EXPERTS AND SOLUTIONS IN SUSTAINABLE DEVELOPMENT
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Packaging tool

Methodological report - CONFIDENTIAL

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Document for

Pilario

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Acronyms

Acronym	Definition
ABS	Acrylonitrile Ethylene-vinyl alcohol copolymer butadiene styrene
CFF	Circular footprint formula
DQA	Data quality assessment
EAA	European Aluminium Association
EOL	End-of-life
ERR	Empty return rate
EVOH	Ethylene-vinyl alcohol copolymer
FEVE	The European Container Glass Federation
FU	Functional unit
HDPE	High density polyethylene
ILCD	International Reference Life Cycle Data System
ISO	International Organization for Standardization
IV	Intrinsic viscosity
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low density polyethylene
OPA	Oriented polyamide
OPET	Oriented polyethylene terephthalate
OPP	Oriented polypropylene
PBT	Polybutylene terephthalate
PC	Polycarbonate
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PET	Polyethylene terephthalate
PLA	Polylactic acid
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PSE	Expanded polystyrene
PVC	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
SSP	Solid State Polymerization or Polycondensation
TEU	Twenty-feet equivalent unit
TPEO	Thermoplastic elastomer
TPEU	Thermoplastic polyurethane
VOC	Volatile organic compound

Definitions

Name	Definition
LCA model	The LCA models are done by LCA experts and apply to a sector or a family of products. They are made available to non-experts through the Pilario interface. This report focuses on 3 LCA models covering the Packaging sector (generic packaging model, PET packaging model and Glass packaging model).
LCA sub-models (modules)	A LCA model is composed of several sub-models or modules. They are aligned with the life cycle stages covered by the LCA model (raw material production, transport supply, manufacturing, etc.)
Live and exported results	The results displayed in the web interface are called the life results. The results exported in documents (Word or Excel) are called the exported results.
Metadata	Refers to the data necessary to identify a packaging or a scenario but has no influence on the LCA results.
Methodological report	It refers to this report, dedicated to describing objectives, data and methodology used in the tool and its limits. The content of the methodological report can help writing the project report.
Primary packaging	Material that directly encloses and protects the product, like a bottle or a can.
Project report	Report written for communicating results obtained with the tool to third party (including aim of the study, methodology, data entered in the tool interface, results and their interpretation).
Secondary packaging	Outer packaging that holds together multiple primary packages, such as a cardboard box containing multiple bottles or cans.
Tertiary packaging	Packaging used for bulk handling, storage and transportation, such as pallets and shrink wrap.
Word export (or compact LCA *Word* export)	On-demand *Word* report generated automatically by the tool (containing main data and results I table and graphs). It can be used as basis for the project report.
Year data	In tables presenting LCIs used in the model, the column "year data" refers to the earliest year for which ecoinvent and other data providers have collected the primary data contributing to the foreground of the described dataset.

1 Introduction

1.1 Objectives of the tool

The Pilario Packaging Tool aims at measuring the "cradle-to-grave" environmental performance of packing and distributing a defined amount of product (solid or liquid).

The tool applies the life cycle assessment (LCA) methodology. The assessment covers the whole life cycle of the packaging, including the extraction of raw materials, the manufacturing operations, the distribution of the finished goods and the end-of-life of the packaging. The impacts of producing the product itself are not included.

The tool is based on a full life cycle model, built with the aim of producing LCA studies complying with the specifications of the International Standards ISO 14040:2006 and 14044:2006. A selected number of parameters of the model are made accessible to the user of the Pilario Packaging tool through a web interface. The detailed methodology is described in this methodological report.

The tool is mainly designed to be used by packaging producers. As potential non-LCA practitioner, they can evaluate the environmental impacts of their packaging from "cradle-to-grave", using the tool interface and associated knowledge base site. For validation of data used and result interpretation, referring to an internal or external LCA expert can be recommended in case of external communication (see chapter 8 for recommendations for communication), as well as for internal use studies.

The tool is a multi-criteria assessment tool, since the following environmental impacts can be calculated (the choice of impact categories and associated characterization methods is discussed in III.1):

- Climate change
- Resource use: minerals and fossils
- Water use
- Acidification
- Eutrophication: terrestrial, freshwater and marine
- Photochemical ozone formation
- Particulate matter
- Human toxicity: cancer and non-cancer
- Ecotoxicity
- Ozone depletion
- Land use
- Ionizing radiation

The Packaging tool does not pre-define packaging solutions. The user can build his own packaging system. However, the list of materials available in the tool allows at least to cover the container types listed in Table 1.

Table 1: Types of containers covered by the tool (non-exhaustive list)

Type of packaging	Material
One-way bottle	PET
	HDPE
	Glass
	Aluminium
Refillable bottle	Glass
	PET
Can	Aluminium
	Steel
Multilayer packaging	Brick
	Pouch
	Bag-in-box
Aerosol	Aluminium
	Aluminium extruded
	Steel
	PET
One-way keg	Steel
	PET
Refillable keg	Steel
Food can	Aluminium
	Steel
Others	Glass jar
	PP cup
	Plastic general line
	Steel general line
	Multi-material closure

The Packaging tool is multi-country since country-specific secondary data is used for electricity mixes and proposed recycling and incineration rates (as explained in section 2.3). Annex 1 provides the list of countries that can be made accessible in the tool.

Results are available in:

- The web interface from the results tab: "live results"
- *Excel* files containing all results as well as the ability to produce graphs and additional table with pivot table functionality
- Word export presenting the systems, the values of the main parameters and the results (no discussion, no interpretation). This document is titled a compact LCA report, this cannot be considered as an ISO-compliant LCA report.

1.2 Type of report

The tool is mainly designed to be used by packaging producers.

The present report describes the methodology used for developing the Packaging tool. Data, methods, assumptions and limitations of the Packaging tool are presented as well as the choice of the hidden data (not accessible via the Packaging tool's interface).

The report does not contain Life Cycle Impact Assessment (LCIA) results nor result interpretations or conclusions about environmental impacts of packaging. Communication of results obtained with the Packaging tool will be the object of a further reporting process to be carried out by the tool user, potentially with the help of an LCA practitioner. According to ISO 14044, a third-party report, called here project report, shall be prepared when results of the LCA are to be communicated to any third party, regardless of the form of communication.

1.3 Intended audience

The objectives that can be met with the tool are listed in section 2.2.

This methodological report is dedicated to the reviewers of the tool and to LCA practitioners. It is also made available to all tool users.

Project reports that will be written by the tool users to communicate on the obtained results will then be addressed to reviewers of the corresponding studies and to a potentially larger audience, including consumers, marketers…

1.4 Critical review

As defined by ISO 14040 and 14044 international standards on LCA, critical review is the process intended to ensure consistency between an LCA study and the principles and requirements of these standards.

There is no specific standard that deals with the review of tools developed for the evaluation of environmental impacts according to the LCA methodology. However, reviews of such tools have been carried out and published in the past and these reviews are primarily based on the ISO 14040 and ISO 14044 requirements, applying its requirements to tools.

Accordingly, the critical review of an LCA tool process aims at checking the following points:

- the methods used in the tool are appropriate to its goal
- the methods used in the tool are scientifically and technically valid
- the data used are appropriate and reasonable in relation to the goal of the tool
- the methodological report is transparent and consistent.

Hence, the scope of the critical review includes:

- Types of goal and scope of the studies intended to be carried out with the Packaging tool
- System boundaries
- Data sources and quality for data hidden in the Packaging tool
- LCI sources and quality
- Selection of the impact categories

The compliance of the tool to ISO 14040 and 14044 standards is verified by an external peer review of the model and data supporting the tool, with the help of the present report. This can be put forward in any communication.

In any cases, when LCA results based on the Packaging tool will be published in the future with the help of a project report, an additional critical review process can be run. Although not mandatory according to ISO 14040&44 standards, it is strongly recommended, especially when the tool user is not an LCA practitioner or has not referred to an LCA expert. This additional peer review aims at controlling the following aspects not yet covered by the present methodological report:

- the good description of the goal of the study
- the relevance of the selected parameter values
- the relevance of the conclusions
    - Are they in line with the results?
    - Do they reflect the uncertainty?

The additional peer review can be carried out by internal or external independent expert(s).

In case of comparative assertions disclosed to the public, critical review is mandatory. It shall be performed by a panel of at least three experts including interested parties. This additional verification shall also include additional verification of the tool itself with focus on the specifications of paragraph 5.3.1 of ISO 14044 (“For LCA studies supporting comparative assertions intended to be disclosed to the public”).

When not mandatory according to ISO 14040&44, the peer review is nevertheless recommended for increasing the reliability of the disclosure and for being in line with the principles of ISO 14025 (applicable to type III Environmental product declaration).

2 Scope of the study

2.1 Definition of the functional unit

According to ISO 14044, the functional unit expresses the quantified performance of a product system for use as a reference unit. According to the ADEME guidelines for LCAs comparing packaging systems, the definition of the functional unit is recommended to include: [1]

- The function(s) (“what”):
    - Usually, the main functions of the packaging are to contain, preserve and transport / store a product. Additional secondary functions can be (for consumer goods): grouping products (or consumption units), enabling/facilitating product manufacture, facilitate product packaging, facilitate product use, inform and/or promote the product
    - It is further recommended to precise the targeted market segments (specificity of the packed products, e.g. still or sparkling water) and the type of points of sales
- The quantity (“how much”): the reference amount of product assessed
- Other specificities describing “how” the function is fulfilled (e.g. storage temperature)
- The required duration of the function (“how long”)
- The geographical scope (areas of production and consumption)
- The time horizon (e.g. current or prospection situation)

In practice in the Packaging tool, the user can choose among the following three ways for modelling the defined functional unit (FU):

- Per litre
- Per unit of primary packaging unit
- Custom: defining the number of functional units per packaging

The following table provides examples of functional units and illustrates the corresponding ways of modelling in the tool.

Table 2: Examples of functional units

Functional unit definitions and corresponding selections in the tool	
Example 1: “Packing and distributing 1 litre of sparkling water in France while ensuring by appropriate protection that the product reaching the point of consumption fulfils quality standards, at least over the period determined by the “best before” or “use by” dates indicated on the packaging.”	
Example of assessed primary packaging	PET bottles of 50 cl

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[1] GUIOT Marianne, GUEUDET Alice, PARISOT Florian, PASQUIER Sylvain, ADEME, PALLUAU Magali, HUGREL Charlotte, BLEU SAFRAN. 2022. Cadre de Référence - ACV comparatives entre différentes solutions d’emballages | Version 01. 147 p. (in English: Reference Framework - Comparative LCAs of different packaging solutions)

Reference flow	2 bottles of 0.5 l
Functional unit choice (in the tool)	Per litre
Fields to be specified in the tool	Primary packaging volume = 0.5 l
Automatic calculations made by the tool	The tool calculates the number of bottles needed to fulfil the FU = 2 (reference flow in the tool)
Example 2: Packing and distributing a serving dose of 25 cl of juice on the go in Germany while ensuring by appropriate protection that the product reaching the point of consumption fulfils quality standards, at least over the period determined by the “best before” or “use by” dates indicated on the packaging.	
Example of assessed primary packaging	PET bottles of 50 cl
Reference flow	0.5 bottle of 0.5 l
Functional unit choice (in the tool)	Custom functional unit
Fields to be specified in the tool	Primary packaging volume = 0.5 l Reference flow = 0.5 primary packaging unit / FU
Automatic calculations made by the tool	The tool multiplies the results per primary packaging unit by the number “primary packaging units / FU” (0.5)
Example 3: Packing and distributing in Europe one manual teeth brush produced in China in 2024	
Example of assessed primary packaging	A packaging containing 1 teeth brush
Reference flow	1 unit of packaging
Functional unit choice (in the tool)	Per unit of primary packaging unit
Fields to be specified in the tool	Primary packaging's content weight = weight of 1 teeth brush
Automatic calculations made by the tool	Results are directly calculated per primary packaging unit (the number of primary packaging unit per FU = 1 is displayed)

Example 4: Packing and distributing in Europe 1000 manual teeth brushes produced in China in 2024	
Example of assessed primary packaging	A packaging containing 3 teeth brushes
Reference flow	333 units of packaging
Functional unit choice (in the tool)	Custom functional unit
Fields to be specified in the tool	Reference flow = 333 primary packaging unit / FU Primary packaging's content weight = weight of 3 teeth brushes
Automatic calculations made by the tool	The tool multiplies the results per primary packaging unit by the number "primary packaging units / FU" (333)

The amounts of packaging used as reference in the tool are defined for packing an amount of product as delivered at the gate (out) of the producer site. This amount of product cannot be distinguished from the amount effectively used by the consumer since, as a limit of the tool, the product losses (and associated packaging losses) taking place at distribution, further storage, retail and use phase are not modelled in the tool.

To ensure that systems are effectively comparable, particular attention must be paid to the definition of the functional unit in case of comparison. Indeed, according to ISO 14044, "*Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s) in the form of their reference flows. If additional functions of any of the systems are not taken into account in the comparison of functional units, then these omissions shall be explained and documented. As an alternative, systems associated with the delivery of this function may be added to the boundary of the other system to make the systems more comparable. In these cases, the processes selected shall be explained and documented*".

A warning in the tool interface draws user's attention on the importance of checking that similar functions are effectively compared, in case of comparisons.

2.2 Goal of the study

The tool can be used for two types of intended applications: [2]

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[2] This terminology is taken from the ILCD Handbook 2010 (§ 5.2.1). Both types of studies will mostly correspond to the "Situation A – micro-level decision support" defined in the ILCD Handbook (§5.3.4). Accounting studies performed with the tool are assumed to support decisions made by other stakeholders (e.g. consumer). Hence, they do not correspond to "Situation C" studies.

ILCD Handbook 2010: European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - *General guide for Life Cycle Assessment -*

- supporting decision to be made by the tool user
- accounting/monitoring (usually helping decisions of other stakeholders).

In the first case, effects of changes in systems are assessed. In the latter, a picture of a situation is taken.

Both types of applications are described separately in the next sections. Specific limits associated with each of these objectives are discussed in section 7.1.

2.2.1 Studies supporting decision of the tool user

When the study supports a decision of the tool user, it quantifies how changes in a system affect its environmental impacts. In the context of the Packaging tool, the changes assessed may typically relate to:

- packaging weights
- packaging materials
- recycled content of materials
- recyclability, type of end-of-life treatments and relative shares of these treatments
- parameters related to energy consumption, supply chain parameters, etc.

These changes concern a priori elements that are under the control -direct or indirect- of the tool user. The time horizon comprises the coming year or near future (a few years). Most frequent goals of such studies are presented in Table 3.

In practice, the study can cover the packaging life cycle associated with one product or with a product group. In the latter case, results obtained by product can be compiled for representing a larger scope. Then, the product group corresponds for example to the sales in one country, the production at one factory, a whole brand, a whole company, etc. For such scopes, not only the performances of each product influence the results but also the portfolio of products (i.e. the product mix).

Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010

Table 3: Goal of studies supporting decision of the tool user

Goal of the study	Description	One product	Product group
Eco-design and packaging improvement	Designing the packaging system while considering the environmental impacts of the packaging along its whole life cycle, i.e. at the design stage where technical opportunities are the highest. In particular, selection of a packaging system (or material) based on a comparison between packaging systems	x	
Process improvement	Quantification of the impact changes associated with a change in a process or life cycle step (e.g. onsite manufacturing, distribution transport, …).	x	
Management - improvement strategy	Projection of the life cycle impacts of a system if implementing several improvement actions (including calculation of the relative potential of improvement of each action). This helps goal setting at a defined time horizon. Or optimisation under budget constraint by prioritizing actions to be implemented for reducing the impacts, in function of their relative contribution to improvement	x	x

Besides internal company decision, the goal of the studies may also include external communication:

- Justification of eco-design choice; This may include comparison between materials. In that case, a critical review carried out by a panel including interested parties is mandatory according to ISO 14040.
- Announcement about projected improvements associated with scheduled actions. Improvements shall be quantified by referring to previous or current performances of the declaring company. Because of potential differences in scope, methodology and data, it is not recommended to use the results for comparison with external results, such as market average or prospective market average.

2.2.2 Accounting / monitoring studies

In this report, accounting and monitoring applications correspond typically to studies where a picture of the current situation is taken. A "film" of the successive situations encountered in the last years can also be obtained.

This information can be used internally, e.g. for benchmarking, target monitoring or performance tracking. Often, the information is communicated externally to various stakeholders: to consumers, in b2b communication, to public authorities, etc. Three types of environmental labels and declarations are distinguished in the ISO 14020 series of standards (cf. Table 4).

Table 4: Types of environmental labels and declarations according to ISO 14020 series of standards

Type	Name of declaration /label	Description	Main ISO standard applicable
Type I	Type I environmental labelling	A Type I environmental labelling programme is voluntary, multiple-criteria-based third-party programme that awards a licence which authorizes the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations and product environmental criteria.	ISO 14024
Type II	Self-declared environmental claims (Type II environmental labelling)	A self-declared environmental claim is a claim statement, symbol or graphic that indicates an environmental aspect of a product, a component or packaging, made without independent third-party certification, by manufacturers, importers, distributors, retailers or anyone else likely to benefit from such a claim	ISO 14021
Type III	Type III environmental declarations	Type III environmental declarations provide quantified environmental data using sets of specific rules, requirements and guidelines defined in Product category rules (PCRs) for a product category. An independent verification procedure shall as a minimum be appropriate to determine whether the Type III environmental declaration is in conformance with the PCR requirements.	ISO 14025

Considering that there are currently no labelling programmes or PCRs focusing on a product category ‘packaging’, the tool cannot as such provide Type I or Type III declarations at the packaging level. For complying with a PCR existing for a product category, it should first be verified that way life cycle steps are assessed with the tool is compliant with the requirement of that specific PCR. Then, LCA results associated with the product itself should be calculated separately and combined with the results obtained with the packaging tool. Therefore, in case of external communication, the tool will mainly support self-declared claims.

The possible goals of accounting /monitoring types of studies are presented in Table 5.

Table 5: Types of environmental labels and declarations according to ISO 14020 series of standards

Goal of the study	Description	One product	Product group
Claim or declaration	Results of the life cycle impact assessment can be communicated for packaging associated with one product or with a group of products. The claim or declaration can be restricted to one impact category, as for example in the case of the Carbon Footprint of Product (CFP)	x	x
Comparison between systems	Disclosure to the public of comparative assertion between packaging systems, using common scope and methodology. In that case, a critical review carried out by a panel including interested parties is mandatory according to ISO 14040	x	x
Performance tracking	Quantitative assessment of impact evolutions over a defined period, at fixed methodology, considering evolutions of internal and/or external data. Aiming at ▪ Either internal use for management purposes related to target setting and monitoring ▪ or external communication (marketing)	x	x

In many cases, the disclosed information might be used in comparison with other sources of data, explicitly or implicitly, and used by the stakeholder to support a decision (e.g. purchase decision). It is important to warn the stakeholder that comparisons with data from other sources should be avoided or made with extreme caution. Indeed, scope, data and methodology can differ among the studies. Although the application of a PCR increases the comparability of LCA results, namely by defining scope and methodology, it is not sufficient to ensure direct comparability of results. Therefore, a critical review is always recommended in case of comparison between products within a product category.

2.3 Geographical and time-related coverage

Table 6 lists the steps for which a country can be selected in the interface (out of a list of countries given in Annex 1) and indicates the effect of the country selection on the modelling and/or displayed default values. This table only mentions secondary data since the user can adapt the values of editable parameters (mostly primary data) to the geographical scope targeted for each step.

LCI and activity data are common to all countries for data and steps other than mentioned in Table 6. For LCIs from ecoinvent, the geography “RER” or “Europe without Switzerland” is selected. This is in line with the geographical scope of most other LCI data sources, like Copert (for truck) or European producer associations (for glass, aluminium). Hence the tool is most representative of the European context. However, it can be used for other countries, with higher uncertainties, as discussed in sections 5.5.1and 7.2.

Table 6: Effect of country selection on country-specific secondary data

Steps	Country-specific modelling of grid-electricity	Other country-specific data
For each packaging component – Composition	No, except for recycled plastic production	/
For each packaging component – For each manufacturing step	Yes	/
For each packaging component – End-of-life	No, except for: ▪ electricity recovered at incineration and landfilling ▪ plastic recycling	Default values proposed for recycling rates and incineration rates
Filling	Yes	/

In terms of time horizon, the year of data entered by the user for editable parameters determine the period studied.

For LCI data and hidden activity data, the tool aims at using the most recent data available (cf. chapter 5). In particular, the ecoinvent LCI datasets will be adapted through annual or bi-annual updates. For other LCIs, when new datasets are published, they are included.

In the future, when updated versions of the tool will be released, a versioning of the tool will be set up, meaning that the user can recalculate results with data and modelling contained in a previous version of the tool.

2.4 System boundaries

2.4.1 Steps included

The packaging life cycle is decomposed into phases, see Table 7. Each phase aggregates processes of a specific stage of the life cycle.

Table 7: List of main sub-phases modelled in the tool

Name in the tool	Description	Applying to
Composition	Cradle-to-gate impacts of raw material production and of secondary material production	Each packaging component (can be primary, secondary or/and tertiary packaging)
Transport supply	Transport of the raw material to the packaging manufacturing site	Each packaging component modelled

Name in the tool	Description	Applying to
Manufacturing	Use of energy and other inputs for packaging manufacturing, as well as other direct emissions (several steps can be modelled) + transport to the next manufacturing step or to the filling plant	Each packaging component modelled
Filling	Use of energy for filling and conditioning at the product producer's site.	The whole packaging + product system
Distribution	Energy use, emissions and infrastructure associated with transport for product distribution (including truck, train, barge, boat and plane)	The whole packaging + product system
Collection	Logistics for collection of refillable/reusable packaging	Each refillable/reusable packaging component modelled
End-of-life	Impacts associated to recycling (including benefits of avoided virgin production), incineration (including benefits of energy recovery) and landfilling	Each packaging component modelled

The filling and distribution phases include steps that are also part of the product life cycle:

- In the filling phase, only the processes depending directly on the packaging are included, i.e. the filling in the primary packaging and the conditioning with further packaging. Other on-site operations related to the product production or conservation are excluded (as long as there are independent of the type of packaging)
- For the product distribution, the impacts of transporting the "packaging + product system" from the factory to distribution centres or to points of sale are fully included in the tool. The type of packaging influences the transport parameters, particularly the effective payload. Therefore, its influence on the comparison between several packaging systems has to be taken into account. In general, there are two possibilities for considering the impacts of the distribution of the packed product in LCA studies on packaging systems:
  - Either including all impacts of the "packaging + product system"
  - Or calculating the part of the transport impacts that can be attributed to the packaging, in relation to the packaging weights and to the relative optimisation of the transport (e.g. the number of trucks required to transport a defined quantity of products).

In practice, the second approach cannot be achieved in the tool. Therefore, all impacts of the "packaging + product system" are considered in the results provided by the tool.

2.4.2 Steps excluded

Concerning excluded steps, this report does not discuss steps or components that could be excluded by the tool user while they can be modelled in the tool. This section rather lists the steps that are not included in the model and are not accessible to the user.

In general, exclusions can be divided into two categories:

- Steps excluded because of out of scope although they can be significant in relation to the life cycle results
- Steps excluded because they generate negligible impacts: When the exclusion of steps or elements is based on a cut-off criterion, the value selected as cut-off for each step is 1% of the impacts obtained for the whole life cycle; cumulated, these steps should not represent more than 5% of the whole life cycle.

In the packaging tool, all exclusions are related to steps considered as being out of scope. Depending on the goal of the study, there can be different ways of justifying step exclusions in view of the ISO 14044 standard.

Firstly, for an eco-design purpose, it is justified to exclude the following steps since they do not affect conclusions drawn for this kind of studies. These steps could however be relevant in case of other study goals. The list is:

- Production of the product; it is considered out of scope since the focus of the eco-design approach is mainly on packaging and transport. This is a limit in case the amount of lost liquid (what remains in the packaging when the user considers it is empty) varies according to the selected material/packaging system.
- Infrastructure for on-site operations (manufacturing and filling sites): Infrastructure is included for transport and for all material production processes. However, for packaging or product producer buildings and installations, infrastructure is not included. It is expected that the effect on differences between systems would be negligible.
- Office activities: this impact is not modelled separately as it is expected to be included in the on-site consumptions. In case office emissions are not included in on-site consumptions allocated by amount of manufactured product, it is expected that the effect of office on differences between systems would be negligible.
- Employee commuting and business travel (for both manufacturing and filling sites): it is considered out of scope and does not influence eco-design studies.
- Non-energetic emissions of GHG due to on-site refrigerant systems (need for cooling is assumed independent of the packaging, hence, to be fully allocated to the product).
- Cooling of beverage in retail and at consumers' place; since some beverages are served cold, the exclusion of the cooling steps can be a limit of the assessment (for the total impact value). However, the influence of the packaging type on the cooling impacts is negligible (at constant consumer behaviour).

Secondly, some steps are excluded because the available data lacks robustness. They could however be a concern for packaging/product producer in specific studies. Their influence on eco-design results might be significant.

- Storage at producer warehouse: in theory, the finished goods can be stored in warehouse at producer factory or at drop-off areas. Practices vary greatly in terms of duration of storage (if any) and of need of heating/cooling in warehouse, preventing generic modelling and default values to be proposed in the tool for this step. The volume of the packaging per litre can be an important parameter. If required by the goal of the study, the associated consumptions can be integrated in the Filling & grouping step or modelled separately if more appropriate (a separate modelling could allow, in case of comparison, accounting of only the differences due to the packaging characteristics, i.e. the impacts of the product storage would not be fully included in the packaging life cycle).
- Storage at retail distribution centre and impacts of retail: a coarse sensitivity analysis suggests that impacts at retail places can bring, depending on the product, a contribution potentially above the cut-off value of 1% of the life cycle. However, the lack of robust data prevents us from modelling it properly in the tool for the moment. Again, the volume of the packaging per litre can be an important parameter.
- Consumer transport between home and retail: This step is not expected to be negligible. However, justifications for exclusion are:
    - There is a lack of robust data and the information delivered might be more confusing than helpful for designers. It is indeed difficult to allocate the driven distance to the sold products as there exist 3 different types of allocation: proportional to the volume, same impact for each product, allocation to the products that motivated to go shopping (and motivated the used mode of transport, e.g. by car). However, whatever the allocation, the types of the various packaging are not expected to bring major differences.
    - It is assumed that the packaging / beverage producer does not intend to communicate on figures including this transport.
- Use of cups at the use phase

Thirdly, the following steps are excluded since they are too specific in the framework of the Packaging Tool. They should be modelled separately by the tool user, with the help of an LCA practitioner, if required by the goal of the study.

- Loss of product at conditioning: Loss at filling can depend on the type of primary packaging. Since production of the product is not included in the tool, this impact can however not be considered. It should be assessed using separate data, if required by the goal of the study.
- Use phase and equipment for keg refill: beer served in keg refill has a very different type of use phase regarding cooling and serving appliance at cafe-hotel-restaurant. There has been no demand so far for modelling these elements.

2.5 Compliance with standards

The tool aims at supporting LCA studies that will be compliant with the ISO 14040&44 standards.

Although the Circular Footprint formula and LCIA methods are taken from the PEF reference document published in 2019, the Packaging tool is not designed to apply PEFCRs.

3 LCA methodology

3.1 Impact categories

Table 8 presents the impact categories proposed in the Packaging tool. They correspond to the list of impact categories retained as midpoint in the ILCD Handbook document "Recommendations for Life Cycle Impact Assessment in the European context". The list of characterization factors is taken from the following website (EF 3.1 package):

https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html

Table 8: List of impact categories and related assessment methods defined by the PEF (Zampori & Pant, 2019); EF package 3.1

Impact category	Model	Unit	Source	Robust-ness
Climate change	Bern model – Global Warming potentials (GWP) over a 100-year time horizon	kg CO2 eq	Intergovernmental Panel on Climate Change, 2021	***I***
Ozone depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon	kg CFC-11 eq	WMO, 1999	***I***
Human toxicity, cancer	USETox model	CTUh	Rosenbaum et al., 2008	***III***
Human toxicity, non- cancer	USETox model	CTUh	Rosenbaum et al., 2008	***III***
Particulate matter	USETox model	CTUe	Rosenbaum et al., 2008	***I***
Ionising radiation, human health	UNEP recommended model	decease incidence	Fantke et al, 2016	***II***
Photochemical ozone formation, human health	Human Health effect model	kBq U235 eq	Dreicer et al., 1995	***II***
Acidification	LOTOS-EUROS model	kg NMVOC eq	Van Zelm et al., 2008 as applied in ReCiPe	***II***
Eutrophication, terrestrial	Accumulated Exceedance model	mol H+ eq	Seppälä et al., 2006; Posch et al., 2008	***II***
Eutrophication, freshwater	Accumulated Exceedance model	mol N eq	Seppälä et al., 2006; Posch et al., 2008	***II***
Eutrophication, marine	EUTREND model	kg P eq	Struijs et al., 2009b	***II***
Ecotoxicity (freshwater)	EUTREND model	kg N eq	Struijs et al., 2009b	***III***

Impact category	Model	Unit	Source	Robust-ness
Land use	LANCA	dimensionless	Beck et al. 2010 Bos et al. 2016	***III***
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 water eq of deprived water	Available Water Remaining (AWARE) as recommended by UNEP, 2016	***III***
Resource use, minerals and metals	CML 2002 model ADP ultimate reserves	kg Sb eq.	Van Oers et al., 2008 CML-IA method v. 4.8 (2016)	***III***
Resource use, fossils	CML 2002 model ADP fossil	MJ	Van Oers et al., 2008 CML-IA method v. 4.8 (2016)	***III***

The JRC defines the indicators' robustness as follows:

I	Recommended and satisfactory
II	Recommended, but needs improvements
III	Recommended, but to be used with caution

3.2 Methodological choices

3.2.1 Accounting for electricity use

As described in Table 6, there are steps for which electricity is modelled separately, without being aggregated within an LCI. For these steps, electricity is by default modelled as grid electricity (see 5.3.1 for more details). However, except for end-of-life, the tool user can choose to model a specific electricity mix for these steps.

It is recommended that the use of a supplier-specific mix be subject to requirements, such as those imposed by reference documents such as PEF guidance or ISO 14067. It aims at avoiding double counting of electricity production means.

The requirements of PEF and of ISO 14067 for modelling electricity according to supplier-specific data are successively presented here. They are very similar regarding the acceptability of contractual instrument. It is recommended to the tool user to conform with these requirements even if he does not aim at being compliant with PEF or ISO 14067. Furthermore, the concluded contractual instruments should commit both parties over several years.

Criteria in PEF method

The PEF method[3] describes the requirements to be met the contractual instrument in order to allocate a supplier-specific renewable electricity mix to the packaging manufacturer of product filler (cf. PEF method, section 4.4.2.2 - page 50)

Criterion 1 *- Convey environmental attributes and give explanation about the calculation method*

- *Convey the energy mix: If there is no energy type mix specified in the contractual instruments, ask your supplier to receive this information or other environmental attributes (e.g. GHG emission rate). If the supplier does not answer, you cannot use a "green mix". If the supplier answers, go to next step.*
- *Give explanation about the calculation method used: Ask your supplier to provide calculation method details to ensure that they follow the above principle.*

Criterion 2 *- Unique claims*

- *Be the only instrument that carries the environmental attribute claim associated with that quantity of electricity generation.*
- *Be tracked and redeemed, retired, or cancelled by or on behalf of the company (e.g. by an audit of contracts, third party certification, or may be handled automatically through other disclosure registries, systems, or mechanisms).*

Criterion 3 *- Be issued and redeemed as close as possible to the period of electricity consumption to which the contractual instrument is applied.*

Recommendations of ISO 14067 regarding electricity

The ISO 14067 standard includes the principle of avoidance of double-counting (section 6.4.9.4 "Electricity").

"6.4.9.4.2 Internally generated electricity

When electricity is internally generated (e.g. on-site generated electricity) and consumed for a product under study and no contractual instruments have been sold to a third party, then the life cycle data for that electricity shall be used for that product.

6.4.9.4.3 Electricity from a directly connected supplier

A GHG emission factor obtained from the organization's supplier for the consumed electricity may be used if there is a dedicated transmission line between the organization and the generation plant from which the emission factor is derived, and no contractual instruments have been sold to a third party for that consumed electricity.

6.4.9.4.4 Electricity from the grid

Life cycle data from a supplier-specific electricity product shall be used when the supplier is able to guarantee through a contractual instrument that the electricity product:

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[3] Zampori, L. and Pant, R., Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 9682 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00654-1, doi:10.2760/424613, JRC115959.

- *conveys the information associated with the unit of electricity delivered together with the characteristics of the generator;*
- *is assured with a unique claim (see 5.12);*
- *is tracked and redeemed, retired or cancelled by or on behalf of the reporting entity*
- *is as close as possible to the period to which the contractual instrument is applied and comprises a corresponding timespan;*
- *is produced within the country, or within the market boundaries where consumption occurs if the grid is interconnected.*

[…]

When information on supplier specific electricity is not available, GHG emissions associated with the relevant electricity grid from which the electricity is obtained shall be used. The relevant grid shall reflect the electricity consumption of the related region, excluding any previously claimed attributed electricity. In case no electricity tracking system is in place, the selected grid shall reflect the electricity consumption of the region.

[…]

Some electricity attributes, such as green certificates are sold without direct coupling to the electricity itself. In some countries, parts of the electricity from renewable energy sources might be sold/exported as renewable electricity without being excluded from the supplied mix. For this reason, in such cases a sensitivity analysis applying the relevant consumption grid mix shall be conducted and reported in the CFP study report to demonstrate the difference in results of the electricity tracking instruments.”

3.2.2 Allocation of recycling benefits and Circular Footprint Formula

The Circular Footprint Formula (CFF) is used for modelling allocation of recycling benefits and end-of-life treatments, as provided in the PEFCR Guidance document v6.3 (May 2018):

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

with

A: allocation factor of burdens and credits between supplier and user of recycled materials.

B: allocation factor of energy recovery processes: it applies both to burdens and credits.

Qs_{in}: quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.

Qs_{out}: quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.

Q_p: quality of the primary material, i.e. quality of the virgin material.

R_1: it is the proportion of material in the input to the production that has been recycled from a previous system.

R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R_2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R_2 shall be measured at the output of the recycling plant.

R_3: it is the proportion of the material in the product that is used for energy recovery at EoL.

$E_{recycled}$ (E_{rec}): specific emissions and resources consumed (per unit of analysis) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.

$E_{recyclingEoL}$ (E_{recEoL}): specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process.

E_v: specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material.

E^*_v: specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.

E_{ER}: specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, …).

$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity respectively.

ED: specific emissions and resources consumed (per unit of analysis) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.

$X_{ER,heat}$ 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.

Table 9 gives the values and sources of CFF parameters that are not accessible in the tool interface (B factor, Xer,heat, Xer,elec and LHV. They are common to all countries (for the efficiencies of the energy recovery, it is a current limit of the tool to use the French values for all countries).

Table 9: Non-editable CFF parameters (common to all end-of-life countries)

Material	B factor	Xer,heat	Xer,elec	LHV (MJ/kg)
Source	Annex C PEF package 3.0	ADEME, “Cadre de Référence - ACV comparatives entre différentes solutions d'emballages”, 2022 (Average data of the French plants)		Ecoinvent 3.10 (meta-data of corresponding incineration dataset)
Alu	0	0.11	0.268	/ (0)
Steel				/ (0)
PET				22.95
PP				32.6
HDPE & LDPE				39.01
PS				38.67
Glass				0.046
Cardboard				15.92
Paper				15.92
Wood				13.99
Other materials (as municipal waste)				11.74

The allocation factor A and the Qs/Qp ratios per material are per default set to the PEF values in the tool (cf. Table 10) but they can be adapted by the tool user.

Table 10: Editable CFF parameters (common to all end-of-life countries)

Material	A	Qsin/Qp	Qsout/Qp
Source	Annex C PEF package 3.0		
Alu	0.2	1	1
Steel	0.2	1	1
PET	0.5	0.9	0.9
PP	0.5	0.9	0.9
HDPE	0.5	0.9	0.9
LDPE	0.5	0.75	0.75
PS	0.5	0.9	0.9
Glass	0.2	1	1
Cardboard	0.2	0.85	0.85
Paper	0.5	0.85	0.85
Wood	0.8	No value in PEF (1 per default in the tool)	

3.2.3 Biogenic carbon

The term “biogenic carbon” refers to CO_2 uptake during biomass growth and release of CO_2, CH_4 and CO along with combustion or degradation of biomass-based packaging material (such as cardboard and wood).

In the LCIA method recommended by the PEF for climate change, only emissions of biogenic methane are included. Uptake and emissions of CO_2 are not taken into account. The carbon cycle is assumed to be neutral, except that part of the carbon is emitted as methane.

Emissions due to land use change are modelled as in the ecoinvent datasets used to model bio-based material production (here cardboard, paper and wood).

3.2.4 Infrastructure

Infrastructure is included for material production, transport, energy supply and end-of-life treatments.

For packaging manufacturing and product filling sites, infrastructure is not included (cf. section 2.4.2).

3.2.5 Elementary flow regionalization

Concerning LCI datasets used in the model, only few of the LCIs coming from outside the ecoinvent database (FEVE, Worldsteel, EAA) contain regionalized flows, potentially for water withdrawal and restitution as well as for land use elementary flows.

Elementary flows associated with primary data are not regionalized (e.g. water consumption at the producer site).

The following PEF EF 3.1 impact categories have regionalized characterization factors:

- Water use
- Land use
- Terrestrial eutrophication
- Acidification

However, due to the LCI sources used, LCIA results for these categories are mostly calculated without spatial differentiation. See discussion in section 5.5.

4 LCA software and tool operation

4.1 LCA software

4.1.1 Range LCA models and Pilario interface

LCA models are created thanks to the LCA software RangeLCA, owned by Pilario. This is an LCA model creator, allowing to link variables to LCI datasets. The LCA models are designed by RDC Environment, the LCA experts partner of Pilario.

LCA calculation are done thanks to the LCA Galaxy server, owned by Pilario. This is a calculation server, allowing to evaluate the LCA indicators. The Galaxy server is also where are stored the LCA models.

The user has access to the Pilario interface which allows them to input their activity data (linked to the variables) and get access to the LCA results.

4.1.2 Three packaging models composed of several modules (submodels)

There are packaging models available in the Pilario interface, each of them is an aggregation of several modules or sub-models. See table below to visualize the modules available in each model.

- The Packaging model is to be used for any packaging producers. Its scope is covering the complete life of the packaging (cradle to grave)
- The PET packaging model includes all the materials of the Packaging model and has, besides, a dedicated module for the PET production. It is to be used by PET granulates producers, PET packaging producers or PET recyclers. Its scope is covering the raw material production until the delivery of the finished packaging to packaging filler and end-of-life (cradle to gate with end-of-life). The specific modelling of PET was achieved thanks to help of the PETCORE association; it is covered in this report under the section **Production of PET (PETCORE module).**
- The Glass packaging model includes all the materials of the Packaging model and has, besides, a dedicated module for the glass production. It is to be used by glass packaging producers. Its scope is covering the raw material production until the delivery of the finished packaging to packaging filler and end-of-life (cradle to gate with end-of-life). The specific modelling of glass was achieved thanks to help of the FEVE federation; it is covered in this report under the section **Production of Glass (FEVE module).**

Submodels	Packaging	PET packaging	Glass packaging
Raw material production	✓	✓	✓
Detailed PET granulates production		✓	
Detailed glass production			✓
Raw material supply	✓	✓	✓
Packaging manufacturing	✓	✓	✓
Transport to filler	✓	✓	✓
Filling, grouping and storing	✓		
Distribution	✓		
Collection of reusable packaging	✓	✓	✓
End-of-life	✓	✓	✓

4.2 Database format

The database associated to the software uses the ILCD format. The nomenclature of elementary flows corresponds to the format EF 3.1.

4.2.1 Import of ecoinvent datasets

Ecoinvent 3.10 datasets are provided in ecospold 2 format. To convert this data to the ILCD format and EF 3.1 nomenclature, a mapping file provided on the ecoinvent website is used by Pilario: the table used by ecoinvent to convert the EF v3.1 LCIA methods (in ILCD format) to ecospold 2, i.e., the reverse operation.

A systematic check of the conversion has been performed. The LCIA results corresponding to the EF v3.1 set of impact categories have been calculated with RangeLCA for all ecoinvent datasets and compared to the LCIA results given by ecoinvent. For all impacts categories, differences in LCIA results amount to less than 0.1%, except for water use that shows differences up to 3%.

The reasons for discrepancies for water depletion have been analysed and discussed with ecoinvent. Instead of using the existing elementary flows (EFs) equivalent to the “resources from water” and “emissions to water” EFs in ILCD, ecoinvent only uses the water flows emitted to air to calculate their results of the impact category “resources – dissipated water”. Ecoinvent confirmed that datasets are not entirely “water balanced”, because of the allocation step, i.e, the flows emitted to air are not strictly equal the difference between “from” and “to” water flows.

Following this systematic check, the conversion of ecoinvent data into ILCD format performed by Pilario is considered robust and satisfactory.

In November 2024, ecoinvent version 3.10.1 has been released for correcting v3.10 (emissions to air in coke production and production volumes in markets for electricity in Brazil). Considering these specific corrections, the LCIA results obtained for 5 ecoinvent datasets implemented in RangeLCA (from ecoinvent v3.10) have been compared to LCIA results provided in ecoquery for ecoinvent 3.10.1 (the electricity mixes were selected following the comments of ecoinvent on their corrections, the other two datasets were selected arbitrarily, without exhaustivity):

- market for diesel, low-sulfur RER
- polyethylene terephthalate production, granulate, bottle grade
- market group for electricity, low voltage - BR
- market group for electricity, low voltage - RLA
- market group for electricity, low voltage - CN

For the dataset "market group for electricity, low voltage - RLA", differences up to 40% were observed. Therefore, the version 3.10 of this dataset has been replaced in all sub-models by a process with the LCIA results extracted from ecoinvent 3.10.1 ecoquery for the EF v3.1 LCIA methods studied (16 categories).

For the other tested datasets, the differences between the LCIA results calculated in RangeLCA and the 3.10.1 ecoquery values were below 1% for most impact categories, up to 2% and 3% respectively for water use and Human toxicity non-cancer. Differences up to 20% were calculated for total ecotoxicity, freshwater and Human toxicity - cancer. However, these differences remain acceptable, considering the uncertainty inherently associated to the results of the (eco)toxicity categories, usually discussed at the interpretation phase in terms of hot spot identification.

4.2.2 LCI import from other sources

Import of LCIs from material producer associations (provided in ILCD format by Worldsteel, EAA and FEVE) followed as much as possible the same verification path: the LCIA results calculated in RangeLCA for the imported LCIs were compared with LCIA results communicated by the associations. When available, the EF v3.1 set of LCIA results was used. PlasticsEurope data were imported from Simapro.

For most LCI datasets and impact categories, the results are similar or differences are below 1%.

For the following two cases, investigation is still ongoing with associations to understand the difference:

Worldsteel – tinplated steel: impact for “Resource use, minerals and metals” is 16% higher than LCIA result communicated by Worldsteel it is related to tin elementary flows).

FEVE – recycled glass: impact for “Human toxicity, non-cancer” is 15% higher than LCIA resylts communicated by the FEVE

For LCIs based on COPERT, RDC Environment made manually the link between the emissions given by the Copert tool and the elementary flows of the database.

4.3 Functioning of the Pilario interface

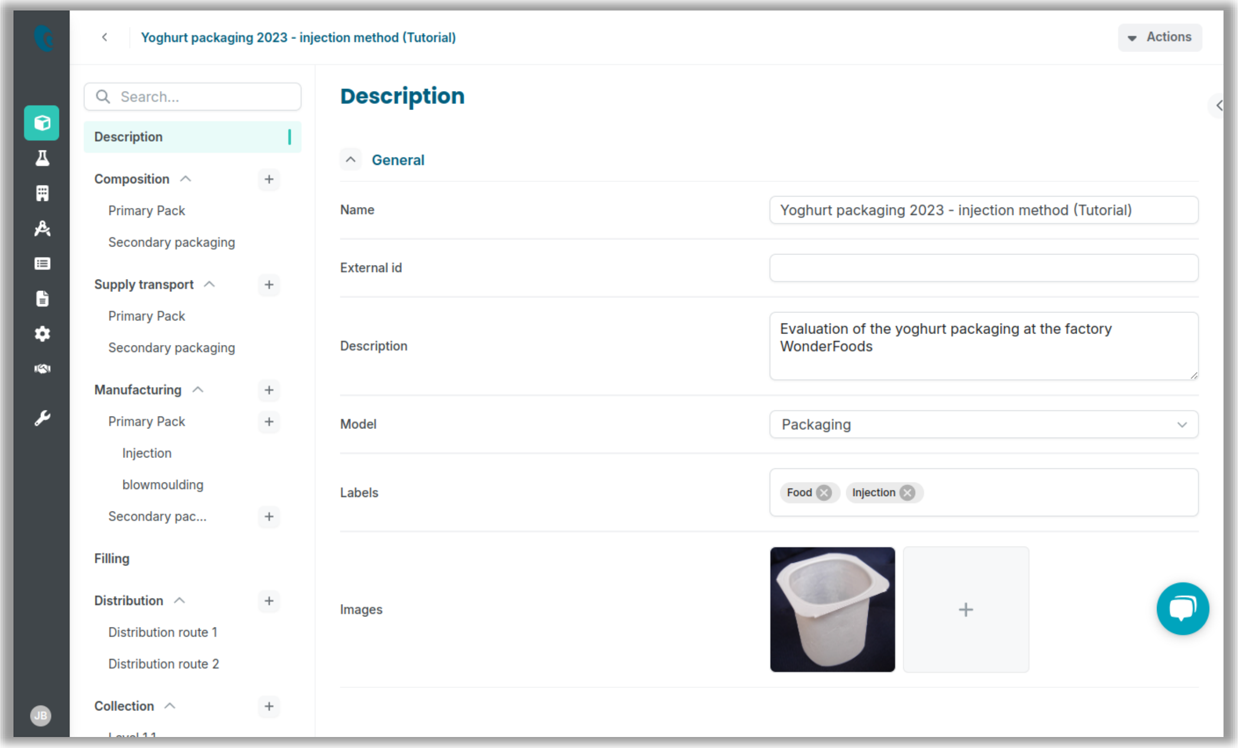
The tool consists of a web application that allows the user to connect from anywhere where Internet access is available by using a web browser. The user can define products from scratch or by using predefined templates which reduce the amount of work needed to perform the LCIA.

Note that for the sake of extension the section presented here is an extract of the main features of the tool. Much more detailed information can be found on the product's manual website at https://help.pilario.com/

4.3.1 Input parameters in the interface

When developing a packaging, the user must define specific parameters related to both the packaging's description and its various stages throughout the life cycle (metadata) and parameters that will have an impact on the LCIA like materials, supply routes, recycling, etc.

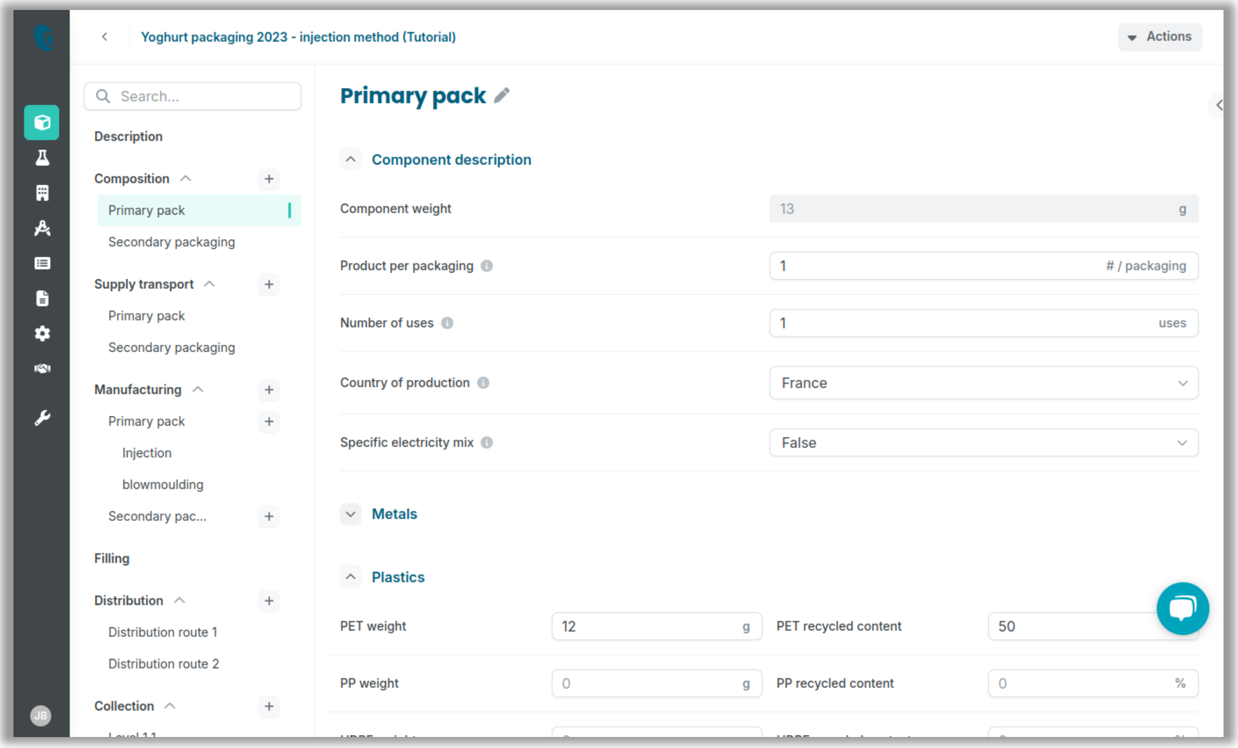
For the metadata parameters, the user can provide, several fields that can help identifying the packaging for further analysis as well as the composition parts and distinct stages of the product's life cycle. See in the example image below different input parameters like name, description, labels and even an image (in the right section of the page), and the composition parts and stages like transportation, manufacturing, etc (in the left column).



Name: Yoghurt packaging 2023 - injection method (Tutorial)
External id:
Description: Evaluation of the yoghurt packaging at the factory WonderFoods
Model: Packaging
Labels: Food ⊗ Injection ⊗
Images

For the calculation of the LCIA, the user needs to provide parameters about the composition materials and the different life stages processes, transportation, recycling rates, etc. These input parameters can be of distinct types like numbers, true or false, drop-down selection lists, etc. Some of these input values might be prepopulated with default values directly or based in defined rules that the user can overwrite if needed.

The image below presents the input page where the user might define the composition of its packaging, in this case, the packaging is composed of two parts: the *Primary pack* and the *Secondary packaging*. The user has also selected *France* as the *Country of Production* which will affect the values used in the calculation.



Primary pack

Component description

Component weight: 13 g

Product per packaging: 1 # / packaging

Number of uses: 1 uses

Country of production: France

Specific electricity mix: False

Metals

Plastics

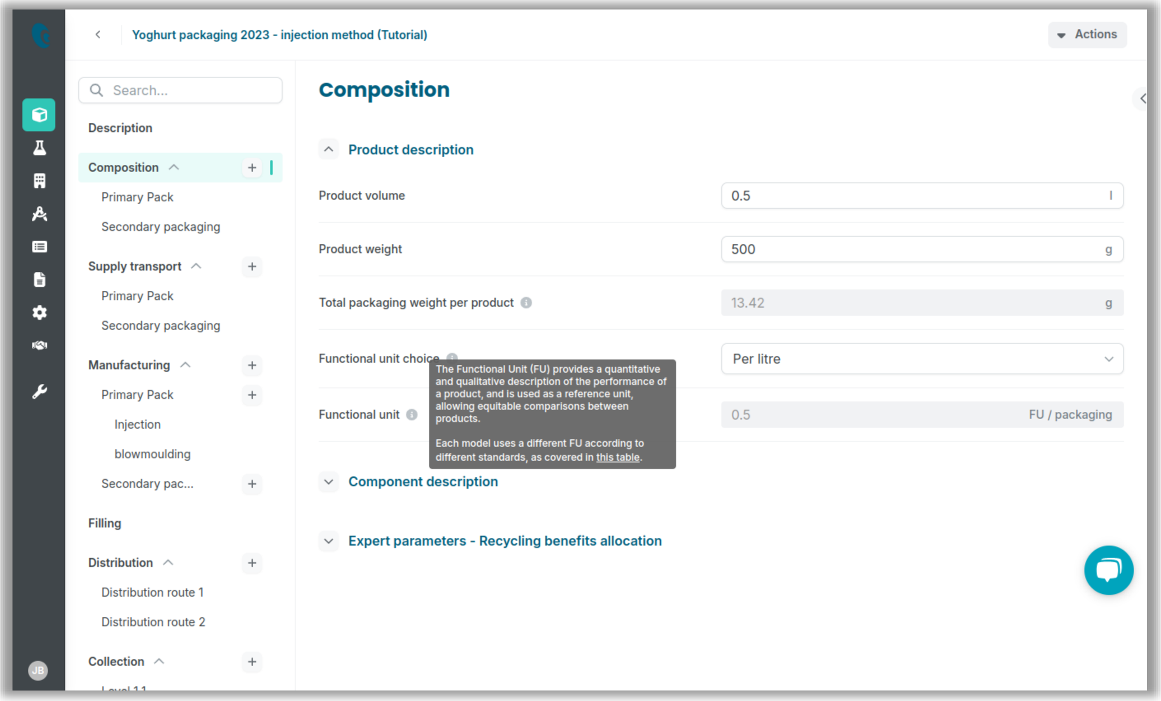
PET weight: 12 g

PET recycled content: 50

PP weight: 0 g

PP recycled content: 0 %

To improve the quality of the data the application presents helper tooltips to guide the user as well as perform certain validation checks and operations. These rules are enforced by the system (i.e. percentages values must remain between 0 and 100) or are based in custom defined rules (i.e. the total packaging weight as the sum of its components). See in the image below an example of a helper text for the input parameter *Functional Unit Choice* and a calculated value *Total packaging weight per primary packaging unit.*



Composition

Product description

Product volume: 0.5 l

Product weight: 500 g

Total packaging weight per product: 13.42 g

Functional unit choice: Per litre

Functional unit: 0.5 FU / packaging

The Functional Unit (FU) provides a quantitative and qualitative description of the performance of a product, and is used as a reference unit, allowing equitable comparisons between products.

Each model uses a different FU according to different standards, as covered in this table.

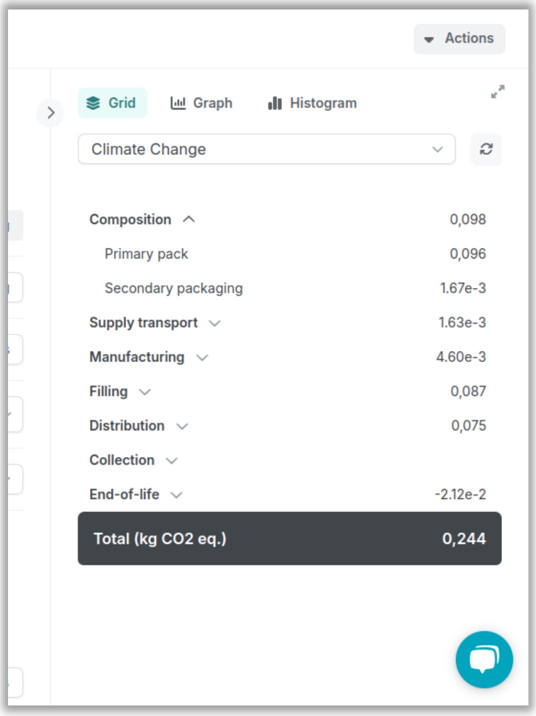
Component description

Expert parameters - Recycling benefits allocation

4.3.2 Getting the results

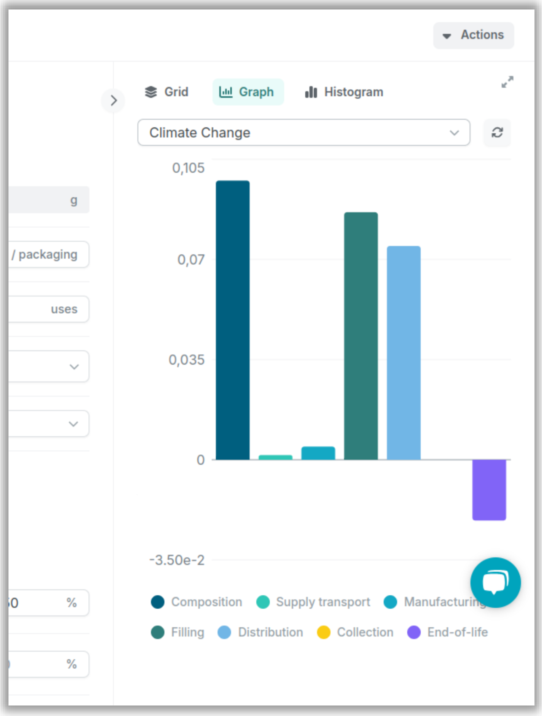
The user can access the results of the LCA within the same application screen, just by expanding the calculation tab on the right side. These results are presented in the different LCIA categorised as a table or a graph depending on the user selection. In the *table* mode, the user can expand per level defined in the composition or different life cycle stage. See in the example image below the results presented in both modes for the category *Climate Change*, and how the user has expanded the table to see the impact of each part composing the packaging.

In the graph section, the results are presented showing one bar chart per life cycle stage. In the histogram section, the life cycle stages are stacked to each other and a dark line shows the total results. For comparison purposes, it is recommended to use the graph section to focus on comparing specific life cycle stage and to use the histogram section to compare the total results of the LCA.



Climate Change

Composition	0,098
Primary pack	0,096
Secondary packaging	1.67e-3
Supply transport	1.63e-3
Manufacturing	4.60e-3
Filling	0,087
Distribution	0,075
Collection	
End-of-life	-2.12e-2
Total (kg CO2 eq.)	0,244

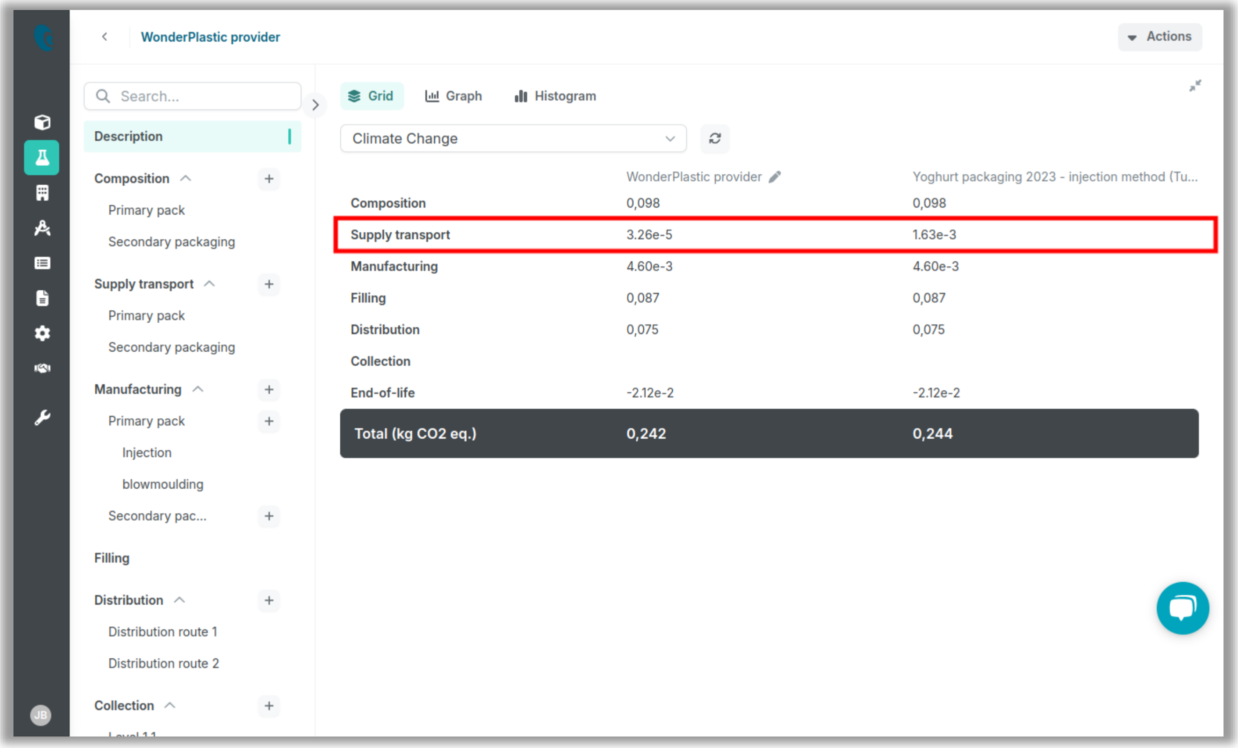


4.3.3 Performing comparative analysis

After having defined several packaging, these can be compared among them to see their different LCIA. Also, the user can use a packaging as the foundation to create others and see how changing different input parameters would affect the LCIA. In Pilario, this is called *scenarios.*

When comparing packaging or scenarios, the user must be sure that the same functional unit was selected for both compared elements.

As an example, see how the user has created a scenario based on the packaging presented above *Yoghurt packaging 2023.* The user has found a new PET provider located much closer, so they change the specific input parameter in *Supply Transport > Primary pack > Truck distance* (reducing it from 1000 to 10). In the results tab, the user can see how the change made has an impact on the *Supply transport* stage.



	WonderPlastic provider	Yoghurt packaging 2023 - injection method (Tu...
Composition	0,098	0,098
Supply transport	3.26e-5	1.63e-3
Manufacturing	4.60e-3	4.60e-3
Filling	0,087	0,087
Distribution	0,075	0,075
Collection		
End-of-life	-2.12e-2	-2.12e-2
Total (kg CO2 eq.)	0,242	0,244

5 Life cycle inventory: key data and assumptions

5.1 Type of data

The different types of data used in the tool can be classified according to several criteria. Firstly, two types of data can be distinguished in LCA studies:

- Activity data expressing the relationships between processes (e.g.: raw material has to be transported over a distance of 100 km to the manufacturing site; or 63% of household waste is treated by incineration in France)
- LCI data corresponding to the resource use and emissions associated with each process and expressed as elementary flows.

Furthermore, primary and secondary data can be defined (according to PEFCR reference document, 2019)[4]:

- Primary data refers to data from specific processes within the supply-chain of the company carrying out the study. Such data may take the form of activity data, or foreground elementary flows (life cycle inventory). Primary data is site-specific, company-specific (if multiple sites for the same product) or supply-chain-specific.
- Secondary data refers to data not from specific process within the supply-chain of the company carrying out the study. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third-party life-cycle-inventory database or other sources.

Finally, as a specificity of tools, the ability to edit and modify data through the tool interface is to be underlined.

Table 11 presents the main data used in the tool for carrying out the life cycle assessment, according to the described classification. In the column “Editable”, “x” means that data is editable, but its value is by default at zero while, for “x + default”, there is a non-zero default value proposed in the tool that can still be modified by the tool user.

Table 11: Types of data

Type of data	Primary / secondary	Editable
Activity data - Composition		
Packaging weights, number of uses, recycled content (when applicable), country of production	Primary	x
Activity data – Transport supply / Distribution / collection / transport step in manufacturing		
Distances by transport mode	Primary	x
Empty return rates and payload	Primary	x + default (for part of parameters)

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[4] Zampori, L. and Pant, R., Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, 2019

Type of data	Primary / secondary	Editable
Manufacturing and filling		
Country of production	Primary	x
Percentage of material loss	Primary	x
Material consumption	Primary	x
Emissions (VOC)	Primary	x
Energy consumption	Primary	x
End-of-life		
Country	Primary	x
Recycling rate and incineration rate	Secondary	x + default
Other parameters of the CFF (except A factor)[5]	Secondary	
LCI – All phases		
	Secondary	(Choice among LCIs for aluminium and steel)

For LCIs from ecoinvent, the system model "Allocation, cut-off by classification" is used.

5.2 Principles of data quality assessment

The criteria considered for data quality assessment (DQA) according to ISO 14044 are:

- Geographical representativeness: Degree to which the dataset reflects the true population of interest regarding geography (given location / site, region, country, market, continent, etc.)
- Technological representativeness: Degree to which the dataset reflects the true population of interest regarding technology
- Time-related representativeness: Degree to which the dataset reflects the specific conditions of the system being considered regarding the time / age of the data
- Completeness: ensuring that all relevant information and data needed for the interpretation are available and complete. According to PEF guidelines v6.3, the completeness check aims at assessing the inclusion of the most important elementary flows contributing to each impact category

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[5] The allocation factor A of the CFF corresponds to a methodological choice. It can be edited in the interface.

- Methodological consistency: degree to which the study methodology is applied uniformly to the various components of the analysis and methods and methodological choices (e.g. allocation, substitution, etc.) are in line with the goal and scope of the study, especially its intended applications as support to decisions.

5.3 Data for transversal modelling

5.3.1 Electricity

Three ways for modelling electricity are used in the models:

- Electricity modelling as embedded in LCIs (from ecoinvent and other sources)
- Country- or continent- specific grid mix
- Specific electricity mix defined by the tool user

As summarized in Table 6, a specific country/continent can be selected for several steps of the life cycle. The corresponding grid electricity is modelled as described in Table 12.

Table 12: LCIs used for modelling country/continent-specific grid electricity

Type of zone	Type of dataset	Example of dataset name
Country	market for electricity, low voltage	market for electricity, low voltage - BE
Continent	market group for electricity, low voltage	market group for electricity, low voltage - RLA

For countries for which there is no ecoinvent dataset (cf. countries in italics in Annex 1), the following modelling is adopted:

- For European countries (Andorra, Liechtenstein, Monaco, San Marino, Vatican): market group for electricity, low voltage – RER
- For non-European countries, the mix of production modes described in Table 13 is adopted (source: supply mix per fuel for the geography GLO and the reference product “electricity, medium voltage”, in ecoinvent 3.7.1). The share of production modes is combined with the datasets presented in Table 14.

Table 13: Shares of production modes for modelling grid electricity in countries for which no ecoinvent dataset is available

Production modes	Shares
Nuclear	11.1%
Coal	39.0%
Natural gas	24.3%
Oil	3.0%
Hydro	16.8%
Wind	4.4%
Solar	0.0%

Production modes	Shares
Biomass	1.1%
Geothermal	0.3%

When putting the selection of a specific electricity mix at 'true' in the tool (Table 15 indicates where it is possible), the user can define the shares of production modes in its specific mix, including the share of grid electricity and the complementary shares of the production modes listed in Table 14. This user-specific mix replaces the country- or continent- specific grid mix. Requirements for this supplier-specific mix are explicated in section 3.2.1.

Table 14: List of LCIs used for modelling a specific electricity mix

Production mode	Share of LCIs (not editable)	Reference product - dataset name	Year data
Nuclear	19%	electricity production, nuclear, boiling water reactor - RoW	1990
	73%	electricity production, nuclear, pressure water reactor - RoW	1990
	8%	electricity production, nuclear, pressure water reactor, heavy water moderated - RoW	2010
Coal	77%	electricity production, hard coal - RoW	2014
	3%	heat and power co-generation, hard coal - RoW	1980
	18%	electricity, high voltage - electricity production, lignite - RoW	1980
	2%	electricity, high voltage - heat and power co-generation, lignite - RoW	1980
Gas	34%	electricity, high voltage - electricity production, natural gas, combined cycle power plant - RoW	2000
	3%	electricity, high voltage - heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical - RoW	2000
	44%	electricity, high voltage - electricity production, natural gas, conventional power plant - RoW	1990
	18%	electricity, high voltage - heat and power co-generation, natural gas, conventional power plant, 100MW electrical - RoW	1990
	1%	electricity, high voltage - heat and power co-generation, biogas, gas engine - RoW	2007
Oil (Fuel)	97%	electricity, high voltage - electricity production, oil - RoW	1980
	3%	electricity, high voltage - heat and power co-generation, oil - RoW	1980

Production mode	Share of LCIs (not editable)	Reference product - dataset name	Year data
Hydro	2%	electricity, high voltage - electricity production, hydro, pumped storage - RoW	1945
	13%	electricity, high voltage - electricity production, hydro, reservoir, alpine region - RoW	1945
	23%	electricity, high voltage - electricity production, hydro, reservoir, non-alpine region - RoW	1945
	11%	electricity, high voltage - electricity production, hydro, reservoir, tropical region - RoW	1970
	51%	electricity, high voltage - electricity production, hydro, run-of-river - RoW	1945
Wind	2%	electricity, high voltage - electricity production, wind, 1-3MW turbine, offshore - RoW	2000
	72%	electricity, high voltage - electricity production, wind, 1-3MW turbine, onshore - RoW	2005
	14%	electricity, high voltage - electricity production, wind, <1MW turbine, onshore - RoW	2000
	12%	electricity, high voltage - electricity production, wind, >3MW turbine, onshore - RoW	2012
Solar	100%	electricity, high voltage - electricity production, solar tower power plant, 20 MW - RoW	2010
Biomass	6%	electricity, high voltage - heat and power co-generation, wood chips, 6667 kW - RoW	2010
	94%	electricity, high voltage - heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 - RoW	2010
Geothermal	100%	electricity, high voltage - electricity production, deep geothermal - RoW	2015

Table 15: Type of electricity modelling available in the tool in function of the step

Step	Country/continent-specific mix	User-specific mix
Composition – for plastic recycling dataset for which electricity has been extracted	x	x
Manufacturing – Energy consumption Electricity consumption	x	x
Filling – Energy consumption Electricity consumption	x	x

Step	Country/continent-specific mix	User-specific mix
End-of-life - for plastic recycling datasets for which electricity has been extracted - For energy recovery at incineration	 x x	

5.3.2 Transport

Modelled transport modes are:

- diesel truck
- train
- boat
- barge
- plane

The same modelling is used for all transport steps:

- supply transport (supply of raw materials as well as intermediate supply transport between manufacturing steps)
- product distribution (several routes can be modelled in parallel)
- refillable/reusable packaging collection (only by truck)
- transport to recycler and to disposal facilities (only by truck)

5.3.2.1 LCI data

The LCIs associated with the modelling of transport are provided in Table 16.

Table 16: List of LCIs used for modelling transport

Transport mode	Step	LCI Dataset name	Source	Year publi	Year data
Truck	Operation: fuel consumption and emissions	Transport - Heavy Duty Trucks Articulated 34 - 40 t – Diesel (urban, rural, highway) Corresponding to a maximum payload of 24 tonnes	Copert 5 tool (v5.2.2)	2018	2007-2016
	Diesel supply	market for diesel, low-sulfur - Europe without Switzerland	Ecoinvent 3.10	2023	2000

Transport mode	Step	LCI Dataset name	Source	Year publi	Year data
	Infrastructure	market for used lorry, 40 metric ton, GLO market for road maintenance, RER market for road – GLO market for maintenance, lorry 40 metric ton, GLO market for lorry, 40 metric ton, RER market for decommissioned road, GLO	Ecoinvent 3.10	2023	2011 1990 2011 2011 2016 2011
Train	Operation, energy supply, infrastructure	market group for transport, freight train, RER	Ecoinvent 3.10	2023	2000-2011
Boat	Operation, HFO supply, infrastructure	transport, freight, sea, container ship, GLO	Ecoinvent 3.10	2023	1990-2011
Barge	Operation, diesel supply, infrastructure	market for transport, freight, inland waterways, barge, RER	Ecoinvent 3.10	2023	1990-2011
Plane	Operation, kerosene supply, aircraft infrastructure	In function of the distances: ■ < 800 km: transport, freight, aircraft, dedicated freight, very short haul, GLO ■ 800-1500 km: market for transport, freight, aircraft, short haul, GLO ■ 1500-4000 km: transport, freight, aircraft, medium haul - market for transport, freight, aircraft, medium haul, GLO ■ > 4000 km: transport, freight, aircraft, long haul - market for transport, freight, aircraft, long haul, GLO	Ecoinvent 3.10	2023	2016

Fuel consumptions and airborne emissions from trucks are obtained from the COPERT 5 tool and methodology (version 5.2.2).

COPERT is the EU standard vehicle emissions calculator. It uses vehicle population, mileage, speed and other data such as ambient temperature and calculates emissions and energy consumption. COPERT's methodology is published and peer-reviewed by experts of the UNECE LRTAP Convention. COPERT 5 is based on the "EMEP/EEA air pollutant emission inventory guidebook 2016 – Update Jul. 2018" (published by LRTAP and EEA).

COPERT estimates emissions of all major air pollutants (CO, NOx, VOC, PM, NH3, SO2, heavy metals) produced by different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles) as well as greenhouse gas emissions (CO2, N2O, CH4). Emissions estimated are distinguished in three sources: Emissions produced during thermally stabilized engine operation (hot emissions), emissions occurring during engine start from ambient temperature (cold-start and warming-up effects) and NMVOC emissions due to fuel evaporation. Non-exhaust PM emissions from tyre and break wear are also included. The total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by the software.

For the packaging model, COPERT data is extracted as emissions and fuel consumption calculated per kilometre driven by a fully loaded vehicle and for a slope equal to zero. Results are distinguished in function of:

- size of the vehicle (gross weight)
- euro standard
- driving / traffic conditions (source: COPERT tool 5):
  - rural (average speed for heavy duty vehicle of 82 km/h)
  - urban (average speed for heavy duty vehicle of 25 km/h)
  - highway (average speed for heavy duty vehicle of 91 km/h)

As presented in Table 16, only trucks with a maximum gross weight in the range 34-40t are included in the model, which corresponds to a maximum payload of 24t.

5.3.2.2 Activity data

The secondary activity data associated with the modelling of transport are provided in Table 17. These are either editable in the interface (as default values) or hidden values in the model (non-editable).

Table 17: List of secondary activity data used for modelling transport

Theme	Description of activity data	Source	Year data	Editable
Truck				
Euro standards	Mix of euro standards in truck fleet: Share euro 3 = 11% Share euro 4 = 19% Share euro 5 = 28% Share euro 6 =43%	Eurostat database (European Commission, 2017) Estimate based on vehicle age data for Europe	2017	No

Theme	Description of activity data	Source	Year data	Editable
Area type	Mix of road area: Urban = 5% Rural = 15% Highway = 80%	RDC assumption		No
Infrastructure	Based on same assumptions as in the ecoinvent dataset (e.g.) “transport, freight, lorry >32 metric ton, EURO5”	ecoinvent 3.10	1990-2009	No
Empty return rate	Default value = 29%	Eurostat	2008	Yes
Boat				
Payload	Default value of load per TEU (Twenty-feet equivalent unit) = 10 tonnes	EcoTransit[6], net weight of average goods per TEU	2014	Yes

There are no default values for other empty return rate or payload values editable in the interface (the values are at 0; or 24 tonnes for the truck payload).

5.3.2.3 Impact modelling

A. Truck

The impacts related to truck transport depend on the following parameters:

- Max payload (fixed at 24t)
- Effective payload (editable)
- Empty return rate (editable)
- Distance (editable)

The following formula relates the COPERT data to the impacts associated with the transport, in function of the mentioned parameters:

Consumption or emissions per functional unit =

Number of trucks * Distance * (70%+30%*payload/max_payload + Empty_return_rate * 70%) * x

Considering that:

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[6] EcoTransIT World, Environmental Methodology and Data, Update 2023, p33. In accordance with the Clean Cargo Working Group (CCWG).

- The number of trucks (or fraction of truck) is obtained as the weight to be transported divided by the effective payload (e.g. if 1 kg has to be transported per distributed packaging unit in a truck loaded at 20 t, the number of truck is 1E-03 / 20 = 5E-05)
- impacts for empty trucks amount 70% of those of trucks at full loading (the factor 70% is a coarse average value derived from the Copert 4 methodology by considering a set of trucks of various gross vehicle weights for both speeds used respectively for rural and urban transportation).
- the 30% remaining varies linearly with the ratio of load to maximum payload (the hypothesis of linearity comes from Copert 3 methodology).
- x is either the fuel consumption or the emissions of the fully loaded truck per km, obtained from COPERT.

B. Train

The ecoinvent dataset corresponds to a reference product of one metric ton*km. It already includes average empty return and load factor as well as representative share of diesel and electric train. However, in order to take specific empty return rate (ERR) into account, the impacts per tonne*km are multiplied by the factor (1 + ERR). It is a simplified modelling, assuming that impacts of empty return are similar to the average impact per outward distance.

C. Boat

The ecoinvent dataset corresponds to a reference product of one metric ton*km. In line with the EcoTransIT tool,[7] it is considered in the model that impacts of container vessels depend on the number of containers (or TEU, Twenty-feet equivalent unit) rather than on the tonnes of freight transported. Therefore, the modelling aims at calculating the number of TEU required per amount of good to be transported per FU and the impacts per TEU. This is obtained through the following formula:

Inventory per functional unit =

Number of TEU * Distance * (1+ERR) * consumption_per_TEU/Consumption per tonne*km * x

Considering that:

- The number of TEUs (or fraction of TEU) is obtained as the weight to be transported divided by the effective load per TEU (editable in the interface, default value = 10 tonnes/TEU)
- ERR is the empty return rate, editable in the interface (it can depend on the sea lane)
- The fuel consumption per TEU*km is taken as the average of the lower and upper bounds of the range in the ADEME 2009 study (used in Base Empreinte, ADEME "Etude de l'efficacité énergétique et environnementale du transport maritime" - Avril 2009)
- The fuel consumption per tonne*km corresponds to the value in ecoinvent UPR (0.00252 kg HFO per metric ton*km)
- x represents the elementary flows of the ecoinvent datasets "transport, freight, sea, container ship, GLO" (Remark: for the impacts of infrastructure contributing to this dataset, the ecoinvent modelling per tonne*km is kept)

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[7] EcoTransIT World, Environmental Methodology and Data, Update 2023, p28

D. Barge

The ecoinvent inventory is based on the consumption of 9.39 g of fuel per metric ton*km.

Our modelling combines, in a fixed ratio, large barges (> 1500 t) and small barges (< 1500). The consumptions of fuel for both types (at average loading) are derived from data provided by a study of CE Delft in 2011.[8] Each type of barge is modelled by the mentioned ecoinvent process proportionally to the fuel consumption.

The parameters available in the tool are the one-way distance and the empty return rate.

The modelling is summarized in the following equation:

Number of ecoinvent reference product modelled per functional unit=

Weight_to_be_transported * Distance * (0.45*6.8+ (1-0.45)*10.4)/9.39 (1+ Empty_return_rate * 0.6)

Considering that

- the ecoinvent reference product is one metric ton*km of “transport, freight, inland waterways, barge”
- 0.45, the share of large barges (derived from ecoinvent v2 report 14 “transport services”)
- 6.8 and 10.4, fuel consumption in g/tkm respectively for large and small barges (according to CE Delft 2011)
- 0.6, the fuel consumption ratio of an empty barge (source: EcoTransIT 2010)[9]

E. Plane

The ecoinvent datasets for plane transport correspond each to a reference product of one metric ton*km. It already includes average empty return and load factor However, in order to take specific empty return rate (ERR), if any, into account, the impacts per tonne*km are multiplied by the factor (1 + ERR). It is a simplified modelling, assuming that impacts of empty return are similar to the average impact per outward distance.

5.4 Data per phase

5.4.1 Composition (production of material)

The phase “composition” includes the cradle-to-gate impacts of material production (from virgin or recycled material sourcing). As mentioned in section 3.2.4, infrastructure is included for material production (a separate inventory for infrastructure is used when it is not included in the material production dataset, as for example for aluminium).

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[8] CE Delft. “Comparison of various transport modes on a EU scale with the STREAM database”, July 2011

[9] EcoTransIT World, “Methodology and Data 2nd Draft Report” May 21th 2010, p65

In some exceptions, the phase “composition” also includes a manufacturing step:

- For aluminium, the tool user can either select the “ingot” or “ingot and rolling” as scope in the interface. In this second case, the ingot production is followed by the sheet production, a semi-finished product that is used for the manufacturing of some aluminium packaging, like cans, although not for all packaging types. Furthermore, associations of aluminium producers also provide LCI data for this step. Therefore, when it is part of the life cycle, it is useful to include it as a full LCI in the production step instead of modelling it in the manufacturing module. The production of sheet is automatically included for aluminium foil and complex alu foil – PE.
- Expanded polystyrene (PSE)
- OPP film
- Foam
- Corrugated board box

The impacts of producing the amount of material lost during manufacturing and filling steps are included in the phase “composition”.

5.4.1.1 LCI data for primary and secondary material production

Table 18 lists the materials that can be selected in the interface and the associated LCI datasets with sources. The geographical scope of the datasets is mentioned as well as the year of publication and the “year data”, i.e. the earliest year for which data providers have collected the primary data contributing to the foreground of the described dataset.

In complement to Table 18, information on technology and system boundaries can be found at https://ecoquery.ecoinvent.org/3.10/cutoff/search for ecoinvent datasets (free access to the documentation) and in Annex 2 for non-ecoinvent LCIs.

The sign # added next to material names in Table 18 indicates that electricity has been extracted from the LCI and replaced by the country/continent-specific grid electricity mix, or by a user-specific mix. It is the case for plastic recycling, for which the share of impacts of electricity within the whole process is significant and electricity can be extracted from the LCIs (through ecoinvent UPRs).

For aluminium and steel, the interface proposes several LCI sources. The user should select the LCI published by producer associations in function of where the material is consumed:

- Aluminium: North American Association for use in North America and EAA for use in Europe (and as proxy for other continents)
- Steel: Worldsteel for use anywhere (APEAL for production in Europe, but older data)

The ecoinvent datasets can also be selected, for example in case the user aims at keeping the same source of data for all materials, when available.

For aluminium, when the user selects the “ingot and rolling” option, the same data source is used for both ingot production and rolling into sheet. If the option “ingot” is selected, only the LCI for ingot production reported in the table is included and not the LCI for sheet.

Table 18: List of materials and sources of associated LCIs

Material	LCI Dataset name	Source	Year publi	Year data
Metals – Virgin (Ev)				
Aluminium “eu_alu_assoc_eaa”	EU-27: Aluminium ingot mix EAA update 2021 (consumption mix) + EU-27: Aluminium sheet EAA update 2021 + aluminium casting facility construction RER	EAA (European Aluminium Association) Ecoinvent 3.10	2024 2023	2021 2002
Aluminium “northamerican_alu_assoc_aa”	Primary aluminum ingot + Aluminum can sheet rolling + aluminium casting facility construction RER	Aluminium Association AA (North-America) Ecoinvent 3.10	2021 2023	2016 2002
Aluminium “ecoinvent”	market for aluminium, primary, ingot - IAI Area, EU27 & EFTA + sheet rolling, aluminium - RER	Ecoinvent 3.10	2023	2010 2000
Alu foil	EU-27: Aluminium ingot mix EAA update 2021 (consumption mix) + EU-27: Aluminium sheet [p-agg] EAA update 2021 + aluminium casting facility construction RER	EAA (European Aluminium Association) Ecoinvent 3.10	2024 2023	2021 2002
Complex Alu foil - PE	EU-27: Aluminium ingot mix EAA update 2021 (consumption mix) + EU-27: Aluminium sheet [p-agg] EAA update 2021 + aluminium casting facility construction RER Polyethylene, LDPE, granulate, at plant	EAA (European Aluminium Association) Ecoinvent 3.10 PlasticsEurope	2024 2023 2019	2021 2002 2015
Steel “Worldsteel”	Steel tinplated steel GLO	Worldsteel	2018	2012-2015

Material	**LCI Dataset name**	**Source**	**Year publi**	**Year data**
	Steel scrap (external supply) GLO (*0.05/0.98), explanation of the formula in Annex 3			
Steel “Apeal”	Steel tinplate without EoL recycling - 1 kg (typical thickness between 0.13 - 0.49 mm) at plant	APEAL	2018	2012
Steel “ecoinvent”	steel, low-alloyed, GLO	Ecoinvent 3.10	2023	2011
Stainless steel	steel production, electric, chromium steel 18/8	Ecoinvent 3.10	2023	2013
Tin plated steel	Steel tinplated steel GLO Steel scrap (external supply) GLO (*0.05/0.98), explanation of the formula in Annex 3	Worldsteel	2018	2012-2015
Tin	tin production	Ecoinvent 3.10	2023	2010
Metals – Recycled (Er)				
Aluminium “eu_alu_assoc_eaa”	Aluminium recycling update 2021 + EU-27: Aluminium sheet [p-agg] EAA update 2021 + aluminium casting facility construction	EAA (European Aluminium Association) Ecoinvent 3.10	2024 2013 2023	2017-2018 2010 2002
Aluminium “northamerican_alu_assoc_aa”	Recycled Aluminum ingot for rolling + Aluminum can sheet rolling + aluminium casting facility construction	Aluminium Association AA (North-America) Ecoinvent 3.10	2021 2023	2016 2002
Aluminium “ecoinvent”	treatment of aluminium scrap, new, at remelter - RER + sheet rolling, aluminium - RER	Ecoinvent 3.10	2023	2005 2002
Steel	Steel tinplated steel GLO	Worldsteel	2018	2012-2015

Material	LCI Dataset name	Source	Year publi	Year data
“Worldsteel”	Steel scrap (external supply) GLO (*-0.95/0.98), explanation of the formula in Annex 3			
Steel “Apeal”	Recycling Steel	APEAL 2012	2018	2012
Steel “ecoinvent”	steel production, electric, low-alloyed, Europe without Switzerland and Austria	Ecoinvent 3.10	2023	2013
Plastics – Virgin (Ev)				
PET	polyethylene terephthalate production, granulate, bottle grade, RER	Ecoinvent 3.10	2023	2015
PP	polypropylene production, granulate, RER	Ecoinvent 3.10	2023	2011
HDPE	polyethylene, high density, granulate, RER	Ecoinvent 3.10	2023	2011
LDPE	polyethylene production, low density, granulate, RER	Ecoinvent 3.10	2023	2011
PS	polystyrene production, general purpose, RER	Ecoinvent 3.10	2023	2001
PC	polycarbonate production, RER	Ecoinvent 3.10	2023	2016
PVC	polyvinylchloride production, suspension polymerisation, RER	Ecoinvent 3.10	2023	2013
PSE	polystyrene production, expandable, RER	Ecoinvent 3.10	2023	2001
OPP	Oriented polypropylene film +chemical factory construction, organics	PlasticsEurope 2005 Ecoinvent 3.10	2005 2023	<2005 2000
OPA	Nylon 6-6 production, RER	Ecoinvent 3.10	2023	1996

Material	LCI Dataset name	Source	Year publi	Year data
PVDC	polyvinylidenchloride production, granulate, RER	Ecoinvent 3.10	2023	2018
PLA	polylactide production, granulate, GLO (based on Nature-Works publication)	Ecoinvent 3.10	2023	2006
POM	Polyoxymethylene (POM) +chemical factory construction, organics	PlasticsEurope (as imported in Simapro) Ecoinvent 3.10	2015 2023	2010 2000
Foam	market for polyurethane, rigid foam	Ecoinvent 3.10	2023	2018
Nylon	Nylon 6-6 production, RER	Ecoinvent 3.10	2023	1996
EVOH	ethylene vinyl acetate copolymer production, RER (proxy)	Ecoinvent 3.10	2023	2000
PP cast	polypropylene production, granulate, RER	Ecoinvent 3.10	2023	2011
HDPE teb	polyethylene, high density, granulate, RER	Ecoinvent 3.10	2023	2011
PE	(50%) polyethylene, high density, granulate, RER (50%) polyethylene production, low density, granulate, RER	Ecoinvent 3.10 Ecoinvent 3.10	2023 2023	2011 2011
Plastics – recycled (Er)				
PET #	polyethylene terephthalate production, granulate, bottle grade, recycled, RoW	Ecoinvent 3.10	2023	2014
PP #	(proxy) polyethylene production, high density, granulate, recycled, Europe without Switzerland	Ecoinvent 3.10	2023	2010

Material	LCI Dataset name	Source	Year publi	Year data
HDPE #	polyethylene production, high density, granulate, recycled, Europe without Switzerland	Ecoinvent 3.10	2023	2010
LDPE #	(proxy) polyethylene production, high density, granulate, recycled, Europe without Switzerland	Ecoinvent 3.10	2023	2010
PS #	(proxy) polyethylene production, high density, granulate, recycled, Europe without Switzerland	Ecoinvent 3.10	2023	2010
Glass				
Ev (100% virgin)	Container glass, virgin	FEVE	2017	2012
Er (100% made of cullet)	Container glass, ER, Recycled Content 100%	FEVE	2017	2012
Fiber materials – Virgin (Ev)				
Cardboard	containerboard production, linerboard, kraftliner, RoW (multiplied by [1/(1-0.2718/1.0632)]) containerboard production, linerboard, testliner, RoW (multiplied by [-0.02718/1.0632])	Ecoinvent 3.10	2023	2020
Paper	paper, woodcontaining, lightweight coated, RER	Ecoinvent 3.10	2023	2000
Wood	EUR-flat pallet production, RER	Ecoinvent 3.10	2023	2000
Cork	cork slab production, RER	Ecoinvent 3.10	2023	2001
Corrugated board	corrugated board box production, RER	Ecoinvent 3.10	2023	2018
Pulp	thermo-mechanical pulp production, RER	Ecoinvent 3.10	2023	1993

Material	**LCI Dataset name**	**Source**	**Year publi**	**Year data**
Kraftpaper	kraft paper production, RER	Ecoinvent 3.10	2023	2018
Boxboard	kraft paper production, RER	Ecoinvent 3.10	2023	2018
Fiber materials – recycled (Er)				
Cardboard	containerboard production, linerboard, testliner, RER	Ecoinvent 3.10	2023	2020
Paper #	graphic paper production, 100% recycled, RER	Ecoinvent 3.10	2023	2008
Additives, adhesives and colorants				
Adhesive mix	Mix of (33%) market for lubricating oil – RER (34%) acrylonitrile-butadiene-styrene copolymer production (33%) dicyclopentadiene based unsaturated polyester resin production	Ecoinvent 3.10	2023	2018 1996 2013
Colorant mix	titanium dioxide production, chloride process – RER (proxy)	Ecoinvent 3.10	2023	2005
Additive mix	(50%) market for chemical, organic - GLO (50%) market for chemical, inorganic - GLO	Ecoinvent 3.10	2023	2011
Coating mix	Confidential recipe			
Compound mix	(Confidential mix of) styrene production, RER butadiene production, RER paraffin production, RER lime production, milled, packed, CH	Ecoinvent 3.10	2023	2015 1997 1995 2000

Material	LCI Dataset name	Source	Year publi	Year data
ABS	acrylonitrile-butadiene-styrene copolymer production, RER	Ecoinvent 3.10	2023	1996
Activated carbon	activated carbon production, granular from hard coal, RER	Ecoinvent 3.10	2023	2005
Anti-fog additive	polyurethane adhesive production, GLO	Ecoinvent 3.10	2023	2015
Black carbon	carbon black production, GLO	Ecoinvent 3.10	2023	2000
CaCO3	market for calcium carbonate, precipitated, RER	Ecoinvent 3.10	2023	2018
Compatibilizing additives	maleic anhydride production by direct oxidation of n-butane, RER	Ecoinvent 3.10	2023	1997
EPE	polyethylene production, low density, granulate, RER	Ecoinvent 3.10	2023	2011
Epoxy resin	epoxy resin production, liquid, RER	Ecoinvent 3.10	2023	2015
Ethyl acetate	market for ethyl acetate, GLO	Ecoinvent 3.10	2023	2011
Glue	polyurethane adhesive production, GLO	Ecoinvent 3.10	2023	2015
Hotmelt glue	polyurethane adhesive production, GLO	Ecoinvent 3.10	2023	2015
Ink	printing ink production, offset, product in 47.5% solution state, RER	Ecoinvent 3.10	2023	2000
OPET	polyethylene terephthalate production, granulate, bottle grade, RER	Ecoinvent 3.10	2023	2015
OPS	polystyrene production, general purpose, RER	Ecoinvent 3.10	2023	2001

Material	LCI Dataset name	Source	Year publi	Year data
Optical brighteners	(20%) fluorescent whitening agent production, DAS1, triazinylaminostilben type, RER (80%) fluorescent whitening agent production, distyrylbiphenyl type, RER	Ecoinvent 3.10	2023	1997 1999
Plasticizer #	soybean meal and crude oil production, RER	Ecoinvent 3.10	2023	1998
PP adhesive Paper	polypropylene production, granulate, RER polyurethane adhesive production, GLO	Ecoinvent 3.10	2023	2011 2015
PVC adhesive Paper	polyvinylchloride production, suspension polymerisation, RER seal production, natural rubber based, DE	Ecoinvent 3.10	2023	2013 1996
Propylene glycol	market for propylene glycol, liquid, RER	Ecoinvent 3.10	2023	2018
Silicone surface coating	silicone product production, RER	Ecoinvent 3.10	2023	1997
Synthetic rubber	synthetic rubber production, RER	Ecoinvent 3.10	2023	1995
TiO2	titanium dioxide production, sulfate process, RER	Ecoinvent 3.10	2023	2005
TPEO	Confidential composition			
TPEU	Confidential composition			
UV stabilizers	bisphenol A epoxy based vinyl ester resin production, RER	Ecoinvent 3.10	2023	2013
CO2	carbon dioxide production, liquid, RER	Ecoinvent 3.10	2023	1979

Material	LCI Dataset name	Source	Year publi	Year data
Thermal paper	market for paper, woodcontaining, lightweight coated, RER phenolic resin production, RoW chemical production, inorganic, GLO chemical production, organic, GLO	Ecoinvent 3.10	2023	2000 2000 2000 2000
PBT	polyethylene terephthalate production, granulate, bottle grade, RER (proxy)	Ecoinvent 3.10	2023	2015

5.4.1.2 Custom material

The user can model the production of a “custom” material by entering directly the LCIA impacts per kg for the 16 impact categories of EF3.1 package.

5.4.2 Transport supply

This step corresponds to the transport of the material to the first step of packaging manufacturing.

For each packaging component, parameters for truck, train, boat, barge and plane transports can be entered by the user. Modelling is presented in section 5.3.2.

The weight to be transported corresponds to the weight of packaging per FU, multiplied by a factor for including cumulated losses of material occurring until the grouping step.

5.4.3 Manufacturing

For each packaging component, each manufacturing step allows modelling the use of energy and other inputs per packaging weight as well as direct emissions of volatile organic compounds (VOC). Furthermore, if relevant, the transport of the manufactured component to another manufacturing site or to the filling plant can be included (cf. section 5.3.2).

The material loss occurring at each step can be determined in the interface. It influences the weight to be produced, considering the weight of packaging fixed in the step “composition” and corresponding to the weight of packaging used for delivering the product.

Table 19 lists the LCIs used to model the elements proposed in the manufacturing interface. Direct VOC emissions are modelled as an elementary flow in the model "non-methane volatile organic compounds, Emissions to air, unspecified ".

Table 19: List of LCIs used for modelling manufacturing

Name	LCI Dataset name	Source	Year publi	Year data
Material consumption				
Water consumption	market for tap water, Europe without Switzerland	Ecoinvent 3.10	2023	2012
Lubricant and oil	lubricating oil production, RER	Ecoinvent 3.10	2023	2000
Washer chemicals	sulfuric acid production, RER	Ecoinvent 3.10	2023	2000
Lime	lime production, milled, loose, Europe without Switzerland	Ecoinvent 3.10	2023	2000
Energy consumption				
Natural gas	heat production, natural gas, at industrial furnace >100kW, Europe without Switzerland	Ecoinvent 3.10	2023	2000
LPG	heat production, natural gas, at industrial furnace >100kW, Europe without Switzerland, with natural gas supply replaced by liquefied petroleum gas production, petroleum refinery operation, Europe without Switzerland	Ecoinvent 3.10	2023	2000
Heavy fuel oil (Fuel)	heat production, heavy fuel oil, at industrial furnace 1MW, Europe without Switzerland	Ecoinvent 3.10	2023	2001
Diesel	heat production, light fuel oil, at industrial furnace 1MW, Europe without Switzerland	Ecoinvent 3.10	2023	1991
Coal	heat production, at hard coal industrial furnace 1-10MW	Ecoinvent 3.10	2023	1988
Electricity	Country/continent-specific mix or user-specific mix, cf. Section 5.3.1			

Some predefined manufacturing process are pre-integrated in the tool. By selecting one of those processes, the user will get a set of default values for the losses and the energy consumption for each process. Those data were extracted from existing datasets available in Ecoinvent 3.10. The following table provides the complete list of predefined manufacturing processes and their associated default values provided by the tool.

Table 20: Predefined processes and default values available in the manufacturing section

Predefined process	Loss rate (%)	Water consumption (l/kg in)	Electricity consumption (kWh/kg in)	Natural gas consumption (MJ/kg in)	LPG consumption (MJ/kg in)	Heavy fuel oil consumption (MJ/kg in)	Diesel consumption (MJ/kg in)
Aluminium 2 parts cylindrical body part	13	7	1.42	1.76	0	0	0
Aluminium 2 parts cylindrical can	13	7	1.5	1.37	0	0	0
Aluminium 2 parts cylindrical end part	13	7	0.85	1	0	0	0
Aluminium 3 parts cylindrical can	9.5	7	0.5	0.57	0	0	0
Cardboard box manufacturing	12	0.28	0.12	0.92	0.01	0.01	0.01
PET bottle blow moulding	0.3	0	0.6223	0	0	0	0
PET masterbatch	2	0	0.6411	0	0	0	0
PET preform injection	0.6	0	1.4826	4.4391	0	0	0
PET tray calendering	0	0	0.2838	0	0	0	0
PET tray lamination	0	0	0.0025	0	0	0	0
PET tray metallization	0	0	0.0709	0	0	0	0
PET tray sheet co-extrusion	3.1	0	0.7096	0	0	0	0
PET tray sheet extrusion	2.4	0	0.6621	0.9696	0	0	0
PET tray thermoforming	5.4	0	0.7112	0.1059	0	0	0
Plastic film extrusion	2	0	0.66	0.6	0	0.21	0
Plastic injection	0.5	0	1.5	4.4	0	0	0
Plastic multilayers blow moulding	0.3	0	0.6223	0	0	0	0
Plastic multilayers co-injection	0.6	0	1.4826	4.4391	0	0	0
Steel rectangular can	3	7	1.24	1.53	0	0	0

5.4.4 Filling

The step filling corresponds to the filling of the product into the packaging at producer’s plant, as well as the grouping and palletization. On-site storage of the packed products at producer’s warehouse can be included in the energy consumptions.

The modelling of energy and water uses is similar to modelling for the manufacturing step (cf. Table 19). As a difference, these consumptions are defined here per packaging unit (while it was per kg of packaging in manufacturing). Furthermore, losses of packaging occurring at the filling step are defined through a single value, applied commonly to all packaging components. As for the manufacturing step, the percentage of loss fixed here is reflected in the weight to be produced and treated at end-of-life.

5.4.5 Distribution

This step corresponds to the distribution of the product from the factory to customer distribution centre or to the place of sale.

The weight to be transported corresponds to the weight of all packaging components and product per FU.

Several routes (with corresponding shares) can be defined by the user. For each route, several transport modes can be combined, among truck, train, boat, barge and plane (the user has access to one distance per transport mode and to the other associated empty return and payload parameters). Modelling of transport is presented per mode in section 5.3.2.

5.4.6 Collection

The "collection" step corresponds to the return trip for refillable packaging or the collection and further logistics for reusable packaging (e.g. pallets).

The weight to be transported corresponds to the weight of refillable/reusable packaging components (per FU). Effective payload must be adjusted by the user in consequence.

Only truck transport is available for this step. Modelling is presented in section 5.3.2.

5.4.7 End-of-life

The end-of-life is modelled according to the CFF (cf. section 3.2.2).

Steps included are waste collection and treatment as well as energy recovery at incineration and avoided virgin material production as benefit of recycling, as modelled by the CFF.

The same waste treatments are applied to the total amount of material produced, i.e. the packaging weight and the amount of material lost during manufacturing and filling steps.

Material-specific end-of-life (EOL) treatments are modelled for the materials listed in the left column of Table 21. Components available in the composition modules are automatically associated with these materials or to the material "other material" modelled as municipal waste.

Table 21: Materials with specific EOL treatments and association of components with these materials

Materials with specific EOL modelling	Associated components
Alu	Aluminium
Steel	Steel, Stainless steel, tinplated steel
PET	PET
PP	PP
HDPE	HDPE, PE
LDPE	LDPE
PS	PS

Materials with specific EOL modelling	Associated components
Glass	Glass
Cardboard	Cardboard, pulp, kraft paper, corrugated board box
Paper	Paper
Wood	Wood
Other materials	Colorant, additive, OPA, PLA, activated carbon, PVDC, ABS, synthetic rubber, POM, ink, foam, nylon, EVOH, HDPE teb, thermal, PBT, alu foil, hotmelt glue, EPE, tin, OPET, TPEU, TPEO, adhesive paper PP, adhesive paper PVC, glue, complex foil Alu-PE, TiO2, black carbon, CaCO3, optical brighteners, UV stabilizers, silicone surface coating, anti-fog additive, compatibilizing additives, epoxy resin, ethyl acetate, propylene glycol, adhesive mix, colorant mix, additive mix, coating mix, compound mix

If a custom material has been defined in "composition", the user must select the material to be used as reference for end-of-life treatments.

5.4.7.1 LCI data

The datasets for Ev and Er in the CFF are the same as those used at the production step (cf. Table 18). As a remark, although aluminium sheet manufacturing can be included in Ev at production (if the tool user selects "ingot and rolling" as scope, cf. section 5.4.1.1), aluminium sheet manufacturing is never included in Ev at end-of-life, since manufacturing into sheet is not avoided by recycling.

Table 22: LCI data for disposal at end-of-life (Eer and Ed of the CFF formula)

Material	Eer (incineration): Reference product - Name dataset	Year data	Ed (landfill): Reference product - Name dataset	Year data
Alu	scrap aluminium - treatment of scrap aluminium, municipal incineration - Europe without Switzerland	2006	waste aluminium - treatment of waste aluminium, sanitary landfill - RoW	1994
Steel	scrap steel - treatment of scrap steel, municipal incineration - Europe without Switzerland	2006	scrap steel - treatment of scrap steel, inert material landfill - Europe without Switzerland	1995
PET	waste polyethylene terephthalate - treatment of waste polyethylene terephthalate, municipal incineration – GLO	2006	waste polyethylene terephthalate - treatment of waste polyethylene terephthalate, sanitary landfill - RoW	1994

Material	Eer (incineration): Reference product - Name dataset	Year data	Ed (landfill): Reference product - Name dataset	Year data
PP	waste polypropylene - treatment of waste polypropylene, municipal incineration - GLO	2006	waste polypropylene - treatment of waste polypropylene, sanitary landfill - RoW	1994
HDPE & LDPE	waste polyethylene - treatment of waste polyethylene, municipal incineration - GLO	2006	waste polyethylene - treatment of waste polyethylene, sanitary landfill - RoW	1994
PS	waste polystyrene - treatment of waste polystyrene, municipal incineration - GLO	2006	waste polystyrene - treatment of waste polystyrene, sanitary landfill - RoW	1994
Glass	waste glass - treatment of waste glass, municipal incineration - GLO	2006	waste glass - treatment of waste glass, sanitary landfill - GLO	2010
Cardboard	waste paperboard - treatment of waste paperboard, municipal incineration - GLO	2006	waste paperboard - treatment of waste paperboard, sanitary landfill – RoW + additional modelling cf. section 5.4.7.2C	1994
Paper	waste paperboard - treatment of waste paperboard, municipal incineration - GLO	2006	waste paperboard - treatment of waste paperboard, sanitary landfill – RoW + additional modelling cf. section 5.4.7.2C	1994
Wood	waste wood, untreated - treatment of waste wood, untreated, municipal incineration - GLO	2006	waste wood, untreated - treatment of waste wood, untreated, sanitary landfill - RoW	1994
Other materials	municipal solid waste - treatment of municipal solid waste, incineration - RoW	2006	municipal solid waste - treatment of municipal solid waste, sanitary landfill - RoW	1994
CO2	End-of-life of purchased CO2 is modelled as an emission of the same amount of CO2 as “carbon dioxide (fossil), emissions to air, unspecified”.			

Avoided impacts thanks to energy recovered at incineration and landfill are modelled as (see also section 3.2.2):

- Electricity: Country/continent-specific grid electricity (cf. section 5.3.1, without the possibility of a user-specific mix)
- Heat: dataset “heat production, natural gas, at industrial furnace low-NOx >100kW – Europe without Switzerland” from ecoinvent 3.10.

5.4.7.2 Activity data

A. Waste collection and transport to recycler

The Table 23 provides the hidden activity data used to model the non-selective waste collection. It also mentions the parameters used for modelling the transport from sorting centres to recyclers, when this transport is not included in the LCI of recycled material production (i.e. with non-ecoinvent Er datasets for aluminium and steel). Table 23 does not apply for the specific model for PET production in the PETCORE tool.

Table 23: Fixed distances and loading for transport between sorting centres and recyclers

Type of waste	One-way distance (km)	Average load (t) in a truck with maximum payload of 24t	Source
Non-selective collection (to disposal treatment plant)			
All materials	50	23	RDC assumption
From sorting centre to recycler			
Aluminium	395	8	Average or most representative values within data provided for France, Spain and Belgium (respective sources are Eco-Emballages, Eco-Embes and RDC in a study for Fost Plus – green dot organization in Belgium)
Steel	276	18	

B. Recycling rates and incineration rates

Table 24: Sources of activity data per country (recycling rates and incineration rates)

Type of activity data	Ref year	Source
R2 (recycling rates)		
Glass bottle	2017 2017 2010-2018	Europe: FEVE (2019) USA: Bottle Bill Program + US EPA “Advancing Sustainable Materials Management” 2019 Other countries: National governmental sources, UNEP reports or other sources + continental averages
Aluminium can	2017 2017 2016-2019	Europe: EAA (2019) USA: Bottle Bill Program + US EPA “Advancing Sustainable Materials Management” 2019 Other countries: National governmental sources, UNEP reports or other sources + continental averages
Steel can	2017 2017 2015-2018	Europe: APEAL (2019) USA: US EPA “Advancing Sustainable Materials Management” 2019 Other countries: National governmental sources, UNEP reports or other sources+ continental averages

Type of activity data	Ref year	Source
PET bottle	2017 2010-2018	Europe: ICIS and Petcore Europe – "Annual Survey on the European PET Recycle Industry" (2019 USA: Container Recycling Institute (2010) Other countries: National governmental sources, UNEP reports or other sources + continental averages
PP bottle	Same as for PET bottle	
Beverage carton	2016-2018 2018 2019 2011-2019	Europe: Green dot organizations for some countries Average Europe: ACE (2019) USA: Carton Council Other countries: Tetrapak (2011-2012) or other sources
Cardboard and paper	2017 2017 2013-2018 2017	Europe: Eurostat (2020) USA: US EPA Other countries: National governmental sources, UNEP reports or other sources Other continents: ERPA (2018)
Incineration rate [10]		
Incineration rates	2017-2018 20012-2015 2001 1997-2017	Europe: Eurostat (2020) Other OECD countries: OECD Environmental Statistics South America: Pan-American Health Organization (PAHO) Other countries: UN Statistics or other sources

C. Modelling of landfilling for cardboard and paper

LCIs for landfilling of packaging are taken from ecoinvent 3.10 database. They include emissions due to material degradation but not the potential energy recovery obtained from landfill gas.

For cardboard and paper, the degradation rate in landfill can be an important topic, because of associated emissions of uncaptured methane (as a reminder, emissions as biogenic CO2 are counted in EF3.1 climate change impact category).

The modelling of emissions of degraded carbon in landfill is illustrated in Figure 1.

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[10] R3 in CFF = (1 – R2) * incineration rate

The parameter values used in the Packaging model are described in Table 25. They are common to all countries.

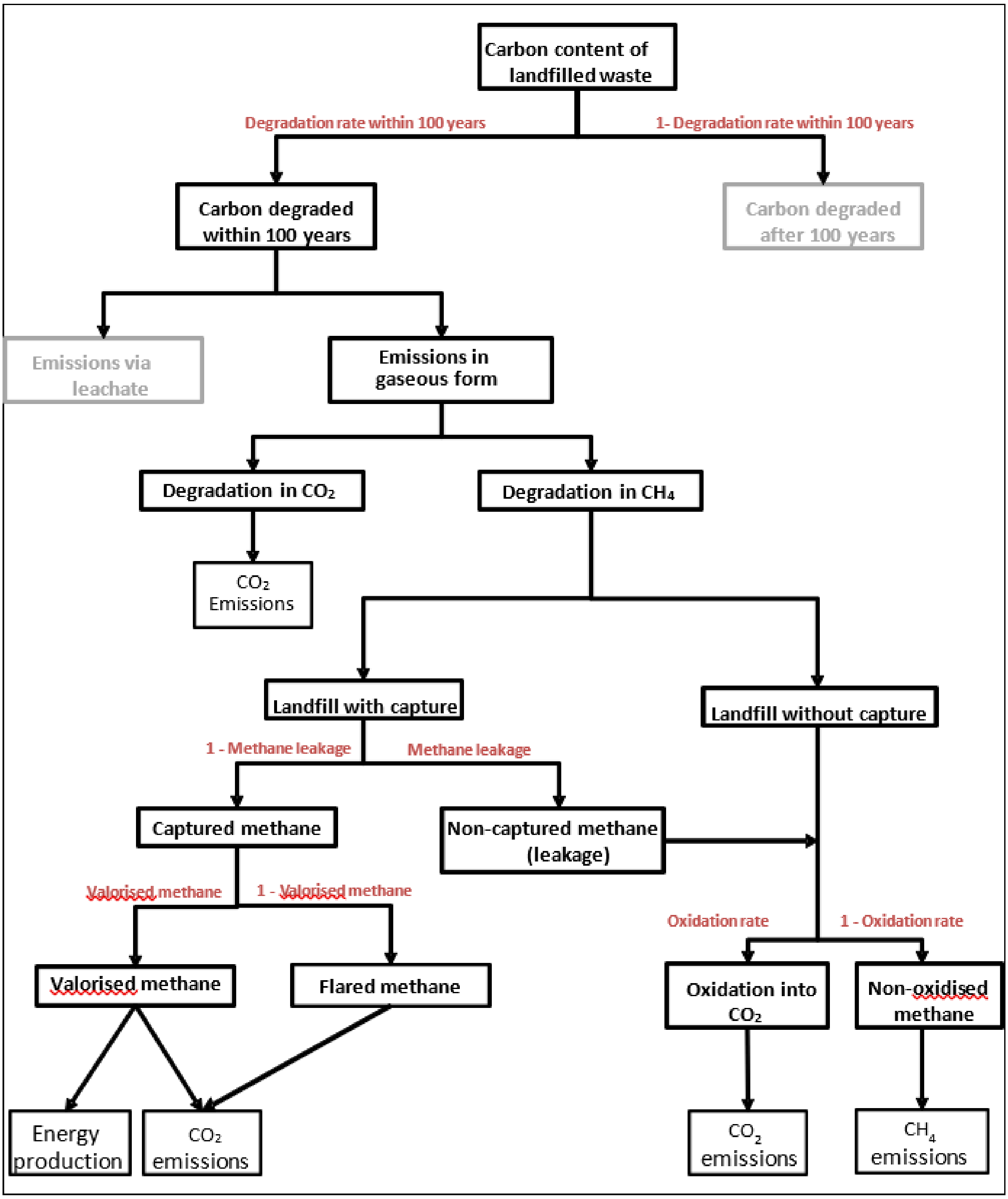

Figure 1: Scheme of the modelling of carbon emissions in landfill

Table 25: Parameters of modelling of carbon emissions due to material degradation in landfill

	Values (hidden)	Source
Degradation rate (within 100 years)		
Cardboard, Corrugated board	32.5%	Ecoinvent: activity “treatment of waste paperboard, sanitary landfill”
Paper	32.5%	
Share of emissions		
Part of degraded carbon emitted in gaseous form	97.1%	Ecoinvent
Fraction gaseous emissions as CO_2 versus CH_4	50%	IPCC recommendation 2006
Fraction of methane in leakage that oxidizes into CO_2	10%	IPCC recommendation 2006
Characteristics of landfill sites		
Share of landfill with gas capture	70%	Assumption
Share of methane leakage in landfill with capture	30%	French study: « RECORD, Application de la méthode Bilan Carbone® aux activités de gestion des déchets, 2009, 133 p, n°07-1017/1A » p79 - p 83 – p103
Share of captured methane valorised as electricity (the remaining part is flared)	36%	
LHV of methane	13.9 kWh/kg	
Efficiency of electricity production	30%	Assumption based on the range of values available in different studies: ▪ 33% in the study “Record” p103 ▪ 28% in ecoinvent report “Life Cycle Inventories of Waste treatment Services – Part II”, 2009
No thermal valorisation		Assumption

5.4.8 Production of PET (PETCORE module)

5.4.8.1 Specificity of the PETCORE tool

In the PETCORE tool, the user has access to a specific step called “PET production” dedicated to modelling the production of PET components. The system boundaries correspond to a cradle-to-gate approach with further inclusion of the supply to the filling site and of the packaging end-of-life. According to the requirements of PETCORE users, the steps that can be attributed to the product itself are not included, i.e. the filling operations and the distribution (no impacts of distribution are included, neither for the product nor for the packaging). Modelling of the steps composition (except for PET), supply transport, manufacturing and end-of-life are the same as for the packaging tool.

The user can model simultaneously several types of PET productions and attribute to each a share within the total amount to be produced.

The different routes modelled are:

- PET - generic
- PET - specific production
- PET – generic recycling
- PET - specific chemical recycling
- PET - specific mechanical recycling
- PET – Specific - LCIA impacts

The modelling is described in this section after a general introduction to PET production.

5.4.8.2 Introduction to PET production

The first step of PET production consists of a transesterification and polymerization reaction to turn the monomers purified terephthalic acid (PTA) [11] and mono-ethylene glycol (MEG) into oligomers. During these steps, recycled feedstock can be added to the process; dimethyl terephthalate (DMT) is added during the transesterification step, BHET can be added during the transesterification and low polymerization step while the PET flakes can be added during these steps as well as the high surface area polymerization.

After the polymerization step, a polycondensation step is used to further increase the average molecular weight of the polyester (longer chains). The method of measuring this increase is ‘intrinsic viscosity’ (IV), this technical characteristic of the PET is used to indicate the grade of the PET and will define the possible applications of the PET resin (e.g. lower IV PET is typically used for textile, while higher IV PET is used for bottle applications). There are two main polycondensation techniques:

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[11] Virgin PET can also be produced through another pathway where DMT is used instead of PTA. This production pathway is out of scope and not included in the PETCORE tool, since this production pathway is no longer economically viable.

- Solid state polycondensation: this is the traditional method where PET is in a solid state (crystalline pellets, flakes) when entering the polycondensation step. The PET is heated to about 200 – 240°C, in a vacuum or inert gas, and kept at this temperature for several hours to increase the IV.
- Liquid state polycondensation: this is a more recent technology where the PET is still in liquid state (‘in the melt’) and brought to a higher temperature range (270 – 280°C) which increases the reaction speed of the polycondensation step.

The PET resin is amorphous, meaning the polymer chains are disordered, but can become crystalline by passing the PET resin through a crystallization phase where the polymer chains are now parallel and closely packed. Crystallinity in PET is usually induced by thermal crystallization and/or by stress or strain induced crystallization (Demirel & al, 2011). Thermally induced crystallization occurs when the polymer is heated above the glass transition temperature and not quenched rapidly enough. In stress-induced crystallization, stretching or orientation is applied to heated polymer and the polymer chains are rearranged in a parallel fashion and become closely packed. Almost all PET for packaging applications is in the amorphous state (APET), with the exception of microwave food trays which are made of crystalline PET [12] (CPET).

The different PET resin production steps are presented in Figure 2, as well as the different kinds of feedstock. These will enter the production process at different steps, which is shown on the figure. The PET can be either completely made up of virgin feedstock, recycled feedstock or a mixture of both. Furthermore, the origin of the feedstock can be either fossil or biogenic (e.g. MEG produced from ethanol from sugarcane).

The PET resins produced from routes 1 to 4 are APET or, if it has undergone an optional crystallisation step, CPET.

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[12] https://www.clearpak.ca/site/clear-plastic-packaging-materials/pet-polyethylene-terethphalate-plastic

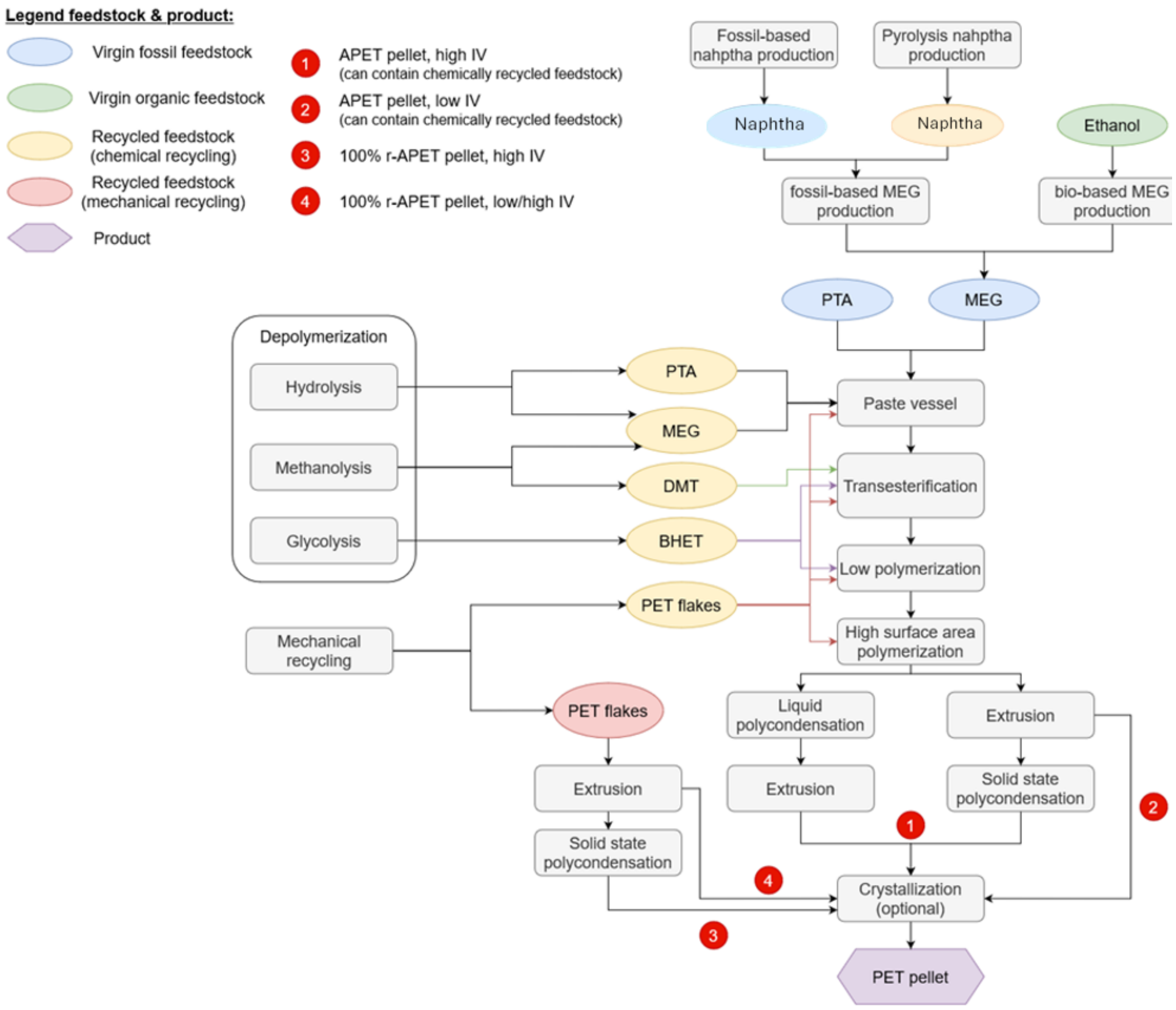

Figure 2: PET resin (pellet) production

The mechanically recycled PET flakes can go through an extrusion and Solid State Polycondensation (SSP) step to yield a high IV rPET pellet, although some industrial processes have eliminated the need for the SSP step and can produce this product through only an extrusion step (e.g. NGR LSP technology and vacurema advance). Therefore, the product no. 4 can either be a low or high IV rPET pellet depending on the technology used.

A. Virgin feedstock

Virgin PET is produced from the monomers:

- Purified terephthalic acid (PTA): typically produced through catalytic oxidation of p-xylene
- Mono-ethylene glycol (MEG): Ethylene glycol is produced from ethylene (ethene), via the intermediate ethylene oxide. Ethylene oxide reacts with water to produce ethylene glycol. MEG can be either fossil-based or biobased:
  - Fossil-based: there are several methods in the petrochemical industry; a primary method is steam cracking where hydrocarbons and steam are heated at elevated temperatures (750–950 °C). Naphtha is often the input for steam cracking to produce this ethylene.

  - Biobased: MEG is derived from ethanol, which can originate from different biological sources such as sugarcane, sugar beet, corn… The ethanol is converted in ethylene glycol through hydrolysis.

B. Recycled feedstock

The recycled feedstock is provided by different recycling technologies:

- Mechanical recycling:
  - The PET flakes produced during mechanical recycling can enter the PET pellet production in two manners:
    - PET flakes enter at one of the PET resin production steps (paste vessel, transesterification, low polymerization or high surface area polymerization), in this case it is indicated as chemically recycled feedstock.
    - PET flakes go through an extrusion step (and an optional solid state polycondensation step) to yield recycled pellets. These can be mixed with virgin PET pellets.
  - The PET flakes are not added during the PET pellet production, but during the production of the PET packaging product together with virgin PET pellets. In this case, the recycled flakes might pass through a pretreatment step to ensure the technical requirements for the packaging are met.
- Chemical recycling:
  - Pyrolysis: a type of thermochemical recycling in which heating occurs in the absence of oxygen. The input of pyrolysis is mixed polyolefins (polyethylene, polypropylene) for which mechanical recycling is not an option. The process produces naphtha which is used in the MEG production (naphtha is cracked to produce ethylene, which is converted into ethylene glycol). This route is not included in the current version of the tool (the MEG that is produced using naphtha, derived from pyrolysis, is not included in the boundaries of the circular economy of PET since the feedstock for this pyrolysis is a mixture of different polyolefins and not PET).
  - Depolymerization: a collection of chemical recycling technologies that break down the PET polymer into its monomers. Different technologies will yield different monomers (for information on the chemically recycled feedstock, see Annex 4):
    - rPTA: product of hydrolysis
    - rMEG: product of hydrolysis or methanolysis
    - rDMT: product of methanolysis
    - rBHET: product of glycolysis

5.4.8.3 Generic PET and RPET

The LCIs used for modelling PET production if the user selects the generic options for PET or RPET are described in Table 26.

Table 26: LCIs used for modelling generic PET production in PETCORE model

Name	LCI Dataset name	Source	Year publi	Year data
PET Generic	polyethylene terephthalate production, granulate, bottle grade, RER	Ecoinvent 3.10	2023	2015
RPET Generic:				
RPET flakes (Er)	polyethylene terephthalate production, granulate, amorphous, recycled - Europe without Swtzerland, with subtraction of 0.48 kWh/kg of „market group for electricity, low voltage - Europe without Swtzerland“	Ecoinvent 3.10	2023	2010
RPET pellets (Er)	polyethylene terephthalate production, granulate, amorphous, recycled - Europe without Swtzerland			2010

5.4.8.4 Specific PET production

This option allows using primary data (material input, energy input) to model the PET resin production (APET or CPET). The upstream transport of the feedstock for the PET resin is also adaptable. Other contributions are modelled according to ecoinvent (cf. section 5.4.8.4D)

A. Material input (Raw materials)

The parameters related to material input that are available and editable in the current version of the tool are presented in Table 27 and corresponding LCI data in Table 28.

Table 27: Adaptable parameters for input materials and default values

Name in interface	Unit	Default value	Source of default value
PTA (Virgin PTA)	kg /kg PET	0.86	Ecoinvent v3.10 *polyethylene terephthalate production, granulate, bottle grade, RER*
MEG fossil (Virgin MEG)	kg /kg PET	0.34	Ecoinvent v3.10 *polyethylene terephthalate production, granulate, bottle grade, RER*

Table 28: LCIs used for modelling monomers for PET production in PETCORE model

Name	LCI Dataset name	Source	Year publi	Year data
PTA (purified terephthalic acid)	purified terephthalic acid production, RER	Ecoinvent 3.10	2023	2011
EGf (fossil ethylene glycol)	ethylene glycols production, thermal hydrolysis of ethylene oxide, RER	Ecoinvent 3.10	2023	2019

The following list of raw materials are not yet included in the current version of the PETCORE tool:

- MEG bio-based
- rMEG from pyrolysis
- rPET Flakes from depolymerization
- rDMT from depolymerization
- rPTA from depolymerization
- rMEG from depolymerization
- rBHET from depolymerization

B. Energy consumption

Table 29 presents the editable parameters for energy consumption and default values for amorphous PET. Energy for crystallisation has to be added for crystalline PET.

Table 29: Adaptable parameters for energy consumptions and default values

Name in interface	Unit	Default value	Source of default value
Electricity consumption	kWh / kg PET	0.199	Ecoinvent v3.10 *polyethylene terephthalate production, granulate, bottle grade, RER*
Gas consumption	MJ /kg PET	2.59	Ecoinvent v3.10 *polyethylene terephthalate production, granulate, bottle grade, RER*
Fuel consumption	MJ /kg PET	0	
Coal consumption	MJ /kg PET	0	

Table 30 lists the LCIs used for modelling energy consumption in the PETCORE model.

Table 30: LCIs used for modelling energy consumption for PET production in PETCORE model

Name	LCI Dataset name	Source	Year publi	Year data
Electricity consumption	Country/continent-specific mix or user-specific mix, cf. Section 5.3.1			
Gas consumption	market group for heat, district or industrial, natural gas, RER	Ecoinvent 3.10	2023	2015
Fuel consumption	heat production, light fuel oil, at industrial furnace 1MW, EU w/o CH	Ecoinvent 3.10	2023	1991
Coal consumption	heat production, at hard coal industrial furnace 1-10MW, EU w/o CH	Ecoinvent 3.10	2023	1988
Diesel	market for diesel, burned in building machine, GLO	Ecoinvent 3.10	2023	2011

C. *Upstream transport*

The upstream transport of the feedstock for the PET resin is also adaptable (cf. Table 31). The same distances are applied to all input materials.

Table 31: Default distances for upstream transport PET resin (editable parameters)

Transport type	Default values of distances (km)	Source of default values
Lorry	130	For suppliers located within Europe Default values recommended in the PEFCR Guidance document v6.3 (May 2018), applying to all other products from supplier to factory
Train	240	
Barge	270	
Boat	0	
Plane	0	

Transport is modelled as described in section 5.3.2.

D. *Other contributions to PET production*

There remain other contributions to PET production than monomer inputs, energy consumption and upstream transport. These contributions are modelled similarly as in the ecoinvent 3.10 dataset “polyethylene terephthalate production, granulate, bottle grade – RER”.

It includes:

- Following LCIs:
    - chemical factory construction, organics – RER
    - market for antimony – GLO
    - market for chemical, organic – GLO
    - market for chemical, inorganic – GLO
    - market for phosphoric acid, industrial grade, without water, in 85% solution state – GLO
- Following elementary flows:
    - Water consumption
    - Emissions to water
    - Emissions to air (other than due to energy consumption), taken from the ecoinvent 3.10 dataset “polyethylene terephthalate production, granulate, amorphous – RER”.

5.4.8.5 Specific mechanical recycling

A. Steps included

A.1 Collection

Post-consumer PET waste can be collected through different collection schemes, for a large part determining the composition of the waste stream and the need for downstream sorting processes to remove unwanted wastes from the PET waste stream. The main collection schemes for post-consumer PET waste are:

- Kerbside collection, also called door-to-door collection: residents are requested to separate potential valuable recyclables (plastic, paper and cardboard, metals) from their household waste, commingled or not, into special receptacles or bags. Example: the blue bag in Belgium which is used to collect plastic packaging waste, metal packaging waste and beverage cartons. These different waste streams are separated after collection in sorting centres.
- Deposit return system (DRS): a deposit is made at time of purchase, which is refunded when the plastic container is returned to an appropriate redemption centre. A DRS specific for PET bottles already exists in 13 European countries, such as Germany, The Netherlands, the Scandinavian countries… and discussions are ongoing in other countries.

A DRS increases the purity of the collected waste material and as a result the quality of the recycled product. It avoids the need for a sorting step to separate the PET waste from other wastes that are collected together in the case of kerbside collection.

The collection impacts are multiplied by the inverse of the sorting yield, meaning that the impacts of the transport of materials being not targeted in the collection scheme are allocated to the target waste materials (see section 5.4.8.5D for explanation on how these impacts are allocated to the PET stream).

A.2 Sorting

The collected post-consumer PET waste is sent to a sorting facility to be separated from other co-collected materials and plastics. Sorting operations at these facilities range from manual sorting of items on a conveyor to highly automated systems using magnets, air classifiers, optical sorters, and other technologies to sort and separate mixed incoming materials. The sorted PET waste is typically turned into bales and sent to recycling facilities. These bales will still contain other material than PET, e.g. PE caps, labels…

The tool user can enter amounts of materials that are sent to incineration or landfill at the exit of the sorting centre (these end-of-life treatments are included in the system boundaries). Such “unsorted waste” corresponds mainly to non-permitted waste, i.e. waste types that are not targeted by the collection scheme (and to small amounts of targeted materials that the sorting centre failed to sort out).

In the example cited above of the blue bag in Belgium, the types of waste targeted by that collection scheme are plastic packaging waste, metal packaging waste and beverage cartons. The targeted outputs at sorting facility would include PET bales, HDPE bottle bales, aluminium can bales, etc. The small amount of cardboard box present due to citizens' error would not be sorted for recycling and might be sent to incineration.

A.3 Recycling process

The system boundaries of the mechanical recycling process start with the reception of the PET bales. The PET undergoes different steps; sorting, shredding and grinding into flakes, and optionally a washing step.

Different options are possible regarding the PET output of the recycling plant:

- rPET flakes
- rPET pellets: flakes that have undergone an extrusion step. SSP can be added as additional step to increase the viscosity of these rPET pellets.

The system further includes the disposal of waste generated at recycling (off-spec pellets and fine PET material). Disposal takes place via incineration and/or landfilling, according to data entered by the user.

B. Modelling of post-consumer waste collection

The modelling of the door-to-door collection and DRS is based on the recommendations by ADEME for LCAs on packaging materials[13] as well as, for DRS, on the ecoinvent dataset for sorting of post-consumer PET waste for transport to collection point. The corresponding activity data is provided in Table 32. It is not adaptable in the tool, but the user can define the respective shares of kerbside and DRS collection schemes. The same parameter values are used for all countries. However, the sensitivity of these parameters to the local context is considered low or, for the distances, moderate. Indeed, collection distances can vary between countries, for example in function of the population density. The use of distances corresponding to the French situation to other countries, mainly European (since PETCORE is a European association), is a current limit of the tool. However, it is considered acceptable provided the study made with the tool does not focus on end-of-life treatments.

Table 32: Hidden activity data used to model the collection of post-consumer waste

Collection method	Parameter	Unit	Value	Source
Kerbside collection	Fuel consumption during collection round (door-to-door) for separately collected plastic waste	l/t	19.4	Average consumption for France
	Transfer distance (from collection round to sorting plant/residual waste treatment plant)	km	50	Average distance for France
	Loading rate transfer distance	%	96%	Assumption (23t/24t)
Deposit return system	Distance by car to collection point (allocated to post-consumer waste)	km/kg	6.22E-4	Ecoinvent 3.10 - market for waste polyethylene terephthalate, for recycling, unsorted, EU w/o CH
	Container for collection	unit	1	
	Transfer distance (from collection round to sorting plant/residual waste treatment plant)	km	50	Average distance for France

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[13] ADEME, "Cadre de Référence - ACV comparatives entre différentes solutions d'emballages", 2022

Collection method	Parameter	Unit	Value	Source
	Loading rate transfer distance	%	96%	Assumption (23t/24t)

Table 33 lists the LCIs used for modelling post-consumer PET waste collection.

Table 33: LCIs used for modelling waste collection for PET production in PETCORE model

Activity	LCI Dataset name	Source	Year publi	Year data
Collection post-consumer waste: kerbside collection				
Collection - Truck	Heavy Duty Trucks Rigid 20 - 26 t - Diesel - Euro VI – Urban (Diesel supply and infrastructure as in Table 16)	Copert 5 tool (v5.2.2)	2018	2007-2016
Transfer - Truck	As in Table 16			
Collection post-consumer waste: deposit return system				
Transport by truck	As in Table 16			
Consumer transport by car	market for transport, passenger car, large size, diesel, EURO 4, RER	Ecoinvent 3.10	2023	2012
Container for collection	market for container, for collection of post-consumer waste plastic for recycling, EU w/o CH	Ecoinvent 3.10	2023	2010

C. Modelling of sorting and recycling steps

Sorting and recycling processes are modelled in a rather similar way in the tool. The data to be entered by the user corresponds to the level of the sorting or recycling plant:

- Waste streams per year:
    - Total amount of waste entering the plant
    - Amount of waste diverted to incineration
    - Amount of waste diverted to landfill
    - Total output of co-products (including PET)

- Energy consumption:
    - Electricity
    - Natural gas
    - Fuel
    - Coal
    - Diesel (only for sorting)
- Other input consumption (only for PET flake production)
    - Water
    - NaOH (for the optional washing step)

The recycling step is decomposed into three sub-steps (specific energy consumption can be defined for each sub-step):

- Waste purification
- Production of flakes
- Production of pellets

The transport from the sorting plant to the recycling plant is taken into account in the upstream transport (with editable distance parameters). If NaOH is used, its supply transport is also included in the upstream transport.

D. Allocation of collection, sorting and recycling impacts

There are two options for allocating the impacts of the sorting step and of the purification and flake production steps at the recycler:

- Mass allocation (default choice): the impacts per ton of waste are obtained by dividing the energy consumption of the plant by the total amount of output products.
- Economic allocation: the user gets access to two additional sections in the interface (one for sorting and one for recycling), allowing the amounts and prices of co-products to be entered. The economic allocation consists in multiplying the impacts of sorting and recycling by the corresponding correction factor, which is calculated as follows:

$$Correction\ factor = \frac{Q_{PET} * P_{PET}}{(Q_{PET} * P_{PET} + \sum_{1}^{n}(Q_i * P_i))} * \frac{1}{\frac{Q_{PET}}{Q_{all}}}$$

With (for either sorting, purification or flake production step):

- Q_{PET} = Total PET output of the step (tonne/year)
- P_{PET}: PET output economic value (€/tonne)
- n: number of co-products that can be modelled in the tool (5 for sorting and 3 for waste purification and flake production)
- Q_i: Output of co-product i (tonne/year)
- P_i: economic value of co-product i output (€/tonne)
- Q_{all}: Total output of the step (tonne/year)

If the number of co-products other than PET exceeds the maximum number n specified in the interface, the tool user should aggregate several streams of co-products by summing the tonnages and calculating the corresponding average economic value.

For the collection step, the same allocation applies as the one selected for the sorting step and the same correction factor applies in case of economic allocation.

The Table 34 presents the LCI data used for modelling the sorting and recycling steps.

Table 34: LCIs used for modelling sorting and recycling for PET production in PETCORE model

Activity	LCI Dataset name	Source	Year publi	Year data
Energy consumption				
As in Table 30				
Other inputs				
NaOH	market for sodium hydroxide, without water, in 50% solution - RER	Ecoinvent 3.10	2023	2018
Water	market for tap water - Europe without Switzerland	Ecoinvent 3.10	2023	2012
Disposal of non-recyclable waste output after sorting				
Incineration	treatment of municipal solid waste, municipal incineration FAE - CH	Ecoinvent 3.10	2023	2006
Landfill	treatment of municipal solid waste, sanitary landfill - CH	Ecoinvent 3.10	2023	1994

5.4.8.6 Specific chemical recycling

A. Steps included

The depolymerisation route is the only chemical recycling route available in the PETCORE tool so far. The steps included are:

- Supply of the PET waste (flakes) to be depolymerised
- The depolymerisation step
- The polymerisation

B. Modelling of the supply of PET flakes

The input for the depolymerization is assumed to be PET flakes. The impact of converting post-consumer PET waste into these flakes is modelled using the ecoinvent dataset "*polyethylene terephthalate production, granulate, amorphous, recycled, EU w/o CH*". This dataset represents the production of rPET pellets, therefore the energy consumption during the last step to convert the flakes into pellets is subtracted from this dataset. This removed energy consumption is 0.48 kWh/kg rPET (based on ecoinvent).

C. Modelling of depolymerisation and polymerisation

Table 35: LCIs used for modelling PET chemical recycling in PETCORE model gives the LCI datasets associated with the use of chemicals and other input materials as well as treatment of generated waste. The use of energy and the upstream transport are modelled as described in Table 30 and in section 5.4.8.4C respectively.

The modelling of PET hydrolase enzyme production is based on life cycle inventory data published by Uekert et al. in 2022,[14] consisting in amounts of inputs (modelled with ecoinvent datasets), emissions to air and soil and land use elementary flows.

The direct emissions at this step that can be edited in the interface are modelled through the following elementary flows:

- Methanol, emissions to air, unspecified
- Ethylene glycol, emissions to water, unspecified
- Ethylene glycol, emissions to air, unspecified

Table 35: LCIs used for modelling PET chemical recycling in PETCORE model

Name	LCI Dataset name	Source	Year publi	Year data
Raw materials				
Methanol (MeOH)	Market for methanol - RER	Ecoinvent 3.10	2023	2011
Ethylene glycol (EG)	market for ethylene glycol - RER	Ecoinvent 3.10	2023	2018
Phosphoric acid (PO4)	market for phosphoric acid, industrial grade, without water, in 85% solution state - GLO	Ecoinvent 3.10	2023	2011

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[14] In Electronic Supplementary Information (table S6) associated with the paper of Uekert et al., *Life cycle assessment of enzymatic poly(ethylene terephthalate) recycling*, Green Chem., 2022, 24, 6531–6543. https://www.rsc.org/suppdata/d2/gc/d2gc02162e/d2gc02162e1.pdf (accessed 09/12/2024)

Name	LCI Dataset name	Source	Year publi	Year data
Sodium hydroxide (NaOH)	market for sodium hydroxide, without water, in 50% solution state	Ecoinvent 3.10	2023	2018
Activated carbon (AC)	market for activated carbon, granular - GLO	Ecoinvent 3.10	2023	2005
Sulfuric acid (H2SO4)	market for sulfuric acid - RER	Ecoinvent 3.10	2023	2018
Organic chemical	market for chemical, organic - GLO	Ecoinvent 3.10	2023	2011
Inorganic chemical	market for chemical, inorganic - GLO	Ecoinvent 3.10	2023	2011
Nitrogen	market for nitrogen, liquid - RER	Ecoinvent 3.10	2023	2011
Water	market for tap water – Europe without Switzerland	Ecoinvent 3.10	2023	2012
Waste treatment				
Hazardous waste	hazardous waste, for incineration - treatment of hazardous waste, hazardous waste incineration – Europe without Switzerland	Ecoinvent 3.10	2023	1997
Non-hazardous waste sent to incineration	treatment of waste plastic, mixture, municipal incineration FAE - CH	Ecoinvent 3.10	2023	2006
Non-hazardous waste sent to landfill	treatment of waste plastic, mixture, sanitary landfill	Ecoinvent 3.10	2023	1994

5.4.8.7 Specific PET – LCIA impacts

The user can enter LCIA results (EF3.1 methods) for to integrate the LCIA impacts of an existing LCA study already done for a specific production of PET (as described in section 5.4.1.2). The ecoinvent 3.10 LCIA values for the dataset “polyethylene terephthalate production, granulate, bottle grade, RER” are provided as default values, in case the user has specific LCIA results only for one or part of the impact categories (e.g. only for climate change). Combining ecoinvent and another source limits the consistency of data but ensure to avoid to model a zero impact for unknown indicators.

5.4.9 Production of glass (FEVE module)

As for the PETCORE tool, the FEVE tool allows the user to model more specifically the production of glass for glass components entered in the “composition” interface. The modelling of the other steps is the same as for the packaging tool (including the end-of-life).

5.4.9.1 Steps included

The FEVE-specific model includes the same steps than the LCIs used in the “composition” step, i.e. the steps listed in Table 36. The model provides the impacts of the whole production part of the CFF, taking the external cullet rate into account.

Table 36: Steps included in the glass production step (FEVE tool)

Steps	Editable parameters
Bill of materials	Yes
Supply transport for raw materials	Yes
Energy consumption for melting and non-melting steps (including fuel supply and combustion emissions)	Yes
Decarbonation emissions	No
Recovered energy	Yes
Cullet sorting and cullet treatment plant	No
Other steps: Infrastructure, waste treatment, water consumption, correction of some emissions to air	No

The criteria for selecting the parameters that can be edited in the interface are mainly:

- primary data under the control of glass producers (decarbonation emissions are calculated from the bill of materials; data related to cullet sorting and treatment is not necessarily available to glass producers)
- parameters having a significant influence on the results or that can vary significantly from one site to another (justifying non-editable parameters for the “other steps”).

5.4.9.2 Modelling of glass production

[The FEVE model is not part of the packaging tool review since an external peer review is already running for this model.]

5.5 Discussion of data quality

Main activity data is accessible in the tool interface, as well the country where the activity takes place. As a consequence, a very good level of representativeness can be reached for all criteria (mainly primary data).

The following discussion of data quality focuses on LCI data, based on data quality requirements described in section 5.2. Activity data non-accessible in the tool is commented when relevant.

Limits of the results provided by the tool and related to data quality are discussed in 7.2.

5.5.1 Geographical representativeness

As discussed in section 3.2.5, spatial differentiation is not taken into account in the LCIA result calculations (or very scarcely), due to limitations of the database and LCI sources used (only a few LCI datasets have regionalized elementary flows). Hence, geographical representativeness is not discussed in terms of localisation of activities and spatial differentiation at the elementary flow level.

The discussion concentrates on data and modelling resulting in elementary flow values.

LCI datasets are common to all countries (cf. section 2.3), except for electricity. Country-specific electricity consumption datasets are used when modelling is based on editable electricity use as activity data, as well as in the cases where electricity has been extracted from ecoinvent datasets (for plastic recycling).

LCIs are mostly representative of the European situation:

- For ecoinvent, the geography “RER” or “Europe without Switzerland” is selected, when available (in many cases, foreground data is mainly collected in Switzerland or Europe and are then extrapolated to other geographical areas)
- For LCI data coming from other than ecoinvent, sources are mainly European:
  - European producer associations for material production, except for steel for which Worldsteel provided LCIs representing world averages
  - European tool COPERT v5 for emissions for transport by truck

The European focus is supported by the higher availability of LCI data from Europe, the reliability of the datasets and frequent update of the data.

Consequently, the geographical representativeness of most datasets is good to very good when modelled activities take place in European countries. For applications outside Europe, the quality level is globally fair as it is assumed that rather similar technologies are used outside Europe for the activities considered in the packaging model, in particular for material production. For datasets related to waste disposal treatments, ecoinvent data extrapolated from Swiss data to Europe or Rest-of-the-World situations is used. It is considered of fair representativeness.

Infrastructures for road and tracks are potentially overestimated by using the Swiss situations as reference for extrapolation.

Concerning activity data, some non-editable data is also common to all countries and representative of the

- European context (mix of euro standards for trucks)
- French situation (energy recovery at incineration, modelling of methane capture in landfill, distances for waste collection)

Using such data for studies covering other regions or countries increases the uncertainty of the results.

5.5.2 Technological representativeness

The technological representativeness depends on the specific packaging system studied. Therefore, it is not possible to provide conclusions applying to all packaging solutions that can be studied. However, it can be highlighted that the LCIs used for material production were selected to best correspond to usual packaging systems (example cans, for aluminium). For helping the tool user to make a more specific assessment, the user has been referred to ecoinvent documentation and to Annex 2 for non-ecoinvent datasets.

Concerning the other life cycle steps (energy use, transport, end-of-life treatments, etc.), the technological representativeness is considered good to very good. It means that the datasets represent exactly the technology to be modelled or correspond to a (very) similar technology.

However, fair or poor quality levels can be attributed to the following activities:

- Electricity modelling for countries for which no “market for electricity, low voltage” dataset is available in ecoinvent 3.10. However, the average technology mixes used for each electricity source is a good approximation and computations dealing with these uncommon countries are rather rare.
- LCI data used to model the additives, adhesives and colorants in the phase “composition” are rather proxies for these materials that can be very specific in function of the tool user (e.g. adhesive or plasticizer).

5.5.3 Time-related representativeness

As a reminder, up-to-date activity data can be used for main parameters since they are accessible in the tool interface.

Concerning LCI datasets, most recent available datasets are used:

- ecoinvent 3.10 is the source for most of LCIs. This database is the last one available at the time of this tool development. However, the primary data collection for the processes might have taken place earlier or much earlier. Data related to energy production, fuel production and infrastructures is considered as still valid, although older. Indeed, limited evolutions have occurred in the related technologies since data collection.
- For FEVE, EAA, Worldsteel, Apeal, AA, the last published version is used.

In general, in case of technological improvement with time, old datasets will tend to overestimate the impacts, which is acceptable in a conservative approach.

5.5.4 Completeness

LCI data consists in peer reviewed data coming from recognized databases and data providers. Data is reputed complete in terms of steps included.

Furthermore, global experience is currently building in the LCA community concerning the use of new LCIA methods, namely for land use, water scarcity, human toxicity and ecotoxicity. Completeness of primary data collection for the most contributing elementary flows cannot be confirmed at this stage for all foreground and background processes involved in dataset computation. Caution is recommended in the interpretation of these impact categories.

5.5.5 Methodological consistency

Approaches in terms of data type are consistent among the different types of packaging, namely concerning:

- the type of data providers (European Associations for most material production)
- the system boundaries
- the attributional approach
- the use of the CFF

However, there are inconsistencies related to the modelling of co-products and by-products between Worldsteel and EAA on the one hand and ecoinvent on the other hand. The formers use system expansion, while for ecoinvent, we use the system model “Allocation, cut-off by classification”.

Furthermore, background databases used for establishing the production LCIs differ among materials, being mainly GaBi or ecoinvent.

Both elements (co/by-product modelling and background database) introduce a small bias and impose the user to be still more cautious in case of direct comparisons between materials (as a reminder, the use of the tool for external communication of comparative results is not recommended unless an additional peer review is performed with the aim of focusing on requirements of the ISO 14040 and 14044 regarding disclosure to the public of comparative assertions).

6 Results and interpretation

As stated in section 1.2, this report does not contain result presentation nor interpretation. These steps shall be carried out by the tool user.

The tool provides results with the following details:

- For the total life cycle, by aggregated phases or by sub-phases
- For each impact category

According to ISO 14044, the interpretation stage comprises:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- an evaluation that considers completeness, sensitivity and consistency checks;
- conclusions, limitations, and recommendations.

Limits of the results presented in chapter 7 are to be considered when conducting the interpretation phase.

The sensitivity check aims at determining how changes in data and methodological choices affect the results and conclusions. It includes consideration of value-choices, rationales and expert judgements.

For studies supporting decision of the tool user and in case of comparison between systems, sensitivity analyses are strongly recommended (and compulsory for comparison to be disclosed to the public, according to ISO 14044).

With the packaging tool, such sensitivity analysis can be carried out by studying several alternative scenarios based on different values of accessible parameters or alternative methodological choices. For example:

- For countries where recycling rates are uncertain, it can be relevant to assess the sensitivity of the results to recycling rates by performing several calculations with different recycling rate values. The influence of other end-of-life parameters can also be assessed, such as the distances for door-to-door collection.
- For materials with uncertain demand and offer of secondary material, testing several methods of recycling benefit allocation helps drawing more robust conclusions.

Depending on the goal of the study, sensitivity analyses can also be performed outside of the tool, with additional calculations related to other data limitations identified (cf. 7.2), with the help of an LCA practitioner.

7 Limits

7.1 Limits of modelling

The main limits related to the modelling are:

- Packaging materials have to be selected within a large but fixed list of materials available in the tool model. This can be a limit in case of eco-design if the user intends to study new or other materials (e.g., bio-based plastics) and uses available materials as proxy.
- The tool focuses on the packaging life cycle. Production of the product is not included, which also prevents the influence of the packaging type on the product losses to be assessed. Compliance with PCRs for specific product categories needs to be checked (no PCR or CFP-PCR is followed in the tool).
- The impacts of distributing the "packaging + product system" are fully included in the packaging assessment (and not only the part of the impacts of the distribution transport attributed to the packaging, cf. 2.4.1). The limits of this approach are:
    - It affects the relative contributions (in percentage) of each life cycle step within the total life cycle of a packaging system.
    - It increases the total impacts of each packaging system and, hence, tends to reduce the relative differences between compared systems. Therefore, in case of packaging comparison made with the tool, it is recommended to explicitly discuss this point at the interpretation stage.
    - Attention has to be paid to the system boundaries in case of external comparison or benchmarking since results provided in literature might not include the impacts of the product transport.
- As explained in section 2.4.2, some life cycle steps are kept out of scope of the tool. Considering the goal and scope of the study, it should be checked whether the excluded steps should be taken into account separately, in addition to the tool results, if relevant in terms of conclusions. If relevant, completing the tool modelling should be carried out with the help of LCA practitioners. Table 37 details the limits in function of the goal of the study (the goals are described in section 2.2) and provides recommendations.

Table 37: Limits due to excluded steps in function of the goal of the study

Goal of the study	Limits of modelling	Recommendations
Studies supporting decision of the tool user		
Eco-design approach: designing the packaging system while considering the environmental impacts of the packaging or product along its whole life cycle	Only material types included in the LCA model can be studied. Excluded life cycle steps have little influence on the conclusions except in very specific cases, where the eco-design affects:	If the tool user notices that his study is concerned by one the listed situations, additional modelling by an LCA practitioner should be carried out for including steps kept out scope.

Goal of the study	Limits of modelling	Recommendations
	▪ loss of product at filling or at the use phase ▪ the use of cup or not at the use phase ▪ storage at retailer ▪ consumer transport (and if these steps have a significant contribution to the impacts)	
Process improvement	Excluded life cycle steps have little influence on the conclusions except in very specific cases, where the process improvement affects: • Storage conditions • Loss of products at conditioning (and if these steps have a significant contribution to the impacts)	If the tool user notices that his study is concerned by one the listed situations, additional modelling by an LCA practitioner should be carried out for including relevant steps kept out scope.
Management - improvement strategy	Excluded steps do not affect the improvements that can be achieved. However, it can influence the targeted relative reduction of impacts (e.g. -10% of the total life cycle impact, as it affects the total life cycle impacts).	If total life cycle impacts are taken as reference, the steps excluded from the calculation of these results should be mentioned together with the targeted reduction objectives.
Accounting/monitoring types of studies		
Claim or declaration (at the scale of one product or product group)	The exclusion of life cycle steps from the assessment can constitute a limit for the results in cases where absolute values associated with the whole life cycle are the core of the assessment.	Besides adding results associated with the production of the product, additional modelling of the relevant excluded steps should be achieved by an LCA/CF expert. When the total life cycle impacts are not the objective of the claim, it is sufficient to mention the excluded steps in the

Goal of the study	Limits of modelling	Recommendations
		internal or external communication.
Comparison between systems	Excluded life cycle steps have little influence on the conclusions except in very specific cases, where the eco-design affects: - loss of product at filling or at the use phase - the use of cup or not at the use phase - storage at retailer - consumer transport (and if these steps have a significant contribution to the impacts)	If the tool user notices that his study is concerned by one the listed situations, additional modelling by an LCA practitioner should be carried out for including steps kept out scope.
Performance tracking	Excluded steps have little or no influence on the evolution of results with time (but it can influence the calculated relative reduction of impacts, as it affects the total life cycle impacts).	In many cases of internal or external communication, indication of the excluded steps is sufficient.

When additional modelling is required for steps kept out of scope, existing Product Category rules, namely PEFCR if existing, can be used as guidance.

Among additional limits of modelling are:

- Losses of packaging related to product losses occurring during transport, storage, retailing and use phase cannot be modelled in the tool. Hence, it is not possible to distinguish between results obtained for functional units where quantities are defined either as effectively used by the consumer or as produced and delivered at the producer gate.
- Losses defined at the filling step are the same for all the elements of packaging of the studied system
- The modelling of end-of-life of material lost at manufacturing or filling are the same as the end-of-life treatments modelled for the packaging after use. It is a rather conservative approach since a more efficient collection of this pre-consumer waste can be expected as well as generally higher recycling rates.

7.2 Limits related to data

Main activity data is accessible in the tool interface so that a very good level of representativeness can be reached for all criteria (mainly primary data).

This section aims at discussing limits associated with data that cannot be adapted by the tool user. Such data comprises LCI datasets and non-editable activity data.

Conclusions of the data quality assessment need to specific to each system studied and to goal and scope of the studies. However, some global comments can be provided here.

In terms of time representativeness, recent data is used for main life cycle steps (namely material production). For steps where older data is used, it is considered sufficiently representative of the current technologies.

Concerning the technological representativeness, LCIs used for material production are selected for representing material as usually used in packaging systems. However, datasets could not be representative of specific packaging systems.

The geographical representativeness depends however on the country. The same LCIs are used for all countries and most represent the European situation. They are however considered fairly representative of other countries since no major reason for regional differentiation has been identified so far (except for aluminium production, which is an electricity intensive process). For non-editable activity data, the fixed values are taken from European or French sources. Applying this data outside Europe increases the uncertainty of the results.

The use of the tool in non-European countries can be discussed as follows. Robustness of the study conclusions is the highest for studies where changes in primary data are assessed while using the same secondary data (e.g. packaging lightweighting). For studies where changes are studied (process improvement, strategy definition, performance tracking), conclusions are in most cases not or little affected by potential geographical differentiation. Uncertainty increases in studies where either the total life cycle impacts are the target (claim/declaration) or packaging systems with different materials are compared (eco-design with different materials or comparison of systems). When uncertainties increase, a higher difference between compared results is necessary for allowing drawing conclusions. In the last situations, it can also be recommended to ask for expert judgment to analyse whether a local specificity is identified that could affect the conclusions drawn with the help of the tool.

Finaly, as pointed in section 5.5.5, LCIs for material production come from different sources, using different background LCI databases (mainly Gabi and ecoinvent). This can induce a potential bias, which must be discussed in case of direct comparisons between materials.

7.3 Limits of LCIA methods

The impact assessment phase of the LCA is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. The LCIA results are relative expressions and do not predict impacts on category endpoints, exceeding of thresholds, safety margins or risks.

When comparing results obtained for the studied products for the various impact categories, the user should bear in mind that various levels of uncertainties are associated with the different categories.

This is reflected in the classification of robustness level made by PEF (cf. Table 8). [15] In case of comparison between systems, the orders of magnitude of differences between results necessary to conclude about the comparison depend on the robustness of the methods.

The robustness of impact assessment methods varies according to the indicator studied. Some indicators still have major limitations:

- Toxicity and ecotoxicity models are not very robust, as they are incomplete (not all pollutants are assessed by the characterization method or covered by life-cycle inventories).
- The characterization models for the impact categories on fossil and mineral resources reflect use rather than depletion.
    - The use category for fossil resources is based on the net calorific value (NCV) of the resources (there is no availability factor involved in the method).
    - The mineral resource use category is based on the ultimate availability of the resource, even though some resources may be very difficult to extract (concentration too low, very poor accessibility).
- Impact categories with a local impact at stake require more detailed modelling than is possible with databases. The following two examples illustrate these limitations:
    - The response of an environment to an ecotoxic substance is directly linked to the initial quality of that environment (particularities in terms of fauna and flora, existing pollution, etc).
    - Pressure on water resources is assessed at watershed level. The factors used in this study represent a European average. They therefore take no account of seasonal or geographical variations in water resource availability. The results obtained for this category of impacts would therefore show different trends for specific or extreme cases of water resource unavailability (scarcity, geographical areas prone to periods of drought, etc.). The reader is therefore invited to exercise caution in interpreting the raw results presented for this impact category.

Furthermore, even if using the list of LCIA methods listed in Table 8, LCAs do not represent a complete picture of the environmental impact of a system. As categories such as biodiversity, renewable resource use and risk of littering are left out, qualitative elements should be taken into account for these categories, when relevant. Any judgments that are based on the interpretation of LCI data must bear in mind this limitation and, if necessary, obtain additional environmental information from other sources (hygienic aspects, risk assessment, etc.).

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[15] According to a ranking of Humbert et al. (Humbert S, Margni M, Jolliet O. IMPACT2002+: User Guide, October 2005), human toxicity as well as ecotoxicity show high uncertainties, as high as 2 or even 3 orders of magnitude. The categories related to ozone layer depletion and mineral resources are of a medium type of uncertainties. Global warming, non-renewable energy, acidification and aquatic eutrophication are characterized by lower degrees of uncertainty.

Another study has assessed uncertainties of LCIA methods at the end-point level: "A spatially differentiated life cycle impact assessment approach, LC-Impact Version 0.5 " https://lc-impact.eu/doc/LC-Impact_report_SEPT2016_20160927.pdf (Accessed 16/02/2021)

7.4 Limits of the tool

No sensitivity / uncertainty analysis is automatically implemented. However, sensitivity analyses can be performed by duplicating cases and changing parameter values in the interface. Most activity data values can be edited in the interface, allowing to cover most relevant cases of sensitivity analyses. The non-editable parameters concern mainly detailed end-of-life modelling and background modelling for truck transport.

8 Recommendations for communication

8.1 Introduction

The rules for communication and the need for critical review described in ISO Standards are very succinctly presented here:

- ISO 14040 & 14044: In case of result communication to a third party, regardless of the form of communication, a third-party report has to be made available (called here project report). Critical review can help to understand LCAs and reinforce their reliability. It can be performed by an internal or an external expert (as long as the expert is not involved in the study); For comparative assertion disclosed to the public, critical review is mandatory and shall be performed by a panel of at least three experts including interested parties. The specifications of paragraph 5.3.1 of ISO 14044 (“For LCA studies supporting comparative assertions intended to be disclosed to the public”) have hence to be verified by such a panel prior to communicating in the sense of comparison.
- ISO 14021 (Self-declared environmental claims): this standard specifies requirements for self-declared environmental claims, including statements, symbols and graphics, regarding products. It further describes selected terms commonly used in environmental claims and gives qualifications for their use. This International Standard also describes a general evaluation and verification methodology for self-declared environmental claims and specific evaluation and verification methods for the selected claims in this International Standard. In summary, the claim has to be verifiable, but no external verification procedure must be carried out prior to the claim.
- ISO 14025: this standard defines how Type III environmental declarations, using predetermined parameters, must be established. In particular, the standard specifies the role of the Program Operator and the way the Product category Rules (PCRs) are developed. Independent verification is mandatory. It can be internal verification, except in case of business-to-consumer declaration, which must be submitted to external verification.

Type III environmental declarations and other environmental labelling schemes are not further discussed here since the tool does not apply any PCR or PEFCR.

8.2 Internal use of the results

In case of internal use of results provided by the tool, no specific standard has to be met. However, it is recommended to:

- Perform a (possibly internal) critical review (especially if no LCA practitioner has been involved in the study made with the tool)
- Be aware that, if the tool user selects a short list of impact categories, the associated results do not represent all relevant potential environmental impacts
- Comply with the requirements stated in ISO 14021 standard related to “Self-declared environmental claims”

Further recommendations related to current modelling limits should be considered in function of the goal of the study.

8.3 External communication

Several types of communication to the public can be distinguished:

- Communication according to ISO 14040 and 14044
- Self-declared environmental claims
- Environmental declaration of type III (not discussed here)

8.3.1 Communication according to ISO 14040 and 14044

ISO 14040 and 14044 standards specify the requirements for publishing LCA results under the form of a project report.

Main requirements of the ISO standards are:

- Any disclosure to the public has to be supported by a third-party report, the content of which is described in chapter 5 of ISO 14044;
- The system boundaries (steps included and steps excluded) have to be justified according to the goal of the study; in case steps excluded appear relevant according to the study goal, separate modelling of these steps is to be integrated in the results published. For example, if the study aims at calculating the environmental impacts associated with a product, steps like on-site infrastructures and storage in producer and retail warehouses have to be assessed and included if material;
- The selection of impact categories has to be discussed and justified according to the goal of the study. This requirement aims at avoiding decisions resulting in damage transfer from one category to another; the larger list of reviewed categories is given in Table 9 of the methodological report; Consistency of the impact categories selected in the Packaging producer tool with the goal of the study has to be verified;
- The value-choices used in relation to impact categories, characterization models and characterization factors shall be described and their consistency and influence on the results discussed (with the help of sensitivity analysis);
- A critical review may be carried out by an independent expert, internal or external. Although not mandatory, such critical review is strongly encouraged when using a tool, especially if no LCA practitioner has been involved in the study made with the tool.

In the current status of critical review, it is not recommended to communicate externally about comparison between packaging systems. Indeed, the disclosure to the public of comparative assertion will only be compliant with ISO 14040 and 14044 if the tool and data are subjected to an additional peer review carried out by a panel of interested parties and dealing with the specifications of paragraph 5.3.1 of ISO 14044.

8.3.2 Self-declared environmental claims

The claims are the less constrained mode of communication. The associated requirements are described in the standard ISO 14021 “Self-declared environmental claims”.

The credibility of claims can be reinforced through various elements. In the case of the Packaging tool, these are namely:

- The critical review of the tool (already performed)
- The additional critical review, specific to the study of which the results are to be communicated. This independent verification can be internal or external, according to the choice of the company in terms of communication strength.

8.4 Communicating on improvements

Internal or external communication of improvements calculated by performance tracking or by simulation of future actions needs to follow some guidelines:

- Compared results must correspond to the same function (same functional unit), e.g. results per litre of product or results for the volume of production corresponding to the end-year of the period assessed.
- Results for the whole life cycle shall be presented for the reference year and the target year. In complement, improvements can be expressed in terms of percentage of reduction or of avoided emissions.
- The parameters and data that are considered variable over the assessed period shall be clearly listed.
- Depending on the data and parameters made variable along the period, the improvements can be attributed to various partners of the value chain. At least, a distinction should be made between internal improvements, under the control of the reporting company, and external improvements. If such distinction is difficult the improvements shall be attributed to the whole value chain.

Further guidance can be found for example in the publication of ICCA and WBCSD “Addressing the Avoided Emissions Challenge - Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies”, October 2013.

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Annex 1. List of possible countries

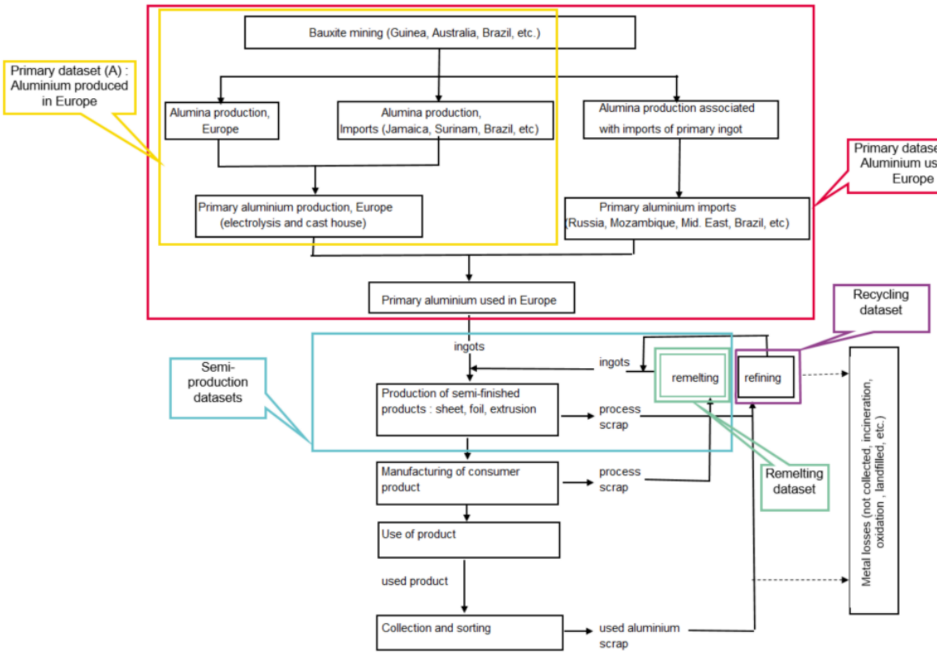
Countries in italics correspond to countries for which there is no “market for electricity, low voltage” dataset in ecoinvent 3.10.

Afghanistan	*East Timor*	Luxembourg	*San Marino*
Albania	Ecuador	Macedonia	*São Tomé and Principe*
Algeria	Egypt	*Madagascar*	Saudi Arabia
Andorra	El Salvador	*Malawi*	Senegal
Angola	*Equatorial Guinea*	Malaysia	Serbia
Antigua and Barbuda	Eritrea	*Maldives*	*Seychelles*
Argentina	Estonia	*Mali*	*Sierra Leone*
Armenia	Ethiopia	Malta	Singapore
Australia	*Federated States of Micronesia*	*Marshall Islands*	Slovakia
Austria	*Fiji*	*Martinique*	Slovenia
Azerbaijan	Finland	*Mauritania*	*Solomon Islands*
Bahamas	France	Mauritius	*Somalia*
Bahrain	Gabon	Mexico	South Africa
Bangladesh	*Gambia*	Moldova	South Korea
Barbados	Georgia	*Monaco*	South Sudan
Belarus	Germany	Mongolia	Spain
Belgium	Ghana	Montenegro	Sri Lanka
Belize	Greece	Morocco	Sudan
Benin	*Grenada*	Mozambique	*Suriname*
Bhutan	Guatemala	Namibia	*Swaziland*
Bolivia	*Guinea*	*Nauru*	Sweden
Bosnia and Herzegovina	*Guinea-Bissau*	Nepal	Switzerland
Botswana	*Guyana*	Netherlands	Syria
Brazil	Haiti	New Zealand	Taiwan
Brunei	Honduras	Nicaragua	Tajikistan
Bulgaria	Hungary	Niger	Tanzania
Burkina Faso	Iceland	Nigeria	Thailand
Burma	India	North Korea	Togo
Burundi	Indonesia	Norway	*Tonga*
Cambodia	Iran	Oman	Trinidad and Tobago
Cameroon	Iraq	Pakistan	Tunisia
Canada	Ireland	*Palau*	Turkey
Cape Verde	Israel	Panama	Turkmenistan
Central African Republic	Italy	*Papua New Guinea*	*Tuvalu*
Chad	Jamaica	Paraguay	*Uganda*
Chile	Japan	Peru	Ukraine
China	Jordan	Philippines	United Arab Emirates
Colombia	Kazakhstan	Poland	United Kingdom
Comoros	Kenya	Portugal	Uruguay
Costa Rica	*Kiribati*	*Puerto Rico*	USA (deposit states)
Côte d'Ivoire	Kuwait	Qatar	USA (non-deposit states)
Croatia	Kyrgyzstan	Republic of the Congo	Uzbekistan
Cuba	*Laos*	*Reunion*	*Vanuatu*
Cyprus	Latvia	Romania	*Vatican City*
Czech Republic	Lebanon	Russia	Venezuela
Democratic Republic of the Congo	*Lesotho*	*Rwanda*	Vietnam
Denmark	*Liberia*	*Saint Kitts and Nevis*	Yemen
Djibouti	Libya	*Saint Lucia*	Zambia
Dominica	*Liechtenstein*	*Saint Vincent and the Grenadines*	Zimbabwe
Dominican Republic	Lithuania	*Samoa*	

Annex 2: Documentation on non-ecoinvent datasets

For allowing the assessment of the technological representativeness of LCIs used for material production, in function of the goal and scope of studies made with the tool, Table 38 provides summarized documentation on non-ecoinvent datasets.

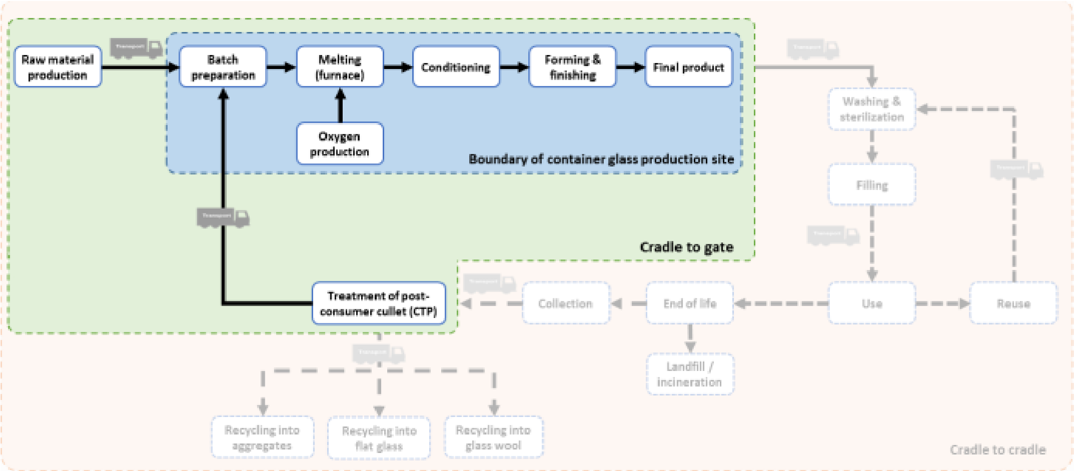
Table 38: Documentation on non-ecoinvent datasets

Name of dataset	**Documentation**
EAA (European Aluminium Association)	
Associated methodological report (2024): https://mailchi.mp/european-aluminium/epr2024	
The system boundaries for EAA datasets are:  Infrastructure is considered not to be included in the system boundaries.	
EU-27: Aluminium ingot mix EAA update 2021 (consumption mix)	The "used in Europe" primary LCI dataset (B) includes primary ingot produced by the European smelters and considers as well as the primary aluminium which is imported into Europe, and which represents 48% of the European consumption in 2021. Global data from the International Aluminium institute have been used for modelling the primary aluminium produced outside Europe and a specific electricity model for the electrolysis process has been developed.
EU-27: Aluminium sheet EAA update 2021	The LCI dataset "sheet", a 'semi-production' process corresponds to the transformation of a sawn aluminium ingot into a semi-product, sheet. This 'semi-production' dataset includes the recycling of the scrap and chips generated during this semi-fabrication stage as well as the recycling of the dross. The dataset corresponds to the production of 1 tonne of sheet.

Aluminium recycling update 2021		The ‘refining’ process LCI dataset correspond to the transformation of the aluminium (pre- or post-consumer) scrap into a casting alloy ingot ready for delivery to the user. This dataset includes the melting, purifying and casting operations. It also includes the salt slag processing. These ‘recycling’ datasets are based on the recycling of the European scrap mix.
Worldsteel		
Associated methodological report (2017): https://worldsteel.org/wp-content/uploads/Life-cycle-inventory-methodology-report.pdf		
Steel tinplated steel		Cradle-to-gate dataset. Production mix, at plant. Blast furnace route and electric arc furnace route. 1kg, typical thickness between 0.13 - 0.49 mm. typical width between 600 - 1100 mm High data quality. Data collected on site by steel industry experts in accordance with the Worldsteel methodology and ISO 14040 standards, and consistency-checked by Worldsteel LCA-experts. Global coke, sinter, pellet, dri, hot metal, slab production based on Worldsteel site specific data. Metallurgical coal data based on global IEA statistics and information from the GaBi database. Other upstream data based on the GaBi database, including country specific electricity and regional energy upstreams. Impacts from scrap processing prior to delivery to site included. The LCI does not include any further processing beyond the steelworks gate such as bending, shaping, cutting, welding etc. This dataset includes raw material extraction (e.g. coal, iron, ore, etc.) and processing, e.g. scrap, coke making, sinter, blast furnace, basic oxygen furnace, electric arc furnace, hot strip mill and further processing. Details on the steel product manufacturing route can be found in Appendix 1 of the 2017 Worldsteel LCA Methodology Report. The steelmaking processes are shown in the flow diagram. Inputs included in the Life Cycle Inventory relate to all raw material inputs, including steel scrap, energy, water, and transport. Outputs include steel and other co-products, emissions to air, water and land. Further information is given in the 2017 Worldsteel LCA Methodology Report. External scrap input includes approx. 2% scrap from manufacturing/fabrication processing. This LCI does not include a credit for recycling of steel at end of life and a burden for steel scrap input during production. This is the preferred approach adopted by Worldsteel, detailed in the 2017 methodology report (Appendix 2). The recovery and use of steel industry co-products outside of the steelworks are taken into account, using the method of system expansion.
Steel scrap (external supply)		Extract of report (A2.6.2): “The Worldsteel methodology assumes the burdens of scrap input and the credits for recycling the steel at the end of the life of a product are equal, per kg, and that all scrap is treated equally. In reality there are numerous grades of steel products and steel scrap but it is not feasible to calculate an LCI for each grade. Collecting scrap at the end of the product’s life and recycling it through the steelmaking process enables the saving of primary, virgin steel production. This is commonly referred to as the integrated or BOF steelmaking route, but in reality, some steel scrap is always required in the process. Thus, there is no

		process using 100% virgin material (with 0% scrap input) and this theoretical value therefore needs to be calculated. Furthermore, it is not the scrap itself that replaces this primary steel, as the scrap needs to be processed or recycled to make new steel. The EAF process is an example of 100% scrap recycling, though some EAFs also use hot metal or DRI (direct reduced iron) as an input to the process. And finally, the EAF process is not 100% efficient, i.e. it needs more than 1 kg of scrap to make 1 kg steel. The LCI associated with the scrap is thus equal to the credit associated with the avoided primary production of steel (assuming 0% scrap input), minus the burden associated with the recycling of steel scrap to make new steel, multiplied by the yield of this process to consider losses in the process: ScrapLCI = (Xpr - Xre)Y Xpr = the theoretical LCI for 100% primary metal production, from the BOF route, assuming 0% scrap input. Xre = the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.”
APEAL		
Steel tinplate without EoL recycling - 1 kg (typical thickness between 0.13 - 0.49 mm) at plant		European, production mix, at plant. blast furnace route 1kg, typical thickness between 0.13 - 0.49 mm. typical width between 600 - 1100 mm. High data quality. Data collected on site by steel industry experts in accordance with the Worldsteel methodology and ISO 14040 standards, and consistency-checked by PE LCA-experts. #Coke, sinter, pellet, hot metal, slab production based on site specific data. #Metallurgical coal data based on global IEA statistics and information from the GaBi database. #Iron ore data obtained from iron ore producer. #Other upstream data based on the GaBi database, including country specific electricity. The LCI does not include any further processing beyond the steelworks gate such as bending, shaping, cutting, welding etc. RDC made corrections to this dataset in order to adapt the water consumption unit (from litre to cubic meter). This dataset includes raw material extraction (e.g. coal, iron, ore, etc.) and processing, e.g. coke making, sinter, blast furnace, basic oxygen furnace, hot strip mill. Details on the steel product manufacturing route can be found in Appendices 2 and 3 of the 2011 Worldsteel LCA Methodology Report. The steelmaking processes are shown in the flow diagram. #Inputs included in the Life Cycle Inventory relate to all raw material inputs, including steel scrap, energy, water, and transport. Outputs include steel and other co-products, emissions to air, water and land. #Further information is given in the 2011 Worldsteel LCA Methodology Report. #This LCI does not include a credit for recycling of steel at end of life and a burden for steel scrap input during production. This is the preferred approach adopted by Worldsteel, detailed in the 2011 methodology report (Appendix 10).
Recycling Steel		This activity represents the production of secondary steel in an electric arc furnace.
PlasticsEurope		
https://plasticseurope.org/sustainability/circularity/life-cycle-thinking/eco-profiles-set/		

POM		Polyoxymethylene (POM), a semi-crystalline thermoplastic, belongs to the polyacetals family of polymers. POM exists in two different forms: homopolymer (POM-h) and copolymer (POM-c). POM has mechanical properties which are suitable for high performance applications, such as injection moulded parts for household appliances. This EPD is for both POM-h and POM-c, as the difference in terms of LCA is small. POM is produced through the polymerisation of formaldehyde (for POM-h) or of trioxane with a smaller quantity of co-monomer (for POM-c). Formaldehyde is produced through the oxidation of methanol. The reference flow, to which all data given in this EPD refer, is 1 kg of POM in pellet form. Coproducts of uranium U (U, depleted, in UO2)/EU-27 and methylal/EU-27 were deleted because they received 0% allocation. Before using the data of this process, you should ensure that you have read the description of the methodology used. See the system model. Infrastructure process: No Subsystems The data describing the overall effect of any extended industrial system is derived from a number of different operators, each of whom take the output from an upstream operation, processing it and passing it on to the next operation downstream. As a result, large systems must be sub-divided into a set of sub-systems such that each sub-system encompasses the activities of a single operator. Cut-off rules The LCI data collection for Eco-profiles aim for completeness - a closed mass and energy balance - and avoid cut-offs altogether. Where quantitative data are available, they are included. However, no undue effort is spent on developing data of negligible significance concerning environmental effects. Where elementary flows are unknown or no quantitative data are available, the following minimum criteria guide Eco-profile data collection: - Include all material inputs that have a cumulative total of at least 98% of the total mass inputs to the unit process; - Include all material inputs that have a cumulative total of at least 98% of total energy inputs to the unit process; and - Include any material, no matter how small its mass or energy contribution, that has significant effects in its extraction, manufacture, use or disposal, is highly toxic, or is classified as hazardous waste (environmental significance significance). Cut-offs may become necessary in cases where no data are available, where elementary flows are very small (below quantification limit), or where the level of effort required to close data gaps and to achieve an acceptable result becomes prohibitive. Flows that are cut off, estimated, or substituted shall be recorded in qualitative and quantitative terms, and the omission shall be examined and justified, if applicable, by a sensitivity analysis considering - Mass: percentage of total input or output mass flows, respectively; - Energy: percentage of total input or output energy flows, respectively; - Cost: percentage of market value; - Environmental significance: percentage contribution significance to relevant impact indicators. Allocation rules Production processes in chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable product and co-product outputs. Wherever possible, allocation is avoided by expanding the system to include the additional functions related to the co-products. To this aim, a generic process with the same function (product) can be introduced, and the examined system receives credits for the associated burdens avoided elsewhere (avoidance allocation, avoided burden). System expansion is only used where there is a dominant, identifiable displaced product, and if there is a dominant, identifiable production path for the displaced product. Often, however, avoiding allocation is not feasible. In such cases, the aim of allocation is to find a suitable partitioning parameter so that the inputs and outputs of the system can be assigned to the specific product subsystem under consideration Since production systems are controlled by different

<table>
<tr><td></td><td></td><td>strategies and allocation is always a value judgment, PlasticsEurope's stipulates the following allocation philosophy: from the following allocation methods the practitioner shall select the one most appropriate to the goal of the production system and transparently record the justification of this choice; the chosen allocation method shall also be noted in the meta-data. The chosen allocation method and its rationale is recorded in the Eco-profile report.
Energy model The energy supply is modelled on a site-specific basis. If direct energy supply is derived from one source, then this should be used, and where energy is taken from a national or regional grid, then this is modelled specifically for the specified geographic region. Generic data for energy is obtained from the database of the International Energy Agency. When accounting for renewable energy or carbon offsets, appropriate quality standards are taken into consideration. In any case, credits are reported as distinct line items, and off-set emissions must not be included in the LCI dataset. Mechanisms for compensating for the environmental impacts of products (e.g. prevention of the release of, reduction in, or removal of greenhouse gas emissions) are outside the boundary of the product system (see draft standard ISO 14067, clause 3.9.4). It is generally not recommended to include renewable energy certificates (RECs) or carbon offsets at all, but where they are (as per decision of the EPT), this is transparently recorded and the flows shall are kept separate. If it is an elementary flow, it is reported as a distinct flow; if it is an intermediate flow, it is non-terminated.
Transport model Transport depends on the relative locations of suppliers to a plant. The transport distances and models are based on the actual transport that is taking place.
Waste model Waste management operations are within the system boundaries.</td></tr>
<tr><td colspan="3">FEVE</td></tr>
<tr><td colspan="3">Link to 2017 publication: https://feve.org/glass-industry-positions/life-cycle-assessment/</td></tr>
<tr><td colspan="3">The system boundaries for FEVE datasets are:
 </td></tr>
<tr><td>Container glass, virgin</td><td></td><td>Virgin container glass (all sizes) to be used for glass bottles and food jars. 1 kg of formed and finished container glass
Production mix. Technology mix. EU-28 + EFTA
* This dataset represents the Life Cycle Inventory (LCI) of the cradle-to-gate production of 1 kg of container glass from primary materials, including (but</td></tr>
</table>

		not limited to) raw material extraction, transport, glass bottle production, ancillary products, internal recycling activities and process waste treatment. ⍰ This dataset is based on the critical reviewed LCA study ("Life Cycle Assessment of Container Glass in Europe") carried out by RDC Environment, commissioned by the European Container Glass Federation (FEVE) and completed in December 2016. In order to deliver the current LCI, the original LCA model of FEVE study was updated by modifying: the background database from Ecoinvent 2.2 to Ecoinvent 3.3; the energy and transport processes to be EF-compliant as available in the LCDN node; by applying the PEF End-of-life formula (“50:50”). * This dataset represents a theoretical container glass made of 100% virgin raw materials and 0% recycled content (R1) or cullet content; the model is extrapolated from real data of the container glass industry by calculating the melting energy at the furnace as function of the external cullet content in the batch. * Average distances from glass manufacturing site to fillers are: - Road transport: 0.35 t*km by articulated lorry 28-32 tons EURO 4 norm - Rail transport: 3.32304E-5 t*km by freight train electric traction - Rail transport: 5.4096E-6 t*km by freight train diesel traction - Boat transport: 8.700937E-2 t*km by transoceanic container ship All common types of furnace technology and colours of container glass (amber, green, flint and other colour) are covered. Site-specific data for FEVE LCA study were collected among 219 furnaces and 7 cullet treatment plants, covering 84% of the European sold volume for the year 2012 and equivalent to 17.5 million tons of sold container glass. The glass type (amber, green, flint, virgin, unspecified) will depend on the cullet composition and raw material composition. All common types of furnace technology and colours of container glass (amber, green, flint and other colour) are covered. Site-specific data for FEVE LCA study were collected among 219 furnaces and 7 cullet treatment plants, covering 84% of the European sold volume for the year 2012 and equivalent to 17.5 million tons of sold container glass. The glass type (amber, green, flint, virgin, unspecified) will depend on the cullet composition and raw material composition.
Container glass, ER, Recycled Content 100%		Recycled container glass (all sizes) to be used for glass bottles and food jars. 1 kg of formed and finished container glass Production mix. Technology mix. EU-28 + EFTA * This dataset represents the Life Cycle Inventory (LCI) of the cradle-to-gate production of 1 kg of container glass from secondary materials, including (but not limited to) transport, glass bottle production, ancillary products, internal recycling activities and process waste treatment. This is the aggregated form. * This dataset is based on the critical reviewed LCA study ("Life Cycle Assessment of Container Glass in Europe") carried out by RDC Environment, commissioned by the European Container Glass Federation (FEVE) and completed in December 2016. In order to deliver the current LCI, the original LCA model of FEVE study was updated by modifying: the background database from Ecoinvent 2.2 to Ecoinvent 3.3; the energy and transport processes to be EF-compliant as available in the LCDN node. * This dataset represents a theoretical container glass made of 0% virgin raw materials and 100% recycled content (R1) or cullet content; the model is extrapolated from real data of the container glass industry by calculating the melting energy at the furnace as function of the external cullet content in the batch. * Excluded stages: collect and transport to the CTP (cullet treatment plant).

		All common types of furnace technology and colours of container glass (amber, green, flint and other colour) are covered. Site-specific data for FEVE LCA study were collected among 219 furnaces and 7 cullet treatment plants, covering 84% of the European sold volume for the year 2012 and equivalent to 17.5 million tons of sold container glass.

Annex 3: Modelling of Ev and Er with Worldsteel LCIs

The scrap content of the published LCI is not communicated. In the previous LCI for tinplate (published in 2013 by Worldsteel), an input of 5% of scrap was considered and is assumed equal for the LCI published in 2018. This LCI does not correspond to an effective 100% virgin LCI.

In order to keep the same modelling as for the other materials and the flexibility in terms of allocation method for recycling benefits, the impacts of the 100% primary production (equivalent to “E_v”) and the recycling step (equivalent to “E_r”) have to be modelled.

Worldsteel does not provide an LCI for steel made from 100% scrap, but rather an LCI called “value of steel scrap”, which represents the impacts of an average virgin production minus the impacts of scrap recycling:

$$\text{LCI value of scrap} = Y(Xpr - Xre)$$

Where: Y is the process yield of the electric arc furnace (more than 1kg scrap is required to produce 1kg steel).

Xpr is the LCI for 100% primary metal production. This is a theoretical value for steel slab made in the BOF route, assuming 0% scrap input.

Xre is the LCI for 100% secondary metal production from scrap in the EAF (assuming 100% scrap input).

In the Packaging model, the 100% virgin production of tinplate (Xpr = E_v) is modelled using the following equation:

$$Xpr = \text{LCI tinplate} + 0.05/Y * \text{LCI value of scrap}$$

For modelling the 100% secondary metal production (Xre = E_r), the following equation is applied:

$$Xre = -0.95/Y * \text{LCI value of scrap} + \text{LCI tinplate}$$

The process yield (Y) is taken equal to 98%.

Annex 4: Depolymerization technologies

Instead of merely physically transforming the shape and macroscopic properties of the plastic (mechanical recycling), chemical changes are made through breaking bonds. Often the goal is to depolymerize the polymers into monomers. These can be used to synthesize new polymers, but other chemical building blocks can result as well. Feedstock recycling is used to describe the recycling back to feedstocks used to make new polymers that is either monomers directly or a crude oil resembling product that can be fed to steam-crackers to produce monomers[16].

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[16] Beyond mechanical recycling: giving new life to plastics waste, Vollmer I. et al, 2020

The Petcore tool will only focus on depolymerization technologies, these are recycling technologies where the bonds of the polymers are broken to form monomers or oligomers.

1. Methanolysis

Methanolysis is based on the treatment of PET with methanol at relatively high temperatures (180-280°C) and pressures (20-40 atm), which leads to the formation of dimethyl terephthalate (DMT) and ethylene glycol (EG) as the main products. The products of the methanolysis are usually separated and purified by distillation or crystallization. Purified DMT can be reintroduced into the PET polymerization process with properties similar to those of virgin DMT[17].

2. Glycolysis

The method involves the reaction of PET, under pressure and at temperatures in the range 180-240°C, with an excess of glycol, usually ethylene glycol, which promotes the formation of BHET. This monomer has to be purified, normally by melt filtration under pressure, prior to its use in the production of new PET polymer. Colours present in the starting PET wastes are not usually or at least hardly removed by glycolysis method. The depolymerization is carried out in the presence of a transesterification catalyst, usually zinc or lithium acetate[18].

3. Hydrolysis

Enzymes are complex protein structures which specifically recognize and process molecules, thereby speeding up chemical reactions. One typical enzyme-driven chemical reaction is hydrolysis. Here, a substrate is cleaved by a reaction with water[18]. The discovery of several PET hydrolases, along with further modification of the enzymes, has considerably aided efforts to improve their ability to degrade the ester bond of PET. Enzymatic hydrolysis of PET results in a mixture of terephthalic acid (TPA) and ethylene glycol (EG).

A major problem in enzymatic degradation of PET is its semicrystalline nature. PET consists of both amorphous and crystalline regions where only the amorphous parts are efficiently processed by poly-esterases. Amorphous PET is used in food trays and packaging, while higher crystallinity is found in PET bottles. Therefore, not all PET waste can presently be used for enzymatic hydrolysis. However, it is possible to convert crystalline PET into amorphous PET, reaching the goal by a detour. The polymer chains of PET are stiff at room temperature, which is disadvantageous for enzymatic processing. The chains increase their flexibility at temperatures around 70 °C and can be more easily accessed by the enzymes. As a consequence, thermostable polyesterases are the most efficient enzymes for degrading PET[18].

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[17] https://www.sciencedirect.com/science/article/abs/pii/B9780444643377000124

[18] https://www.enzycle.eu/enzymes-pet/

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