vlinear + Wlinear)
Utility factor (L/Ld)(I/Id) or (L/Ld)(U/Ud)	X		U / Ud

Secondary data sources

Nine variables used in the PCI were identified as acceptable for the use of secondary data, in order to reduce the burden of primary data required for the calculation. Secondary data sources for these variables are identified below.

Fraction Recycled content of material:
Values for recycled content of material based on material type can be obtained from the UP Scorecard. This data is titled “Regions: Default values for Recycled Content (RC), Recycling Collection Rates (RR) and Compost rates”, and can be found at:
https://docs.google.com/document/d/1EzHW_WnUKtTKyRE9f3O6SEXCUOx_viJdcPcYlQyjAQ4/edit?tab=t.0#heading=h.hfhxbm36o1tn
It can also be found in Annex C of the PEF method (https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html), that gives Default application-specific and material-specific values for the parameters to be used in the application of the Circular Footprint Formula. The relevant parameter to look at here is R_1.

Efficiency of component production, Efficiency of raw material production, Efficiency of recycled material production, Efficiency of material separation:
Efficiency data has a relatively minor impact on the final PCI score. Specific efficiencies are challenging to measure, and variable. However, many sources agree that efficiency of component and raw material production (including recycled material and separation), are generally around 60-80%. A value of 0.7 is therefore suggested in the absence of specific data.

Fraction of recovered material losses (component), Fraction of recovered material losses (raw material):
These values describe the fraction of material loss which is recovered at each stage. Literature suggests that due to cost implications, a high proportion of material losses are likely to be recovered. These values are linked to efficiency, and in the absence of process specific data, a value of 0.7 is likely to be conservative.

10.2. Annex 2: UP Scorecard Chemicals of Concern calculation

Presence score

The first of the two indicators within the scorecard's CoC methodology is the Presence Score and is based on the published Food Contact Chemicals Priority (FCCprio) List (Wiesinger et al., 2025). FCCprio identifies known chemicals of concern potentially present in foodware and packaging products. It was developed and is being maintained by the Food Packaging Forum Foundation based on the methodology of the PlastChem Project (Wagner et al., 2024).

The chemicals within the FCCprio List are ranked into four tiers. All chemicals within these four tiers have publicly available data identifying one or more of the following hazards: carcinogenic, mutagenic, or toxic to reproduction (CMR); endocrine disruption; specific target organ toxicity after repeated exposure (STOT-RE); persistent, bioaccumulative, and toxic (PBT); and/or persistent, mobile, and toxic (PMT).

The four tiers are differentiated by considering evidence for human exposure to these hazardous chemicals using the Food Packaging Forum Foundation’s published databases on: intentional use in the manufacture in FCMs (FCCdb), migration and extraction of FCMs (FCCmigex), and presence of FCCs in humans (FCChumon). Accordingly, Tier 1 chemicals have evidence for human exposure due to their detection in human biomonitoring programs as well as evidence for migration from FCMs; Tier 2 chemicals have evidence for migration from FCMs, but they have not been included in human biomonitoring programs; Tier 3 chemicals have evidence for being present in FCMs but not to migrate; and Tier 4 chemicals only have evidence for intentional use in the manufacture of FCMs, but their presence in FCMs has not been experimentally shown.

Table 10.3 outlines the four compliance levels that a foodware or packaging component can achieve based on the FCCprio List. Full details regarding the FCCprio List's data sources, criteria applied, and ranking methodology are provided in the separate methodology document (Wiesinger et al., 2025).

In many cases, the FCCprio List goes beyond current legal and regulatory requirements, which could help suppliers and purchasers stay ahead of emerging regulations and consumer concerns. However, in the event of a possible conflict, legal requirements must be followed. To reflect the best science available, the FCCprio List will be periodically updated and referenced in future versions of the UP Scorecard.

Table 10.3. Compliance levels considering the FCCprio List for a foodware or packaging component

Compliance Level	Description
0	Intentionally contains (or may contain) chemicals of concern identified in Tier 1.
1	Does not intentionally contain any chemicals of concern in Tier 1. Does not intentionally contain any per- and polyfluoroalkyl substance (PFAS). This is defined as a substance containing a fully fluorinated carbon atom or as containing a perfluorocarbon moiety (i.e. CF2) (Scientists’ Statement on Defining PFAS, 2024). Note: Should new scientific evidence become available, this requirement may be updated to include additional classes of chemicals.
2	Does not intentionally contain any of the chemicals of concern identified in Tier 1 (including all PFAS) and Tier 2.

3	Does not intentionally contain any of the chemicals of concern identified in Tiers 1 (including all PFAS), 2, and 3.
4	Does not intentionally contain any of the chemicals of concern identified in Tiers 1 (including all PFAS), 2, 3, and 4.

Once a level of compliance has been established for a foodware or packaging product, a progressive approach to verify the claims of this compliance has also been established to offer the scorecard user increased confidence in the data they are using for decision making. Table 10.4 shows a set of four levels from which a user can choose, when describing the level of disclosure to validate self-documented compliance with one of the compliance levels from Table 10.3.

Table 10.4. Disclosure levels for claimed compliance of a foodware or packaging component with the FCCprio List

Disclosure Level	Description
0	Supplier is unable to provide information about in-scope chemicals of concern in the materials within the foodware or packaging component
1	Supplier self-reports compliance with all in-scope chemicals of concern within the level
2	Supplier provides a statement on their website or a written (preferably publicly available) declaration from an officer level representative of the company self-reporting compliance with all in scope chemicals of concern within the level
3	Supplier provides third party verified certificates of analysis (CoA) and/or approved certification program equivalent (preferably publicly available) for all in-scope chemicals of concern within the level

The assigned compliance level (Table 10.3) and disclosure level (Table 10.4) for a foodware or packaging component are used together by the scorecard to identify the resulting score for the Presence of Chemicals of Concern, as shown in the matrix in Table 10.5.

Table 10.5. Matrix defining a foodware or packaging component's score within the methodology for the presence of chemicals of concern based on the level of FCCprio List compliance and the level of disclosure

		Disclosure Level			
		Level 0	Level 1	Level 2	Level 3
Compliance Level	Level 0	10	10	10	10
	Level 1	10	9	8	7
	Level 2	10	8	6	5
	Level 3	10	7	5	3
	Level 4	10	7	4	1

For example, a component with Level 1 FCCprio List compliance based on Level 1 (self-reporting) disclosure would receive 9 points representing a poor score (as categorized in Table 10.5). In contrast, a component that is compliant with Level 4 of the FCCprio List and has Level 3 (third-party verified) disclosure would receive 1 point indicating the best possible score.

Unless the user inputs information to describe a packaging component's compliance level with the FCCprio List and a disclosure level, the component by default is automatically assigned to have Level 0 compliance and a Level 0 disclosure (resulting in the worst CoC Presence Score of 10).

Migration Potential score

Apart from considering the intentional presence of chemicals of concern in a foodware or packaging component, the second aspect of this methodology considers the propensity for any present chemicals of concern to migrate from the component into the food. This chemical migration leads to chemical exposure to the consumer that could result in adverse health effects. While chemicals in a component can migrate from it during all stages of its life cycle (including manufacturing and end of life), the focus within this methodology is placed on considering the migration of chemicals into food during the product's use phase.
Hundreds of different chemicals of concern across the four tiers in the FCCprio List can be present at different levels in the thousands of different food contact material (FCM) compositions that exist on the market (and be used in foodware and packaging products). Also, specific products within the same use category may vary considerably. This is in addition to the thousands of non-intentionally added substances (NIAS) that could be present in a component, are often not analytically identifiable, and could also be of concern. As very limited quantitative information exists in the public domain to describe the presence or migration of these chemicals from most products during their different uses and applications, a qualitative and generalized approach has to be applied to take into consideration this human exposure potential. The scorecard focuses on the generic properties of the different food contact materials and the role that the properties of the food itself can play in increasing migration.
This is done by considering 1) the inertness of the FCM in the foodware or packaging component and 2) the properties of the food in contact with the component.

Material Inertness
The inertness of a material can be described by proxy through testing its overall migration rate, which is the total amount of chemicals that migrate into the food. While standardized tests do exist for determining overall migration from an FCM, very little data exist in the public domain to quantitatively describe this for most FCMs, and the resources required to test this for the thousands of different FCMs on the market are far beyond the scope of the UP Scorecard as a free resource.
Therefore, to qualify the inertness of the different generic foodware and packaging products in the scorecard, a set of seven scientific FCM experts with testing expertise were consulted. They were each asked to independently qualitatively score the overall migration potential from a set of 34 generic FCMs included in §Appendix Table 10.1 from 'very low' to 'very high'. When determining their score for each material, the experts were asked to always consider a standard food contact area (6 dm^2/kg food) and the worst-case food conditions that could increase the overall migration (e.g. high temperature, acidic, high fat content, etc.). To translate the results from this expert consultation into a numerical score, a point scale was implemented from 10 (highest overall migration; least inert) to 1 (lowest overall migration ; most inert).
The results from the consultation showed that the experts have varying opinions on the overall migration potentials of most materials. However, a consensus was reached for a small subset of the materials: glass, stainless steel, and ceramic were identified as having the lowest overall migration potential (highly inert), while recycled paper and board was identified as having the highest overall migration potential (least inert). For all of the other materials in Table 10.1, no consensus could be reached. Recycled paper and board was therefore assigned a score of 10, and glass, stainless steel, and ceramic were assigned scores of 1. Without additional scientific data to inform the overall migration potential of the other materials in Table 10.1, a precautionary approach is taken that assumes the worst-case and assigns a score of 10 for these other materials. As this is a highly uncertain

assumption, all CoC results presented for products in the scorecard based on these FCMs are clearly marked as being uncertain using a hashed circle on the scorecard's results page. Future versions of the scorecard will aim to improve this approach following additional expert input and data provided by product manufacturers.
Using the assigned scores for each FCM shown in Appendix Table 10.1, these are translated over to each of the foodware and packaging components considered in the scorecard and shown in §Appendix Table 10.2 based on the primary FCM they contain that is in direct contact with the food.

Food and Material Interaction
In addition to the inertness of the food contact material, the conditions of use and the chemistry of the foodstuff also have an influence on the migration of chemicals out of a food contact material used for foodware or packaging. To address these interactions between food and FCM, this metric adapts an evaluation scheme developed and published by (Geueke et al., 2022) for the Association of the Swiss Organic Agriculture Organisations (Bio Suisse). The approach creates a food and material interaction score based on six factors that influence chemical migration for a component including: typical storage time, storage temperature, fat content of the food, acidity of the food, aggregate state of the food, and the volume of the foodware of food packaging as an indicator of the surface-to-volume ratio.

For a component, one of five values is chosen that most accurately describes each of the six factors as shown in Table 10.6. These values each correspond to a score from 1 (best, leading to least migration) to 5 (worst, leading to most migration). The scorecard includes a set of predefined foods that can be used to compare foodware and packaging products, and users have the option to create and save new custom foods. Table 10.3 in the Appendix provides an overview of the pre-defined foods available in the scorecard along with their values set for each of the six factors of food and material interactions.

Table 10.6. Scoring scheme evaluating six factors of food and material interactions leading to lower or higher potential for chemical migration based on typical storage conditions and physical-chemical properties of the foodstuffs

Storage time		**Storage temperature**		**Fat content (of foodstuff)**		**Acidity (of foodstuff)**		**Aggregate state of the food**		**Typical packaging size**	
<4 days	1	<0°C	1	0-2%	1	pH >7	1	Solid food with punctual contact	1	>1 L or >1 kg	1
4-7 days	2	0-8°C	2	3-10%	2	pH 5-6.9	2	Solid food with full contact	2	0.5-1 L or 0.5-1 kg	2
8-14 days	3	9-18°C	3	11-20%	3	pH 3-4.9	3	Semi-solid food	3	0.25-0.49 L or 0.25-0.49 kg	3
15-30 days	4	>18°C	4	21-30%	4	pH <3	4	Liquid food	4	0.1-0.249 L or 0.1-0.249 kg	4
>30 days	5	Any heating >40°C in the packaging	5	>30%	5	Not applicable	5	Not applicable	5	<0.1 L or <0.1 kg	5

A high fat content, for example, increases the transfer of fat-soluble chemicals from the foodware or packaging into the food. Similarly, acidic foods and beverages can also raise the migration levels of certain chemicals. It also makes a difference whether solid or liquid foods are in contact with the foodware or packaging material. When migration into solid foods occurs, the chemicals are mainly found in the portion of the food that is closest to the

FCM, whereas chemicals are more evenly distributed throughout liquid foods and can therefore reach higher overall concentrations over time.
High storage temperatures and long contact times can further increase the migration rates and final concentrations of chemicals in foods. The surface-to-volume ratio between the packaging (surface) and the food (volume) also influences the migration behavior. A small packaging item releases relatively higher amounts of chemicals per unit of food because the surface-to-volume ratio is higher in smaller sized packaging.
The Food and Material Interaction Score for a foodstuff and its storage conditions is the sum of the individual scores (a value of 1 to 5) for each of the six factors in Table 10.6. This results in a raw score within a range of 6 to 28. This raw score is then linearly transformed into a value within the range of 1 to 10, in order to match the range of the Inertness Score.
The Inertness Score and the Food and Material Interaction Score are given equal weight in defining the Migration Potential Score.
Migration Potential Score=Inertness Score + Food and Material Interaction Score

Overall score

Component CoC Score=Presence Score+Migration Potential Score

The Overall Raw CoC Score for the product is a weighted average of its Component CoC Scores:

$$W = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{n} w_i}$$, where

W = Overall Raw Chemicals of Concern Score for a product

n = number of components in the product

w_i = food contact weighting factors, as defined in Table 10.7

X_i = raw Component Chemicals of Concern Score for component *i*

As a final step, the normalized Overall Chemicals of Concern Score for a product (as presented to the user in the UP Scorecard results) is calculated by linearly transforming the Overall Raw Chemicals of Concern Score to a value within the range of 1 to 100:
= 1 + 99 * (20 - *W*) / (20 - 2)

Table 10.7. Weighting factors for calculating the Overall Raw Chemicals of Concern Score from the Component Chemicals of Concern Scores. These weights represent the likelihood of different components to come into direct contact with the foodstuff.

Type of Food Contact	Weighting factor (ω_i)
Direct contact: The component is intended to be in direct contact with the foodstuff most of the time. Example: main walls of a bottle or container.	1
Intermittent contact: The component may sometimes be in direct contact with the foodstuff, but this does not occur frequently. Example: lid of a bottle or container. OR Indirect chemical migration possible: The component cannot come into direct contact with the foodstuff, but it is not behind a functional barrier or a highly inert material layer (e.g. aluminum, glass, stainless steel, or ceramic). Example: a paper label glued onto a PE container.	0.1

No chemical migration possible: The component cannot come into direct contact with the foodstuff and it cannot migrate through the direct food contact material (either because it is behind a functional barrier or the direct food contact layer is highly inert, e.g. glass or stainless steel) Example: a paper label glued onto a glass or stainless steel container.	0

Table 10.8. Assigned inertness scores within the Chemicals of Concern (CoC) metric for each generic food contact material based on expert review. Materials that reached an expert consensus are bolded. Scoring scale ranges from 10 (least inert) to 1 (most inert)

Food Contact Material	Assigned Inertness Score	Expert consensus reached?
Aluminum, uncoated	10	No
Amorphous polyethylene terephthalate (APET)	10	No
Bagasse (dry fiber from sugarcane/sorghum)	10	No
Bamboo	10	No
Bamboo-melamine	10	No
Biaxially oriented polypropylene (BOPP)	10	No
Cellulose	10	No
Ceramic	**1**	**Yes**
Cork	10	No
Crystallized polylactic acid (CPLA)	10	No
Expanded polystyrene (EPS)	10	No
Glass	**1**	**Yes**
High density polyethylene (HDPE)	10	No
Low density polyethylene (LDPE)	10	No
Melamine	10	No
Molded fiber (generic)	10	No
Oriented polyamide (OPA)	10	No

Oriented polypropylene (OPP)	10	No
Paper and board	10	No
Paper and board, alternative fibers (e.g. grass)	10	No
Paper and board, recycled	**10**	**Yes**
PE with 40% lime (Ecoclean Calymer)	10	No
PET	10	No
PET, recycled	10	No
Polyacrylate (acrylic)	10	No
Polyamide/nylon	10	No
Polyethelene napthalene (PEN)	10	No
Polylactic acid (PLA)	10	No
Polypropylene (PP)	10	No
Polystyrene (PS)	10	No
Soft polyvinyl chloride (PVC) (e.g. films and gaskets)	10	No
Stainless steel	**1**	**Yes**

Table 10.9. Assigned inertness score for each generic foodware and packaging product for the Chemicals of Concern (CoC) metric present in the scorecard on a scale from 10 (least inert) to 1 (most inert). Materials that reached an expert consensus are bolded. Products assigned a precautionary worst-case score given a lack of expert consensus and available data are labelled in this table and also clearly flagged for the user on the scorecard's results page.

Scorecard Generic Food Contact Article	Representative Primary FCM	Assigned Inertness Score Based on Primary Food Contact Material	Worst-case score assigned due to lack of expert consensus?
acrylic container	Polyacrylate (acrylic)	10	Yes
aluminum can, epoxy lined	Low density polyethylene (LDPE)	10	Yes
aluminum takeout (cold)	Low density polyethylene (LDPE)	10	Yes

aluminum takeout (hot)	Low density polyethylene (LDPE)	10	Yes
bamboo bowl	Bamboo	10	Yes
bamboo plate	Bamboo	10	Yes
bamboo utensil	Bamboo	10	Yes
beverage carton	Low density polyethylene (LDPE)	10	Yes
bioPET (30%) clamshell takeout (cold)	PET	10	Yes
bioPET (30%) cup (cold)	PET	10	Yes
bioPET (30%) lid (cold)	PET	10	Yes
bioPET bottle	PET	10	Yes
bioPET bowl	PET	10	Yes
bioPET film	PET	10	Yes
bioPET ramekin	PET	10	Yes
bioPET tray	PET	10	Yes
cardboard sleeve	Paper and board	10	Yes
ceramic bowl, reusable	**Ceramic**	**1**	**No**
ceramic mug (hot), reusable	**Ceramic**	**1**	**No**
ceramic plate, reusable	**Ceramic**	**1**	**No**
ceramic ramekin, reusable	**Ceramic**	**1**	**No**
CPLA bowl	Crystallized polylactic acid (CPLA)	10	Yes
EPS foam bowl	Expanded polystyrene (EPS)	10	Yes
EPS foam clamshell (hot)	Expanded polystyrene (EPS)	10	Yes
EPS foam clamshell takeout (cold)	Expanded polystyrene (EPS)	10	Yes
EPS foam cup (cold)	Expanded polystyrene (EPS)	10	Yes

EPS foam cup (hot)	Expanded polystyrene (EPS)	10	Yes
EPS foam cushion	Expanded polystyrene (EPS)	10	Yes
EPS foam plate	Expanded polystyrene (EPS)	10	Yes
EPS foam ramekin	Expanded polystyrene (EPS)	10	Yes
EPS foam tray	Expanded polystyrene (EPS)	10	Yes
glass bottle, PP lid	**Glass**	**1**	**No**
glass bowl, reusable	**Glass**	**1**	**No**
glass cup (cold), reusable	**Glass**	**1**	**No**
glass jar, steel lid	**Glass**	**1**	**No**
glass jar, steel lid, reusable	**Glass**	**1**	**No**
glass mug (hot), reusable	**Glass**	**1**	**No**
glass plate, reusable	**Glass**	**1**	**No**
glass ramekin, reusable	**Glass**	**1**	**No**
HDPE bottle	High density polyethylene (HDPE)	10	Yes
HDPE tray, reusable	High density polyethylene (HDPE)	10	Yes
molded fiber bowl, H2O resist	Molded fiber (generic)	10	Yes
molded fiber bowl, PFAS lined	Molded fiber (generic)	10	Yes
molded fiber clamshell, H2O resist (hot)	Molded fiber (generic)	10	Yes
molded fiber clamshell, PFAS coating (hot)	Molded fiber (generic)	10	Yes
molded fiber cup (hot)	Molded fiber (generic)	10	Yes
molded fiber lid (hot)	Molded fiber (generic)	10	Yes
molded fiber plate, PFAS lined	Molded fiber (generic)	10	Yes
molded fiber plate, uncoated	Molded fiber (generic)	10	Yes

molded fiber ramekin (small bowl), PFAS lined	Molded fiber (generic)	10	Yes
molded fiber tray, H2O resist	Molded fiber (generic)	10	Yes
molded fiber tray, PFAS lined	Molded fiber (generic)	10	Yes
molded fiber tray, uncoated	Molded fiber (generic)	10	Yes
nylon cushion	Polyamide/nylon	10	Yes
nylon film	Polyamide/nylon	10	Yes
paper bowl, PE lined	Low density polyethylene (LDPE)	10	Yes
paper bowl, PLA lined	Polylactic acid (PLA)	10	Yes
paper cup, insulated, PLA lined (hot)	Polylactic acid (PLA)	10	Yes
paper cup, PE lined (cold)	Low density polyethylene (LDPE)	10	Yes
paper cup, PE lined (hot)	Low density polyethylene (LDPE)	10	Yes
paper cup, PLA lined (cold)	Polylactic acid (PLA)	10	Yes
paper cup, PLA lined (hot)	Polylactic acid (PLA)	10	Yes
paper cup, unlined (cold)	Paper and board	10	Yes
paper cushion	Paper and board	10	Yes
paper plate, PE lined	Low density polyethylene (LDPE)	10	Yes
paper plate, PLA lined	Polylactic acid (PLA)	10	Yes
paper ramekin, PE lined	Low density polyethylene (LDPE)	10	Yes
paper ramekin, PLA lined	Polylactic acid (PLA)	10	Yes
paper straw	Paper and board	10	Yes
paper takeout, PE coating (cold)	Low density polyethylene (LDPE)	10	Yes
paper takeout, PE coating (hot)	High density polyethylene (HDPE)	10	Yes
paper takeout, PLA coating (cold)	Polylactic acid (PLA)	10	Yes

paper tray, PE lined	Low density polyethylene (LDPE)	10	Yes
paper tray, PLA lined	Polylactic acid (PLA)	10	Yes
paperboard, corrugated	Paper and board	10	Yes
PE bag	Low density polyethylene (LDPE)	10	Yes
PE film	Low density polyethylene (LDPE)	10	Yes
PE foam cushion	Low density polyethylene (LDPE)	10	Yes
PET bottle	PET	10	Yes
PET bowl	PET	10	Yes
PET clamshell takeout (cold)	PET	10	Yes
PET cup (cold)	PET	10	Yes
PET film	PET	10	Yes
PET lid (cold)	PET	10	Yes
PET ramekin	PET	10	Yes
PET tray	PET	10	Yes
PLA bottle	Polylactic acid (PLA)	10	Yes
PLA clamshell takeout (cold)	Polylactic acid (PLA)	10	Yes
PLA cup (cold)	Polylactic acid (PLA)	10	Yes
PLA lid (cold)	Polylactic acid (PLA)	10	Yes
PLA ramekin	Polylactic acid (PLA)	10	Yes
PLA straw	Polylactic acid (PLA)	10	Yes
PLA tray	Polylactic acid (PLA)	10	Yes
PLA utensil	Polylactic acid (PLA)	10	Yes
PP bowl	Polypropylene (PP)	10	Yes

PP clamshell (hot)	Polypropylene (PP)	10	Yes
PP cup (cold)	Polypropylene (PP)	10	Yes
PP film	Polypropylene (PP)	10	Yes
PP lid (cold), reusable	Polypropylene (PP)	10	Yes
PP lid (hot), reusable	Polypropylene (PP)	10	Yes
PP ramekin	Polypropylene (PP)	10	Yes
PP soup container with lid	Polypropylene (PP)	10	Yes
PP straw	Polypropylene (PP)	10	Yes
PP utensil	Polypropylene (PP)	10	Yes
PS bowl	Polystyrene (PS)	10	Yes
PS clamshell takeout (cold)	Polystyrene (PS)	10	Yes
PS cup (cold)	Polystyrene (PS)	10	Yes
PS lid (cold)	Polystyrene (PS)	10	Yes
PS lid (hot)	Polystyrene (PS)	10	Yes
PS plate	Polystyrene (PS)	10	Yes
PS ramekin	Polystyrene (PS)	10	Yes
PS straw	Polystyrene (PS)	10	Yes
PS tray	Polystyrene (PS)	10	Yes
PS utensil	Polystyrene (PS)	10	Yes
PVC film	Soft polyvinyl chloride (PVC)	10	Yes
stainless steel bottle, PP lid, reusable	**Stainless steel**	**1**	**No**
stainless steel bowl, reusable	**Stainless steel**	**1**	**No**
stainless steel pkg, HDPE lid, reusable	**Stainless steel**	**1**	**No**

stainless steel ramekin, reusable	**Stainless steel**	**1**	**No**
stainless steel straw, reusable	**Stainless steel**	**1**	**No**
stainless steel takeout (cold), reusable	**Stainless steel**	**1**	**No**
stainless steel takeout (hot), reusable	**Stainless steel**	**1**	**No**
stainless steel tumbler (cold), reusable	**Stainless steel**	**1**	**No**
stainless steel utensil, reusable	**Stainless steel**	**1**	**No**
wood utensil	Wood	10	Yes

Table 10.10. Values set for each of the six factors of food and material interactions for the predefined foods available to users in the scorecard.

Food Name	Storage time	Storage temperature	Fat content (of foodstuff)	Acidity (of foodstuff)	Aggregate state of the food	Typical packaging size
Soda	> 30 days	> 18ºC	0–2%	pH < 3	liquid food	0.25–0.5 L
Milk	4–7 days	0–8ºC	3–10%	pH 5–7	liquid food	> 1 L
Water	> 30 days	> 18ºC	0–2%	pH 5–7	liquid food	0.25–0.5 L
Hot Soup	< 4 days	heating >40°C in packaging	3–10%	pH 5–7	liquid food	0.25–0.5 L
Coffee	< 4 days	heating >40°C in packaging	0–2%	pH 3–4.9	liquid food	0.25–0.5 L
Cheese	8–14 days	0–8ºC	> 30%	pH 3–4.9	semi-solid food	0.1–0.24 L
Salad	< 4 days	0–8ºC	0–2%	pH > 7	solid, punctual contact	0.25–0.5 L
Fresh produce	< 4 days	0–8ºC	0–2%	pH > 7	solid, punctual contact	0.51–1 L
Yogurt	8–14 days	0–8ºC	3–10%	pH 3–4.9	semi-solid food	0.1–0.24 L
Dry pastries	> 30 days	> 18ºC	21–30%	pH > 7	solid, full contact	0.25–0.5 L
Hot, Oily, Acidic	> 30 days	heating >40°C in packaging	> 30%	pH < 3	liquid food	< 0.1 L
Cheese Pizza (non-frozen)	< 4 days	heating >40°C in packaging	3–10%	pH 5–7	solid, full contact	0.25–0.5 L

10.3. Annex 3: Environmental impact categories explanation

Acidification

Acidification has contributed to a decline of coniferous forests and an increase in fish mortality. Acidification can be caused by emissions to the air and deposition of emissions in water and soil. The most significant sources are combustion processes in electricity, heat production, and transport. The more sulphur the fuels contain the greater their contribution to acidification. The potential impact of substances contributing to acidification is converted to the equivalent of moles of hydron (general name for a cationic form of atomic hydrogen, mol $H+$ eq).

Climate Change

It is an indicator linked to global warming and is the most widely used in various regulations, with a standard dedicated to its regulation (*ISO 14064*). It is also the most robust LCA indicator (*JRC European Comission et Pant 2019*). In fact, it is a model developed by the IPCC, based on scientific consensus and regularly updated (*Hervé 2023*).
This indicator refers to the increase in the average global temperatures as result of greenhouse gas (GHG) emissions. The greatest contributor is generally the combustion of fossil fuels such as coal, oil, and natural gas. The global warming potential of all GHG emissions is measured in kilogram of carbon dioxide equivalent (kg CO_2 eq), namely all GHG are compared to the amount of the global warming potential of 1 kg of CO_2.

Eutrophication, freshwater

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P), which promotes growth of algae or specific plants. If algae grow too rapidly, it can leave water without enough oxygen for fish to survive. Nitrogen emissions into the aquatic environment are caused by fertilisers used in agriculture, but also by combustion processes. The most significant sources of phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. The potential impact of substances contributing to freshwater eutrophication is converted to the equivalent of kilograms of phosphorus (kg P eq).

Particulate matter

This indicator measures the adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO_2). Usually, the smaller the particles, the more dangerous they are, as they can go deeper into the lungs. The potential impact of is measured as the change in mortality due to PM emissions, expressed as disease incidence per kg of PM2.5 emitted.

Photochemical ozone formation

Ozone (O_3) on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog (“summer smog”) is present in cities. The potential impact of substances contributing to photochemical ozone formation is converted into the equivalent of kilograms of Non-Methane Volatile Organic Compounds (e.g. alcohols, aromatics, etc.; kg NMVOC eq).

Resource use, fossils:

It sums up the total quantity of fossil fuels (gas, lignite, oil, coal, etc.) consumed at different stages in the product's life cycle. In a way, it provides information on the product's contribution to resource scarcity, and therefore to supply criticality and rising prices. What's more, resource consumption is one of FREC's priorities, as it is in the objectives of EPR, particularly for packaging. Moreover, the manufacture of plastic products contributes to the depletion of fossil fuels (oil). If the functions fulfilled by these plastic products are to be maintained over the long term, it is essential to preserve the resource base.

The earth contains a finite amount of non-renewable resources, such as fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting resources today will force future generations to extract less or different resources. For example, the depletion of 28 fossil fuels may lead to the non-availability of fossil fuels for future generations. The amount of materials contributing to resource use, fossils, are converted into MJ.

Resource use, minerals and metals

This impact category has the same underlying basic idea as the impact category resource use, fossils (namely, extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources). The amount of materials contributing to resource depletion are converted into equivalents of kilograms of antimony (kg Sb eq).

Water use

The abstraction of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers water withdrawals directly from natural freshwater reserves. Contrary to the "water stress" indicator (which reduces the sum of withdrawals to the criticality of water depending on the geographical area), the water flow indicator accounts for water consumption as a gross value consumed. It is not a question here of accounting for actual water consumption, which corresponds to water withdrawn minus water discharged (Maeseele et al. 2021), but only for water withdrawn, since considering discharged water would require qualifying the pollution level of this discharged water. With groundwater levels becoming increasingly low (BRGM 2023), due in particular to heatwaves, it is necessary to be able to model solutions with the smallest possible water footprint. The potential impact is expressed in cubic metres (m3) of water use related to the local scarcity of water.

References

AFNOR. s. d. « Les indicateurs qualité ». https://bivi.afnor.org/notice-details/les-indicateurs-qualite/1294794.

Baud, Pascal, Serge Bourgeat, et Catherine Bras. 2023. « Indicateurs et indices ».

BRGM. 2023. « Nappes d'eau souterraine au 1er avril 2023 et risques de sécheresse estivale | BRGM ». 2023. https://www.brgm.fr/fr/actualite/communique-presse/nappes-eau-souterraine-au-1er-avril-2023-risques-secheresse-estivale.

Commission Européenne. 2023. « Publication du règlement européen sur les matières premières critiques | MineralInfo ». 2023. https://www.mineralinfo.fr/fr/actualite/actualite/publication-du-reglement-europeen-sur-matieres-premieres-critiques.

Hervé, Nicolas. 2023. « Synthèse du sixième rapport de synthèse du GIEC ».

JRC European Comission, et Pant. 2019. « Product Environmental Footprint (PEF) method .pdf ».

Maeseele, Camille, Charlotte Pradinaud, Sandra Payen, et Philippe Roux. 2021. « L'empreinte eau - Memento graphique ». https://doi.org/10.15454/RX5E-Q558.

10.4. Annex 4: Single-use database per use case

[i]Use Case	FU	Alternatives	Example
Vytal	Contain, allow serving in a take-away in France of 1200mL of a 3-side prepared dish	600mL PE laminated cardboard box	https://www.papstar-shop.fr/panier-repas-carton-3-compartiments-600-ml-5-cm-x-14-8-cm-x-18-3-cm-marron-37039.htm?utm_source=google&utm_medium=cpc&utm_id=22525146233&utm_campaign=Performance%20Max%20-%20mittlere%20Marge&utm_adgroupid=&utm_adgroupname=&utm_accountid=140-151-1330&utm_term=&utm_network=x&gad_source=5&gad_campaignid=22518712539&gclid=EAIaIQob-ChMIw6jByvyqjgMVAKODBx3kkzevEAQYASABEgKSNfD_BwE
		PP box or container with lid	https://www.papstar-shop.fr/boites-repas-avec-couvercle-charniere-pp-3-compartiments-5-9-cm-x-21-5-cm-x-21-88489.htm https://www.cenpac.fr/emballages-alimentaires/barquettes-boites-pots-caisses-caissettes/barquettes-alimentaires/boite-alimentaire-3-compartiments-150-cc/p640277
		1350mL Bagasse box	https://www.lusini.com/fr-fr/pdp/165471/
		900mL Bagasse container + RPET lid	https://www.emballagefute.com/937-2435-barquette-bagasse-compartimentee.html
Asevi	Contain and distribute enough softener product to do 50 laundries, in Spain for large scale retail trade.	HDPE bottle with PP cap	Original Asevi bottle
Ausolan	Contain and enable microwave and oven heating of 1 portions of food for catering services.	PP container with attached lid	https://envasescui.es/wp-content/uploads/2021/11/catalogo-envases-cui-2021.pdf
Dawn Meats	Contain 250g of meat, preserve it for 21 days and deliver it from the producer's factory to the restauration businesses	SU PET container with film	Original Dawn Meats tray
Uzaje	Contain, allow distribution and refrigerated storage for 2 days of 500mL of prepared dish in a supermarket in France	500mL PET box	https://www.cenpac.fr/emballages-alimentaires/barquettes-boites-pots-caisses-caissettes/boites-pots-alimentaires/boite-rectangulaire-couvercle-charniere/p12058
		480mL PP container + film or lid	https://www.cenpac.fr/emballages-alimentaires/barquettes-boites-pots-caisses-caissettes/barquettes-alimentaires/barquette-scellable-transparente/p16141
		500mL PE laminated cardboard container+ film	https://www.cenpac.fr/emballages-alimentaires/barquettes-boites-pots-caisses-caissettes/barquettes/barquette-carton-scellable-food-k/p16114