FLEXIBLE
PACKAGING EUROPE

Guidance
for life cycle assessment of flexible packaging

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Disclaimer

This document, published by the association Flexible Packaging Europe, is prepared by Quantis in collaboration with six European flexible packaging converting companies and the association. It is the result of the combined efforts by Quantis staff and experts from participating organisations. Stakeholders within the flexible packaging sector have reviewed drafts, ensuring that the guidance broadly represents the consensus of the majority of the project members involved. However, it does not imply that every member agrees with every word.

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Acronyms and abbreviations

ASI	Aluminum Stewardship Initiative
AWARE	Available WAter REmaining
BOM	bill of materials
CFF	Circular Footprint Formula
CO_2	carbon dioxide
CTUe	comparative toxic units for ecosystems
CTUh	comparative toxic units for human health
DQR	Data Quality Rating
EEA	ethylene-ethyl acrylate
EF	Environmental Footprint
ERA	European Rotogravure Association
EMA	ethylene methyl acrylate (EMA)
EVA	ethylene vinyl acetate
EOL	end-of-life
FU	functional unit
g	gram
GHGs	greenhouse gases
HDPE	high-density polyethylene
IPA	Isopropyl acetate
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
JRC	Joint Research Centre
kBq U^{235} eq	kilobecquerel uranium-235 equivalent
kg	kilogram
kg CFC-11 eq	kilogram of trichlorofluoromethane or freon-11 equivalent
kg CO_2-eq	kilogram of carbon dioxide equivalent
kg N eq	kilogram of nitrogen equivalent
kg NMVOC eq	kilogram of non-methane volatile organic compounds equivalent
kg P eq	kilogram of phosphorus equivalent
kg Sb eq	kilogram of antimony equivalent
km	kilometer
kWh	kilowatt-hour
LCA	Life Cycle Assessment

LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Assessment
LCS	Life Cycle Stage
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
LHVs	lower heating values
LUC	land use change
m^3	cubic metre
MDI	methylene diphenyl diisocyanate
MEK	methyl ethyl ketone
MJ	Megajoule
mol H^+	mole of hydrogen ion
mol N eq	mole of nitrogen equivalent
MW	molecular weight
ODP	ozone depletion potential
PE	polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PET	polyethylene terephthalate
PLA	polylactic acid
PM	particulate matter
PP	polypropylene
PPWR	Packaging and Packaging Waste Regulation
Pt	point for dimensionless values
PVC	polyvinyl chloride
PVDC	polyvinylidene chloride
FPE	Flexible Packaging Europe
t	tonne
tkm	tonne kilometer
VOC	volatile organic compounds

Definitions

This glossary defines key terms used in this document. The majority of these definitions are based on the report: “Suggestions for updating the Product Environmental Footprint (PEF) method” (Zampori et al., 2019).

Activity data	This term refers to information which is associated with processes while modelling Life Cycle Inventories (LCI). The aggregated LCI results of the process chains that represent the activities of a process are each multiplied by the corresponding activity data and then combined to derive the environmental footprint associated with that process. Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of fuel used, output of a process (e.g. waste), number of hours equipment is operated, distance travelled, floor area of a building, etc. Synonym of “non-elementary flow”.
Acidification	EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.
Allocation	An approach to solving multi-functionality problems. It refers to “partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006).
Application specific	It refers to the generic aspect of the specific application in which a material is used. For example, the average recycling rate of PET in bottles.
Background processes	Refers to those processes in the product life cycle for which no direct access to information is possible. For example, most of the upstream life-cycle processes and generally all processes further downstream will be considered part of the background processes.
Characterization	Calculation of the magnitude of the contribution of each classified input/output to their respective EF impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterization factors for each substance and EF impact category of concern. For example, with respect to the EF impact category “climate change”, CO_2 is chosen as the reference substance and kg CO_2-equivalents as the reference unit.

Climate change	Also referred to as Global Warming Potential. Capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example, CO_2-equivalent units) and specified time horizon (e.g. GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years respectively). It relates to the capacity to influence changes in the global average surface-air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.
Company-specific data	It refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous to “primary data”. To determine the level of representativeness a sampling procedure may be applied.
Comparative assertion	An environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function (including the benchmark of the product category) (adapted from ISO 14044:2006).
Comparison	A comparison, not including a comparative assertion, (graphic or otherwise) of two or more products based on the results of an LCA study.
Cradle to grave	A product’s life cycle that includes raw material extraction, processing, distribution, storage, (use), and disposal or recycling stages. All relevant inputs and outputs are considered for all stages of the life cycle.
Critical review	Process intended to ensure consistency between an LCA and the principles and requirements of the LCA methodology followed (e.g., PEF, ISO standards 14044, etc.).
Declared unit	A quantified amount of a product used as a reference point for an LCA study, particularly when assessing the environmental impact of products that do not serve a uniform function, or when a functional unit cannot be clearly defined. Unlike the Functional Unit, which is used to compare the performance or impact of products based on a common function they provide, the declared unit is primarily used for products for which the function and functionality are not the primary focus of the LCA or are too varied to standardize.
Downstream	Occurring along a product supply chain after the point of referral.
Ecotoxicity, freshwater	Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and

	function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.
Eutrophication	Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland accelerate the growth of algae and other vegetation in water. The following degradation of such organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. Three EF impact categories are used to assess the impacts due to eutrophication: Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine.
Foreground processes	Refer to those processes in the product life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the producer or its contractors (e.g. goods transport, head-office services, etc.) belong to the foreground processes.
Functional unit	The functional unit defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions "what?", "how much?", "how well?", and "for how long?".
Human toxicity – cancer	EF impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer.
Human toxicity – non cancer	EF impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.
Input flows	Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products (ISO 14040:2006).
Ionising, radiations, human health	EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

Land use	EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in quality multiplied by the area).
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14040:2006).
Life cycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040:2006).
Life cycle inventory dataset	A document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. A LCI dataset could be a unit process dataset, partially aggregated or an aggregated dataset.
Output flows	Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases (ISO 14040:2006).
Ozone depletion	EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).
Particulate matter	EF impact category that accounts for the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NO_x, SO_x, NH_3).
Photochemical ozone formation	EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.
Primary data or site-specific data	This term refers to data from specific processes within the supply chain of the user of this LCA guidance. Such data may take the form of activity data, or

	foreground elementary flows (life cycle inventory). Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the user of this LCA guidance. In this method, primary data is synonym of “company-specific data” or “supply-chain specific data”.
Primary packaging	Material that immediately covers the product. For example, primary packaging can consist of plastic film or bag, a bottle, paper wrapping.
Reference flow	Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.
Resource use, fossil	EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).
Resource use, minerals and metals	EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).
Secondary data	It refers to data not from a specific process within the supply-chain of the company performing a PEF study. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third party LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and may also be based on financial data, and contain proxy data, and other generic data. Primary data that go through a horizontal aggregation step are considered as secondary data.
Secondary packaging	Packaging or containment of a primary package. Packaging for multiple products and their labels are also considered to be secondary packaging.
Sensitivity analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the results of an LCA study (based on ISO 14040: 2006).
System boundary	Definition of aspects included or excluded from the study. For example, for a “cradle-to-grave” EF analysis, the system boundary includes all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

Tertiary packaging	Packaging conceived so as to facilitate handling and transport of a number of sales units or grouped packaging in order to prevent physical handling and transport damage.
Unit process	Smallest element considered in the LCI for which input and output data are quantified (based on ISO 14040:2006).
Water use	It represents the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. According to the PEF Method (2021), it assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (see also https://www.wulca-waterlca.org/aware.html).

1. Introduction

“Flexible Packaging is produced through adding value to a wide variety of substrate materials including plastic films, paper and aluminium foil – either separately or in combination – mainly for primary retail food packaging and non-food packaging applications such as pet food, tobacco, cosmetics and personal care, household detergents, and pharmaceutical and medical products. This specifically excludes shrink and stretch films used for secondary packaging, pallet hoods and pallet wrap, carrier bags, supermarket and self-service counter bags, silage bags, refuse and industrial sacks, etc. Inevitably, there remain some grey areas.”[1]

The European flexible packaging industry is committed to supporting Europe's transition to a circular and resource-efficient economy. This commitment involves eco-designing flexible packaging to minimize environmental impacts while maintaining its essential role in the safe and proper delivery of food, medical, pharmaceutical, home, and personal care products. The industry emphasizes the importance of Life Cycle Thinking to assess environmental impacts. Moreover, the industry aims to achieve circularity by ensuring that flexible packaging does not become waste, improving recyclability through initiatives like CEFLEX[2], supporting actions of redesign and innovation, both in packaging design and sorting and recycling technologies. It supports regulatory measures that promote a circular economy and is committed to monitoring progress in recyclability. Additionally, the industry is focused on preventing leakage and littering of flexible packaging into the environment by implementing efficient production practices, advocating for proper waste collection and management, and raising consumer awareness[3].

To accelerate progress towards sustainable consumption and production, the industry is dedicated to collaborating with the entire value chain, sharing best practices, and enhancing the global performance of flexible packaging in the circular economy. To achieve this goal, sustainability experts from six European flexible packaging converting companies and the association Flexible

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[1] https://www.flexpack-europe.org/

[2] CEFLEX Design Check Tool https://design-check.ceflex.eu/

[3] https://www.flexpack-europe.org/sustainability-vision

Packaging Europe, together with Quantis, an environmental sustainability consultancy, have joined forces to provide guidance for the implementation of Life Cycle Assessment (LCA) of flexible packaging solutions. LCA guidelines for flexible packaging are critical for accurately assessing and improving the environmental sustainability of packaging solutions. They can support informed decision-making by businesses, policymakers, and consumers, driving innovation and sustainability in the packaging industry. This guidance is intended for use by LCA practitioners, both in the flexible packaging industry as well as further downstream in companies who use flexible packaging to safely and efficiently package their products.

Quantis, in collaboration with the six above-mentioned flexible packaging converting companies and the association Flexible Packaging Europe were constituting the Technical Secretariat of the developing Product Environmental Footprint Category Rules (PEFCR) for flexible packaging from 2018 to 2023. In 2023 the group decided to collectively stop the PEFCR process and shift the remaining resources into this guidance. As a follow up, this LCA guidance was developed from 2023 to 2024 to support the environmental assessment of flexible packaging from a Life Cycle Thinking perspective. Through research and data provided by different members of the Technical Secretariat, it was possible to identify particularities related to the production processes of flexible packaging. This guidance is designed to facilitate LCAs which include flexible packaging.

Life Cycle Assessment, or LCA, is a leading methodology used to assess the environmental performance and impacts of a product across its full life cycle. LCA methods have been defined by the International Organization for Standardization (ISO) 14040/14044 standards (ISO 2020a, ISO 2020b). LCA is an internationally recognized approach that evaluates the potential environmental impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, manufacturing, use, and end-of-life treatment. It is important to note that LCA does not exactly quantify the real impacts of a product or service due to data availability and modelling challenges. However, it allows us to estimate and understand the potential environmental impacts which a system might cause over its typical life cycle, by quantifying (within the current scientific limitations) the likely emissions and resources consumed. Hence, environmental impacts calculated through LCA should not be interpreted as absolute, but rather as relative values. Ultimately this is not a limitation of the methodology since LCA is generally utilized to compare different systems performing the same function, where the relative differences in environmental impacts are key for identifying the best solutions.

Among other uses, LCA can identify opportunities to improve the environmental performance of products, inform decision-making, and support marketing, communication, and educational efforts. The importance of the life cycle view in sustainability decision-making is sufficiently strong that over the past several decades it has become the principal approach to evaluate a broad range of environmental problems, identify social risks, and help make decisions within the complex arena of socio-environmental sustainability.

2. Scope of the guidance

This section describes the objective of the LCA guidance. It also includes the intended audience, the disclosures and declarations, and the review procedure.

2.1. Objectives

This LCA guidance aims to provide recommendations for calculating the environmental impacts of different types of flexible packaging. It serves as a guide for developing flexible packaging specific LCAs as well as comparative assessments between flexible packaging and alternatives. It also aims to ease the process of conducting life cycle assessment, increase methodological consistency, and reduce documentation requirements for practitioners, potentially laying foundational grounds in harmonizing methodological approaches in LCA for flexible packaging.

2.2. Intended audience

This document is designed to guide the development and understanding of product-specific flexible packaging LCAs, following the directions outlined herein. It gives guidance to develop the life cycle inventory of flexible packaging and is primarily aimed at the following groups:

- Sustainability teams or LCA practitioners employed by manufacturers of flexible packaging systems.
- Reviewers of such LCAs who have the methodological knowledge but not the necessary product related expertise.
- Downstream packaging users who must incorporate flexible packaging into their comprehensive product or packaging LCAs.

2.3. Existing international standards and guidelines

Different standards and guidelines are currently available and widely applied by LCA practitioners. This LCA guidance builds on these existing standards, adhering to ISO 14040/44, while also incorporating what is considered most critical and feasible from the Product Environmental Footprint (PEF) method (European Commission (2021)). The PEF method shall be applied in the evaluation of environmental impacts (selection of impact categories) and in the modelling choices, e.g., modelling of transportation and end-of-life (EoL). If part of the LCA study, the critical review shall be performed at the end of the LCA study according to ISO 14071 and 14044 by one independent external expert (refer to section 3.1.5).

The most frequently used LCA guidelines mentioned in this guidance and their summarized description are listed in Table 1.

Table 1 Existing LCA guidelines.

Standard	Description
ISO 14040	describes the "Principles and framework" of LCA (ISO 2020a)
ISO 14044	"details the requirements for conducting an LCA" (ISO 2020b)
ISO 14067	"is the generic standard for the quantification of the carbon footprint of products" (ISO 2019)
ISO 14071	"provides requirements and guidelines for conducting a critical review for any type of LCA study and the competencies required for the review" (ISO 2014b)
PEF	"is a Life Cycle Assessment (LCA) based method to quantify the environmental impacts of products (goods or services)" (Zampori L, Pant R 2019)
GHG Protocol (Product Standard)	can be used to understand the full life cycle carbon emissions of a product

3. Methodological approach

This section includes a detailed description of the four steps (Goal and Scope, Life Cycle Inventory, Life Cycle Impact Assessment and Interpretation) to conduct a flexible-packaging specific LCA according to ISO 14040/44 – and partly PEF – as well as describe the sub-categories of each step.

The life cycle focuses on cradle-to-gate and cradle-to-grave assessments for flexible packaging, considering manufacturing conditions prevalent in Europe.

3.1. Goal & Scope of the LCA

3.1.1. GOAL OF THE STUDY

In the case of flexible packaging, the LCAs could be performed to:

- Analyze the potential environmental impacts of flexible packaging structures and main drivers.
- Support product development or ecodesign of flexible packaging.
- Highlight the differences between packaging products, especially in case of newly developed products where improvements have been made.
- Compare the potential environmental impacts of the currently available packaging material with the flexible packaging as an alternative. Note that the inventory data in this guidance can be applied only to the flexible packaging materials.

3.1.2. SCOPE OF THE STUDY

The scope of the study describes the studied product, the product system and the boundaries, data sources (including data quality), and the methodological frameworks. In the case of comparative studies, the functions of the studied system should also be included. The main requirements are defined in the next sections.

3.1.2.1. Functional unit, declared unit and reference flow

The function of flexible packaging encompasses enclosing, safeguarding, and maintaining the integrity of consumer goods whereas the functional unit (FU) defines the extent of this “function” delivered by flexible packaging, quantified for a specific quality and timeframe (ISO 2006a). The declared unit (as defined in section **Definitions**) represents the amount of one product that can be used as a reference for the (partial) quantification of environmental impacts, such as carbon footprint (ISO 2019). For cradle-to-gate LCA studies, the use phase and the function of the product are not strictly defined. Hence, the application of the declared unit is more appropriate.

The function of the flexible packaging structures is defined as the following: to package, protect and preserve consumer goods for a specified quality and duration; they can also provide other services like convenience of use and information to the consumers. The chosen functional unit will depend on the scope of the assessment (cradle-to-gate or cradle-to-grave, refer to section 3.1.2.2). For comparative LCAs:

- It can be a 1:1 comparison of declared unit for flexible packaging structures using different materials and fulfilling the same function (e.g. 1 m2 of flexible packaging material A and B) or
- It can be 1 item, which corresponds to how much material is needed from all comparable materials to package a specific product (e.g. one pouch).

In the case of non-comparative LCAs, it can be assumed the functional unit for flexible packaging is equal to the declared unit, i.e. **1 m^2** of flexible packaging material or **1 item**.

The reference flow is the amount of packaging required for the extent of function:

- Specifying area (in m^2), grammage (in g/m^2) and composition of the substrates (in % weight and mm of thickness) of required flexible packaging material.
- If applicable, specifying weight (kg) and composition of materials (in % of weight) of required non-flexible packaging structures (for example spouts).

- Specifications of the packaging structure regarding barrier level, mechanical properties and additional functions:
    - Oxygen barrier
    - Water vapour barrier
    - Light protection
    - Rigidity
    - Toughness
    - Puncture resistance
    - Thermoformability
    - Heat resistance
    - Seal strength
    - Retortability
    - If applicable: Easy opening, resealing
    - Any additional parameters that may be required for a specific product in terms of functionality, quality, duration of service, protection and preservation of the product.

3.1.2.2. System boundaries

The system boundaries for assessing flexible packaging include cradle-to-gate, covering steps from resource extraction to the production factory gate, including waste treatment, and cradle-to-grave, which adds distribution and end-of-life stages and potentially the use phase (see

Figure 1). This guidance does not cover modeling the use phase, as it involves the finishing of flexible packaging materials by the producer, filling the packaging, and storing the final product. These processes are specific to the product itself and cannot be reliably predicted.

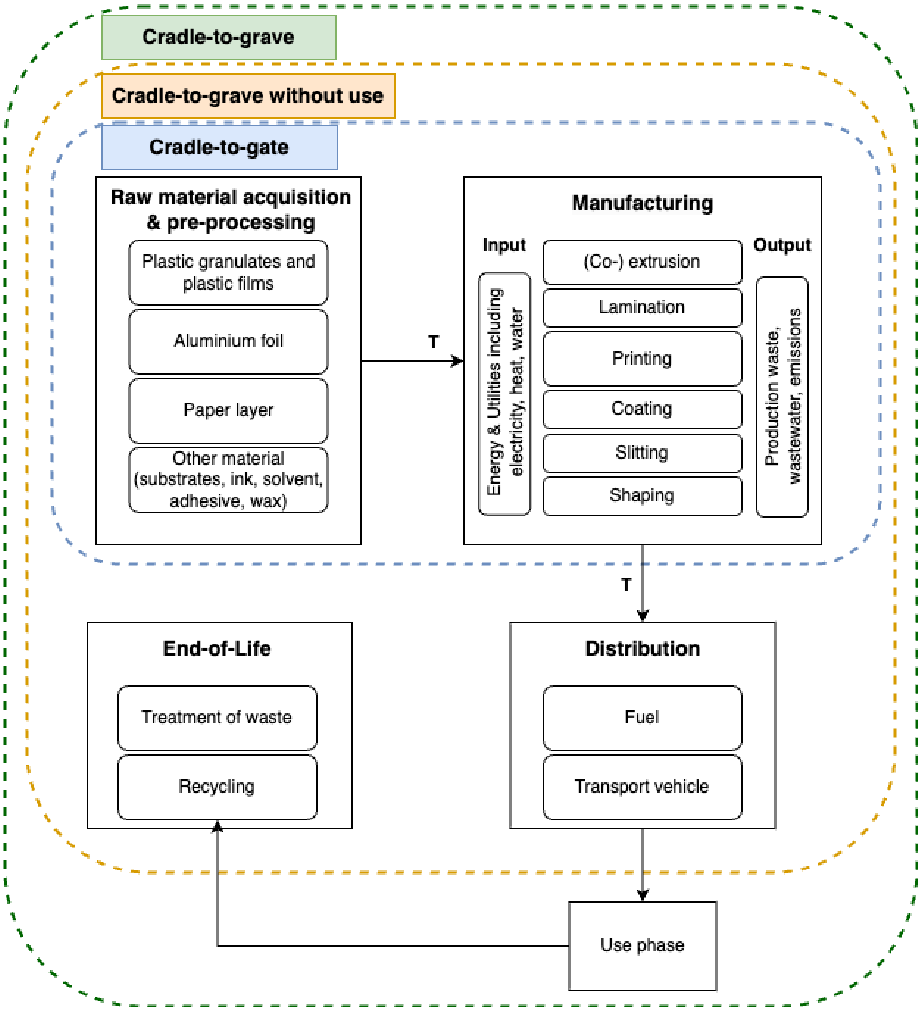

Figure 1 System boundary diagram for flexible packaging cradle-to-gate and cradle-to-grave without use phase. In this Figure, T stands for transport. The foreground processes are represented by the processes in the manufacturing stage, while the other stages include background processes.

Due to the variations in application and processing of different packaging materials, it is recommended to follow a cradle-to-grave scope for a comparative LCA. In a cradle-to-grave assessment, the life cycle stages and processes reported in Table 2 should be included in the system boundary of flexible packaging.

Table 2 Processes included per life cycle stage

Life cycle stage	Short description of the processes included
Raw materials acquisition and pre-processing	• Production of plastic granulates and pellets • Paper production • Aluminium foil production • Production of coating materials, adhesives, solvents, inks, tie layers, heat seal lacquers, sealants • Raw material transport to manufacturing plant • Packaging for handling
Manufacturing	• Processing of plastic granulates: (co-)extrusion, etc. • Lamination • Printing (flexography and rotogravure) • Coating • Slitting • Shaping • Scrap treatment
Distribution	• Transport from factory gate to product manufacturers
Use	• The use of the flexible packaging material: resources (e.g. water, energy, equipment) required for the production of the packaging itself (i.e. forming a pouch, thermoforming a tray, etc.) and for the filling of the packaging material with the good it is meant to package/cover/preserve. **Note: As this step is specific to the subsequent processing of the material and cannot be predicted, it is not included in the scope of this study.* • The use of the packaged good by the end consumer. This may include refrigeration and transport from retailers to consumers. However, this is depending on the product and cannot be predicted: therefore, this is out of scope of this guidance.
End-of-Life	• Waste for disposal • Treatment of waste (recycling, incineration with and without energy recovery, landfill, direct fuel substitution…)

Depending on the composition and application of flexible packaging, some of the above-mentioned processes may not be applicable. In general, only processes that exist within the context of a product shall be included within the system boundaries. For example, processing steps involved in the production of specific flexible packaging structures, such as storage at elevated temperatures for curing, shall be included.

Packaging waste and the waste treatment are to be considered in the “end-of-life” stage. In this case, different scenarios have to be assessed (refer to sections 3.2.5 and 3.6).

3.1.2.3. Cut-off criteria

Cut-offs should always be avoided and, whenever this is possible, the complete Bill of Material (BOM) should be considered.

3.1.2.4. Data collection

Data preference is given to primary data from manufacturing facilities or suppliers, as it best reflects the environmental impacts of the modelled product. If primary data is not available, secondary data from third-party providers can be applied.

The hierarchy that is recommended to apply for assessments aligned with this guidance is listed below.

1. Supplier data (primary data): list of inputs and outputs of materials, energy, waste and emissions is provided and calculated according to the reference flow of the model. If processes already modelled are provided by the suppliers, the respective LCIs can also be included in the model, even if not critically reviewed. In this case, methodology shall be consistent with the intended assessment (impact assessment method, cut-off criteria, EoL modelling, etc.)
2. LCA data from suppliers: the impacts related to suppliers’ processes, only if they have been critically reviewed by external parties. LCA practitioners must ensure that methodology is consistent with the intended assessment (impact assessment method, cut-off criteria, EoL modelling, etc.).

3. Association data (e.g. PlasticsEurope) and third-party data providers (ecoinvent[4] and MLC i.e. Managed LCA Content (formerly, GaBi database by Sphera[5]); cm.chemicals (LCA Database for Chemicals and Plastics, by Carbon Minds[6])

When secondary data from databases are unavailable, a suitable proxy may be used instead. However, it shall be reviewed in the data quality assessment, included in the limitations sections, and considered when interpreting results.

LCA studies are deemed valid provided that the materials and technology used in the production process remain consistent with those specified in the models, and the total environmental impacts fall within a range of ± 20% (confidence interval). The average validity of a study is between 2 and 4 years. This validity considers regular database updates, updates in the impact assessment methods, and modifications of suppliers. It is thus recommended to rigorously document and record any changes to database versions used and methods, as well as standards, that result in deviations of results.

For the selection of datasets from the database, it is recommended to use datasets specific to the country where the modelled production site is located. If the dataset specifically representing that country is not available, an alternative dataset representative of the European average can be used as a proxy.

3.1.2.5. Assumptions and limitations

For ensuring the quality and comparability of the flexible packaging material LCA study, it is highly recommended to use primary data obtained directly from manufacturing facilities and suppliers, and to minimize assumptions and limit them to stages typically not identified as hotspots in flexible packaging LCAs, such as the use phase and transportation. However, due to inevitable challenges such as data limitations, system boundary definitions, or methodological constraints, making some assumptions is almost unavoidable, e.g.:

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[4] https://ecoinvent.org/database/

[5] https://sphera.com

[6] https://www.carbon-minds.com/products/data/carbon-footprint-and-lca-data/

- **Material sourcing**: Assuming the source of raw materials and the impacts associated with extraction and processing.
- **Production processes**: Estimating the energy consumption and emissions during the manufacturing of the flexible packaging, using generic or averaged data.
- **Transportation**: Assuming distances, modes of transportation (truck, ship, rail), and the types of fuels used for transporting raw materials and finished flexible packaging.
- **Use (out of scope of this guidance)**: Making assumptions about the production and the filling of the packaging.
- **End-of-Life**: Estimating the percentage of packaging that is recycled, incinerated, or landfilled, and the associated environmental impacts.
- **Recycling rates and processes**: Assuming the efficiency of recycling processes and the quality of recycled materials, which can vary greatly by region.
- **Energy recovery**: When considering incineration, assumptions about the efficiency of energy recovery from waste-to-energy processes may be necessary.
- **Life span**: Estimating the useful life of the packaging before it becomes waste.
- **Biodegradation**: For biodegradable materials, assumptions regarding the rate of biodegradation and the conditions in which it occurs must be made.
- **Consumer behavior**: Presumptions about how consumers handle flexible packaging, including disposal and recycling behaviors.
- **Geography**: Assuming the geographic location for the material sourcing, production and disposal of the flexible packaging material. This can affect the environmental impacts depending on the region due to variations in climate, energy mix, waste management infrastructure, and local regulations.
- **Technological advances**: Projecting current data into the future without accounting for potential technological or process improvements that could significantly alter impact assessments.
- **Regulatory factors**: Anticipating changes in environmental regulations that could affect the management of flexible packaging waste.

This list encompasses a broad spectrum of possible assumptions necessary for the analysis. However, it is important to also consider LCA-specific nuances and other particularities specific to the datasets used. Each assumption can introduce uncertainty into the LCA results, so documenting them transparently and considering their potential impact on the study's conclusions and on the overall quality is essential.

Limitations can also arise from the modelling approach: the combination of more than one background database or the combination of a background database (e.g. ecoinvent) with association data (e.g. PlasticsEurope) brings additional limitations to the model as different databases are based on different data sources and following specific guidelines. Therefore, some modelling decisions of different databases are not consistent with each other, and they should be considered for the critical interpretation of the results (see section 3.8).

3.1.2.6. Selection of impact assessment method and categories

Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment. The method suggested for flexible packaging LCAs developed in this LCA guidance to evaluate environmental impact is the most recent version available of the Product Environmental Footprint (EF) method (Zampori L, Pant R 2019). However, other methods could be potentially used, depending on the goal of the study. Table B-2 in *Appendix B: Overview of product footprint methodological standards* compares PEF with ISO 14067 and GHG Protocol for product assessments.

The EF 3.1 method assesses 16 different impact categories. It is the result of a project for the European Commission that analyzed several Life Cycle Impact Assessment (LCIA) methodologies to reach a consensus.

Table 3 List of EF 3.1 impact indicators.

EF impact category	Impact indicator	Unit	Characterization model
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2-eq	Baseline model of 100 years of the Intergovernmental Panel on Climate Change (IPCC) (based on IPCC 2021)
• Climate change – fossil			
• Climate change-biogenic			
• Climate change – land use and land use change			
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11-eq	Steady-state ODPs as in (WMO 2014 + integrations)
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fantke et al, 2017)
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fantke et al, 2017)
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP, 2016)
Ionising radiation, human health	Human exposure efficiency relative to U^{235}	kBq U^{235} -eq	Human health effect model as developed by Dreicer et al., 1995 (Frischknecht et al, 2000)
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC -eq	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H^+ -eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N -eq	Accumulated Exceedance (Seppälä et al., 2006, Posch et al, 2008)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P -eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N -eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe

EF impact category	Impact indicator	Unit	Characterization model
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fantke et al, 2017)
Land use	• Soil quality index (dimensionless) • Biotic production (kg biotic production) • Erosion resistance (kg soil) • Mechanical filtration (m3 water) • Groundwater replenishment (m3 groundwater)	Dimensionless (pt)	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)
Water use	User deprivation potential (deprivation-weighted consumption)	m^3 world -eq	Available Water Remaining (AWARE) as recommended by UNEP, 2016
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb -eq	CML 2002 (Guinée et al., 2002) and (van Oers et al., 2002).
Resource use, fossils	Biotic resource depletion – fossil fuels (ADP-fossil)	MJ	CML 2002 (Guinée et al., 2002) and (van Oers et al., 2002)

The prioritization of indicators during the interpretation phase will be influenced by various factors, such as the company's specific environmental objectives. Whether it is analyzing one product or comparing flexible to other packaging, it is essential to weigh the trade-offs among indicators, as each packaging type presents advantages and challenges across their life cycles.

3.1.3. COMPARISONS AND COMPARATIVE ASSERTIONS

Comparative assertions can be made between flexible packaging structures or between flexible and alternative packaging structures for primary packaging. A comparison can be made only if the packaging structures fulfil the same function with the same performance (functional equivalency), quantified by the same functional unit in the form of their reference flows related to the same kind and quantity of product filled and consumed.

Secondary and tertiary packaging shall be included in case their amounts or properties differ between the compared packaging systems with respect to the functional unit.

Furthermore, equivalent data quality, allocation procedures, and decision rules shall be applied to both systems.

This guidance is applicable for conducting LCAs for flexible packaging and can also be used for the comparison of packaging structures used to pack the same product, where at least one of the alternatives is a flexible packaging structure. Rules defined in this section are not intended for comparisons of different products and their packaging (for example liquid handwash in bottles vs a soap bar wrapped in paper). However, some of the data, assumptions and modelling guidance provided in this document could apply to the assessment of the packaging used in the product comparison. Inherent differences in the kind or quality of product filled or differences in application depending on / or offered by the type of packaging should be described as additional information.

The comparative LCA shall include all life cycle stages in addition to the use e.g., filling of the packaging material as this may highlight significant differences between the comparable packaging materials. These stages are reported in Table 2.

For such comparative assertions, the three-step method described below shall be followed:

Step 1

Define the product that is being packaged. Define the minimum required functions, extent of function, quality, and provided duration of service for the specific packaging structures being compared. Include all primary packaging needed to fulfil the required function and to ensure safe shipping and storage of the product. Include secondary and tertiary packaging should they differ between the compared packaging systems. For product dependent systems, include the packaged product in comparative assertions[7].

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[7] According to the PEF method, product dependent processes are directly or indirectly determined or influenced by the product design or are related to instructions for use of the product. These processes depend on the product characteristics and therefore contribute to differentiation between two products. All instructions provided by the producer and directed towards the consumer (through labels, websites or other media) shall be considered as product dependent (Zampori et al., 2019).

The extent of the function refers to the amount of product packaged. An example for spaghetti pasta is provided below:

- Product that is being packaged: spaghetti pasta
- Required function: transportation and storage of spaghetti pasta
- Extent of function: packaging for 500 g of spaghetti pasta
- Quality: quality of pasta retained (physical and chemical and sensorial state)
- Duration of service: 24 months

An example for the Bolognese sauce for pasta is provided below:

- Product that is being packaged: Sauce for pasta Bolognese
- Required function: transportation and storage of pasta sauce Bolognese
- Extent of function: packaging for the sauce used for 500 g of pasta, heating of sauce
- Quality: quality of pasta sauce retained (physical and chemical and sensorial state); resistance to heating-processes for sterilization and preparation of the product filled
- Duration of service: 12 months

Step 2

Define the parameters that describe the specified function, quality, and duration of each packaging structure.

- Reference flow: Amount of packaging required for the extent of function
    - Specifying area (in m^2), grammage (in g/m^2) and composition of the substrates (in % weight and mm of thickness) of required flexible packaging structures
    - If applicable, specifying weight (kg) and composition of materials (in % of weight) of required non-flexible packaging structures
- Functional unit: pack and protect the defined amount of a specific product for the specified quality and duration defined in step 1.

- Specifications of the packaging structure regarding barrier level, mechanical properties and additional functions (see the list of specifications mentioned in section 3.1.2.1)

Note: any other aspects that do not serve to package, protect, or preserve the product, such as aesthetics, appearance, or marketing are not in the scope of this guidance and shall not be included in the comparisons.

An example for spaghetti pasta for defining parameters is provided below:

- 500 g spaghetti pasta packaged
- Rigidity to avoid fracture of pasta
- Easy opening

Step 3

Compare flexible packaging structures (including primary packaging, and if relevant, secondary and tertiary packaging) that provide the same function, extent of function, quality, and duration as defined in the first step of this comparison.

The comparison shall be conducted for all impact categories.

The comparative analysis shall be made based on this guidance, together with the latest PEF method, which is in line with the ISO 14040 and 14044 standards.

3.1.4. DISCLOSURES AND DECLARATIONS

For comparative LCA studies that are intended to be disclosed to the public, additional reporting requirements apply. ISO 14044 references for these requirements are listed in Table 4.

Table 4
Recommended chapters from ISO 14044:2006 for comparative LCA studies that are intended to be disclosed to the public

Aspect	Reference in ISO 14044:2006
What shall be included in a final sensitivity analysis?	4.2.3.3.3
When is a critical review required?	4.2.3.7, 6.1
Details on sensitivity and uncertainty analysis	4.4.5
Details on sensitivity check	4.5.3.3
Further reporting requirements	5.3.1

3.1.5. REVIEW PROCEDURE

A critical review of the LCA report including collected data, modelling approach, specific assumptions, LCA results and their interpretation is required before any external communication, especially in the case of a comparative assessment. The report of this critical review is to be included in the LCA report, commonly in the Annex. The panel is composed by one or more reviewers who are independent LCA experts and/or experts on (flexible) packaging.

3.2. Life cycle inventory

Specific procedures and requirements related to the data and the data collection are detailed in the following section. In addition, some modelling decisions and specificities related to the production of flexible packaging are indicated, aiming to facilitate the modelling developed for the studied products that could serve for alignment of LCA practices in flexible packaging.

3.2.1. RAW MATERIALS

This life cycle stage includes the extraction of resources through the gate of the flexible packaging production facility (processing and manufacturing plant). Following processes shall be considered:

- Production of raw materials to be used as substrate;

- Pre-processing of semi-finished inputs (including losses and waste);
- Production and end-of-life of packaging materials used for handling;
- Transportation between the extraction and pre-processing facilities and to the production facility (manufacturing plant).

If the raw materials have recycled content, the credits and impacts associated to those raw materials shall be allocated and modelled accordingly (see also section 3.2.5). Furthermore, impact of end-of-life for any pre-processing and manufacturing waste has to be modelled consistently, i.e. with the same end-of-life modelling approach.

Following materials are commonly used in flexible packaging:

- **Polyethylene (PE)**: Including low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE), used for their flexibility and strength.
- **Polypropylene (PP)**: Known for its versatility and barrier properties against moisture, used in snack bags and similar products.
- **Polyethylene Terephthalate (PET)**: Often used for its clarity, strength, and barrier to gas and moisture.
- **Polyvinyl Chloride (PVC)**: Known for its barrier properties.
- **Polyvinylidene chloride (PVDC):** Known for its barrier properties and therefore used in pharma blister packaging.
- **Polyamide**: Valued for its toughness and barrier properties, often used in vacuum-sealed packaging.
- **Bioplastics**: Made from renewable resources. Examples: Polylactic Acid (PLA) or cellulose-based plastics (e.g., cellophane).
- **Biodegradable plastics**: Can be made from renewable sources and decompose under certain conditions. Examples: Polylactic Acid (PLA) or Aliphatic-aromatic-polyester-based plastics.
- **EVOH** (ethylene vinyl alcohol copolymer): Known for its barrier properties
- **Aluminium foil**: Used for its excellent barrier properties against light, oxygen, and moisture; often used in combination with plastics.
- **Paper**: Often coated or laminated with plastics or aluminium, used for its natural look and feel and printability.

These materials are often used in combination, as laminates, to capitalize on the strengths of each material, such as improved barrier properties, mechanical strength, and printability.

The transportation modes of raw materials are typically mass-limited and the impact should be modelled per weight (e.g. ton) transported by kilometer. The actual distances and weights should be used, if available. If not, assumptions for distances and transport means need to be used. In case of multi-sourcing for the same item, the allocation of resources and emissions should be done by mass allocation. Packaging of raw materials can be excluded based on the cut-off criteria (see section 3.1.2.3).

3.2.2. MANUFACTURING

Various conversion processes are available to process material into flexible packaging structures that meet required technical specifications (see also section 3.1.2.1). Following processes are included in this guidance:

- Extrusion or coextrusion of one or more plastic granulate(s);
- Lamination of two or more flexible packaging substrates using a bonding agent;
- Printing of flexible packaging;
- Coating;
- Slitting;
- Shaping.

Manufacturing of flexible packaging can be very variable with different manufacturing pathways depending on the requirements and applications, for example a structure may undergo lamination – slitting – shaping, or printing – wax coating – slitting, etc. The processes above have been selected due to their applicability for most types of flexible packaging products and manufacturing pathways, covering the most intensive processes as a conservative approach. Additional manufacturing processes are not part of this guidance due to lack of data, such as metallization and biaxial orientation (please see section 5 for information on limitation of this guidance). To fill these gaps, the experts who contributed to this guidance suggest following assumptions if no primary data are available:

- For metallization: using a default coating weight equals to 0.1 g/m^2 aluminium with 5% average waste rate;
- For biaxial orientation: using a cast film processing dataset with 5% average waste rate.

In general, the following inventory data is required to model conversion processes:

- Material consumption (granulate, substrate such as paper or aluminium, other materials such as ink);
- Energy consumption: electricity, natural gas, steam, etc.;
- Direct emissions (for example from solvent handling and usage);
- Water consumption;
- Amount of output film;
- Material losses;
- Waste treatment of manufacturing waste (internal or external recycling, hazardous waste, incineration and landfill).

The following sections include indicative data to model these processes in the absence or in case of difficult access to primary data.

3.2.2.1. Extrusion

Extrusion is a common process for conversion of plastic granulates and pellets into plastic films. Cast film and blown film extrusion are the usual extrusion techniques in the manufacturing of flexible packaging. Granulates or pellets are introduced into an extruder barrel, absorbing heat as it moves through the barrel, effectively melting the plastic (Abeykoon, 2022). In cast extrusion, the molten plastic is forced through a flat die, so the resulting plastic film has a flat shape, then cooled down. Certain materials, such as polypropylene, are best suited for cast extrusion. Cast extrusion allows the stretching of the produced film in 1 or 2 directions by a subsequent process, generating so-called “orientated” films or “biaxially orientated” films. This process enhances certain mechanical properties, e.g. the barrier function or the transparency. In blown film extrusion, the molten plastic exits the extruder through a vertical die head and compressed air is injected into the molten material, causing it to swell and rise vertically in tubular form. After cooling, rollers flatten the film into a flat tube. Coextrusion refers to the extrusion of two or more plastic resins into a multilayer film through the assembly of multiple extruders.

To model the extrusion process, data on following parameters should be collected:

- Material consumption (substrate);
- Electricity consumption;
- Consumption of auxiliary materials;
- Amount of extruded plastic;
- Water use for cooling (usually this is a closed system and only leaked water shall be counted);
- Material losses;
- Waste treatment of manufacturing waste (internal or external recycling, incineration and landfill).

Depending on the manufacturer, there may be natural gas consumption or steam use. Table 5 contains some indicative data for the amount of energy used in extrusion processes, as well as on substrate losses and recycling or waste treatment. The wide range provided for energy consumption reflects a high variability of this parameter, mainly due to the properties of the plastic(s) (e.g. melting point) and complexity of the multilayer structure. Manufacturing waste from this process has high rates of recycling, as the materials experience low contamination and, depending on the resin, they can be recycled and retain properties of a high-quality material.

Table 5 Range specifications to model extrusion processes

Extrusion process	Parameter	Amount	Unit	Comments
Blow extrusion	Substrate losses	2–10	% of input substrate	N/A
	Electricity	150 – 500	Wh/kg extruded film	For PE or PP: 0.5 kWh/kg
Cast extrusion	Substrate losses	2 – 5	% of input substrate	N/A
	Electricity	150 – 700	Wh/kg extruded film	For PE or PP: 0.7 kWh/kg
	Natural gas	0 – 200	Wh/kg extruded film	N/A
Cast and blow extrusion	Internal recycling rate	10 – 50	% of waste	Waste = substrate waste + cleaning/purging waste
	External recycling rate	45 – 90	% of waste	
	Incineration rate	0 – 5	% of waste	
	Landfill rate	0	% of waste	

Source: data collection and expert estimates by members of FPE.

3.2.2.2. Lamination

In this process, two or more flexible packaging substrates are joined together using a bonding agent, such as an adhesive (adhesive lamination with or without solvent), a molten resin (extrusion lamination) or a polymer dispersion (dispersion lamination) (Leguern et al., 2010). To model a lamination process, the following data points should be collected:

- Material consumption (substrates, bonding agents and solvents, if applicable);
- Consumption of auxiliary materials;
- Electricity consumption;
- Natural gas consumption;
- Water consumption (usually for cooling process where only leaked water shall be counted and, more relevant, as input for extrusion and dispersion lamination);
- Emissions associated to solvent use (volatile organic compounds -VOCs-, incineration, etc.), if applicable;

- Amount of laminated film;
- Waste treatment of manufacturing waste such as losses and solvents (internal or external recycling, incineration and landfill).

Substrate waste from this process is often externally recycled where possible, the recyclability will depend on the materials constituting the layers. See also section 3.2.5 for more insights in the recyclability of flexible packaging structures. A guidance in modelling solvent waste treatment and emissions is provided in section 3.2.6.4.

3.2.2.2.1. Adhesive lamination

Main adhesives used in adhesive lamination are crosslinking polyurethane materials. In the case of solvent lamination, two component polyurethane is used, with an isocyanate reacting with a multifunctional alcohol mixed into the adhesive directly before application. For solventless lamination, typically polyurethane with one or two components is used, with isocyanate reacting with environmental humidity (e.g. in paper) or with a multifunctional alcohol mixed into the adhesive directly before application. If the materials are not known from the technical specification of the flexible packaging product, methylene diphenyl diisocyanate (MDI) and polyol can be used as proxies for these materials.

Solvent lamination (dry bond lamination) uses adhesives containing solvents as a carrier for the adhesive resins. Some of the solvents used for solvent adhesive lamination include ethyl acetate, isopropyl acetate (IPA), acetone and methyl ethyl ketone (MEK). Solvents are evaporated during drying process and the evaporated solvents (VOCs) may be recovered for reuse or undergo an air pollution treatment through regenerative thermal oxidizers before being released to the atmosphere.

Solventless lamination, as the name specifies, does not use solvent for adhesive resins and a drying process is not needed.

Table 6 and Table 7 contain some indicative data for solventless lamination and solvent-based process, respectively. The higher gas consumption for solvent lamination is associated to the drying process. Solvents are also used in adhesive lamination for cleaning of the equipment in small amounts per square meter of laminated film.

Table 6 Range specifications to model solventless lamination process

Parameter		Amount	Unit	Comments
Substrate losses		3 – 7	% of input substrate	N/A
Electricity		3 – 15	Wh/m^2 film	N/A
Natural gas		2 – 5	Wh/m^2 film	N/A
Adhesive (without solvent)		1.5 – 2.5	g/m^2 film	N/A
Adhesive waste		0.1	g/m^2 film	N/A
Cleaning solvent (ethyl acetate)		0.5 – 1	g/m^2 film	Use of cleaning solvent is a must.
Substrate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	50 – 85	% of waste	N/A
	Incineration rate	10 – 50	% of waste	N/A
	Landfill rate	0 – 5	% of waste	N/A
Solvent waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	50 – 85	% of waste	N/A
	Incineration rate	15 – 50	% of waste	Recuperation/Recovery = 50%
	Landfill rate	0	% of waste	N/A

Source: data collection and expert estimates by members of FPE.

Table 7 Range specifications to model solvent lamination process

Parameter		Amount	Unit	Comments
Substrate losses		2 – 5	% of input substrate	N/A
Electricity		3 – 10	Wh/m^2 film	N/A
Natural gas		15 – 35	Wh/m^2 film	N/A
Adhesive (without solvent)		2.5 – 4.5	g/m^2 film	The suggested value for dry adhesive. In case of wet adhesive: 3.5-12 g/m^2 film
Adhesive waste		2 – 8	% of adhesive	N/A
Solvent		1.5 – 9	g/m^2 film	N/A
Solvent waste		5 – 25	% of solvent	N/A
Cleaning solvent (ethyl acetate)		0.5 – 1	g/m^2 film	Use of cleaning solvent is particularly relevant.
Substrate/ laminate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	50 – 85	% of waste	N/A
	Incineration rate	10 – 50	% of waste	N/A
	Landfill rate	0 – 5	% of waste	N/A
Adhesive waste	Hazardous waste incineration	100	% of waste	N/A
Solvent waste	Internal recycling rate	0 - 70	% of waste	For internal recovery - creditable against fresh solvent.
	External recycling rate	50	% of waste	Whether creditable against fresh solvent or solely to cleaning solvent depends on the quality of the recycled solvent.
	Incineration rate	50	% of waste	N/A
	Landfill rate	0	% of waste	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.2.2. Extrusion lamination

In the case of extrusion lamination, the bonding agent between two substrates is a molten polymer resin. Some of the polymers used for extrusion lamination include:

- Ethyl vinyl acetate (EVA) for bonding PE to PVC;
- LDPE for bonding plastic or aluminium foil with paper or paperboard;
- Acid containing adhesives such as ethylene-ethyl acrylate (EEA), ethylene methyl acrylate (EMA) and terpolymers of ethylene, acid and acrylate to bond with aluminium foil;
- Anhydride modified polyolefins like terpolymers of ethylene, maleic anhydride and acrylates (Mieth et al, 2016).

Table 8 contains some indicative data for extrusion lamination process. Energy consumption is primarily driven by the resin melting and extrusion processes, which will vary depending on the chosen resin.

Table 8 Range specifications to model extrusion lamination process

Parameter		Amount	Unit	Comments
Substrate losses		5 – 8	% of input substrate	N/A
Electricity		5 – 40	Wh/m^2 film	Range for 5 – 50 g/m^2 extrusion-mass
Natural gas		0 – 45	Wh/m^2 film	N/A
Molten polymer		10 – 20	g/m^2 film	Common range, but it can be higher.
Substrate/laminate waste	Internal recycling rate	0 – 15	% of waste	N/A
	External recycling rate	75 – 85	% of waste	N/A
	Incineration rate	0 – 15	% of waste	N/A
	Landfill rate	0	% of waste	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.2.3. Dispersion lamination

Dispersion or wet bond or water-based lamination uses dispersions (mainly water-based) as carriers of the adhesive. Such adhesives include:

- Poly(vinyl acetate) emulsion or copolymers of vinyl acetate and ethylene or acrylic esters;
- Crosslinking acrylic-vinyl acetate and copolymer emulsions, used commonly for snack packages;
- Acrylic emulsion pressure-sensitive adhesive, for pressure-sensitive labels;
- Polyurethane dispersions, where some chemical resistance is required (Mieth et al, 2016).

Table 9 contains some indicative data for dispersion lamination process.

Table 9 Range specifications to model dispersion lamination process

Parameter		Amount	Unit	Comments
Substrate losses		5 – 7	% of input substrate	N/A
Electricity		3 – 25	Wh/m² film	N/A
Natural gas		20 – 60	Wh/m² film	N/A
Adhesive (dry, without water)		1 – 3	g/m² film	1-5 if paper substrate is included
Water		0 – 0.5	g/m² film	N/A
Substrate/ laminate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	60 – 80	% of waste	N/A
	Incineration rate	10 – 50	% of waste	N/A
	Landfill rate	0	% of waste	N/A
Wastewater		0 – 0.5	g/m² film	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.3. Printing

The printing process adds information or patterns to the flexible packaging structures using ink. Printing inks are provided at a high concentration of colorants, pigment binders and additives in solvents or water. Table 10 shows the typical components of solvent-based and water-based inks.

Table 10 Composition of inks for solvent-based and water-based ink

Ink type	Parameter	Components
Solvent-based ink	Pigments binders	Nitrocellulose, maleic resin, polyvinyl butyral, polyamide, polyurethane
	Solvents	Alcohols (ethanol, isopropanol), esters (ethyl acetate, isopropyl acetate), ethoxy propanol
	Additives	Plasticizers, slip additives (lubricants), adhesion promoters
Water-based ink	Pigments binders	Styrene-acrylic co-polymers, acrylic co-polymers, maleic resins
	Solvents	Water, isopropanol, glycol ether, propylene glycol
	Additives	Amines, biocides, defoamers, wetting agents, polytetrafluoroethylene and polyethylene waxes, slip agents

Source: Mieth et al (2016).

Additional solvents need to be used to adjust the viscosity of the ink for its suitability to the printing processes, with ethyl acetate, ethanol and ethoxy propanol as the most common solvents. Smaller amounts of solvents are also used for cleaning purposes of the equipment.

The most common printing methods for flexible packaging in Europe are flexographic printing and rotogravure, as estimated by the European Rotogravure Association (ERA) (Siever, 2020). Gravure printing and flexographic printing have generally similar applications. For applications requiring very high print quality, gravure printing can provide better definition and colour rendering (Leguern et al. 2010). However, high definition flexo printing has made significant advancements in narrowing the gap between flexo and gravure printing in terms of quality and resolution. For any of these, following data points should be collected:

- Material consumption (substrate, ink and solvents);
- Consumption of auxiliary materials;
- Electricity consumption;
- Natural gas consumption;

- Water consumption for cooling (usually this is a closed system and only leaked water shall be counted);
- Amount of printed film;
- Waste treatment of manufacturing waste, such as losses, ink and solvents (internal or external recycling, incineration and landfill).

Printing losses, energy, ink, and solvent consumption can greatly fluctuate based on the print design, ink types, substrate, and batch size. A guidance in modelling solvent waste treatment and emissions is provided in section 3.2.6.4.

3.2.2.3.1. Flexographic printing

In flexography, the patterns to be printed are engraved in relief on photopolymer plates mounted on the printing cylinders. The film is printed on a central drum by the various printing cylinders, one for each colour. The film then passes through a heating tunnel to be dried (Leguern et al. 2010).

Table 11 contains some indicative data for flexographic printing process.

Table 11 Range specifications to model flexographic printing process

Parameter		Amount	Unit	Comments
Substrate losses		7 – 13	% of input substrate	N/A
Electricity		5 – 30	Wh/m^2 film	N/A
Natural gas		10 – 55	Wh/m^2 film	N/A
Solvent ink dry		1 – 2	g/m^2 film	N/A
Solvent ink wet		2 – 5	g/m^2 film	N/A
Additional solvent		3 – 10	g/m^2 film	N/A
Cleaning solvent		0.1 – 0.2	g/m^2 film	N/A
Solvent composition	Ethanol	25 – 75	% of solvent	N/A
	Ethyl acetate	10 – 20	% of solvent	N/A
	Ethoxy propanol	5 – 15	% of solvent	N/A
Substrate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	0 – 50	% of waste	N/A
	Incineration rate	50 – 100	% of waste	N/A
	Landfill rate	0 – 10	% of waste	N/A
Solvent waste	Internal recycling rate	0	% of waste	In-house distillation, creditable against cleaning solvent
	External recycling rate	0 – 50	% of waste	Creditable against cleaning solvent
	Incineration rate	50 – 90	% of waste	VOC loss cannot be avoided
	Landfill rate	0	% of waste	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.3.2. Rotogravure printing

The patterns to be printed are engraved onto metallic cylinders and are arranged in a series. The substrate passes successively between different printing cylinders that contain the various colours of the pattern to be printed. Between each colour, drying devices ensure that the deposited ink dries (Leguern et al. 2010).

Table 12 contains some indicative data for rotogravure printing process.

Table 12 Range specifications to model rotogravure printing process

Parameter		Amount	Unit	Comments
Substrate losses		15 – 20	% of input substrate	N/A
Electricity		12 – 25	Wh/m² film	N/A
Natural gas		40 – 120	Wh/m² film	N/A
Solvent ink (wet; containing 70% solvent)		3 – 10	g/m² film	N/A
Additional solvent		5 – 10	g/m² film	N/A
Cleaning solvent		0.1 – 0.5	g/m² film	N/A
Solvent composition	Ethanol	15 – 40	% of solvent	N/A
	Ethyl acetate	60 – 80	% of solvent	N/A
	Isopropyl acetate	0 – 5	% of solvent	N/A
	1-propanol	0 – 5	% of solvent	N/A
	Methyl ethyl ketone	0 – 10	% of solvent	N/A
Substrate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	0 – 95	% of waste	N/A
	Incineration rate	5 – 100	% of waste	N/A
	Landfill rate	0	% of waste	N/A
Solvent waste	Internal recycling rate	0– 70	% of waste	In case of internal recovery. Creditable against fresh solvent.
	External recycling rate	0 – 95	% of waste	Whether creditable against fresh solvent or solely to cleaning solvent depends on the quality of the recycled solvent.
	Incineration rate	5 – 90	% of waste	VOC loss cannot be avoided.
	Landfill rate	0	% of waste	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.4. Coating

In this process, the flexible packaging substrate is coated with a layer of wax (wax coating), a molten resin (extrusion coating) or a polymer (dispersion coating), to enhance the appearance or alter the physical properties of the packaging (Mieth et al, 2016).

To model the coating processes, following data points should be collected:

- Material consumption (substrate and coating material);
- Auxiliary materials consumption;
- Electricity consumption;
- Natural gas consumption;
- Water consumption;
- Amount of coated film;
- Waste treatment of manufacturing waste such as losses and coating material (internal or external recycling, incineration and landfill).

3.2.2.4.1. Wax coating

This process coats paper (also in the form of an outside layer in or multilayer films) with wax. The paper side is coated with molten wax and then the film is cooled down (Leguern et al. 2010).

Table 13 contains some indicative data for wax coating process.

Table 13 Range specifications to model wax coating process

Parameter		Amount	Unit
Substrate losses		3 – 5	% of input substrate
Electricity		3 – 45	Wh/m^2 film
Natural gas		6 – 8	Wh/m^2 film
Wax		8 – 9	g/m^2 film
Substrate waste	Internal recycling rate	0	% of waste
	External recycling rate	90 – 95	% of waste
	Incineration rate	5 – 10	% of waste
	Landfill rate	0	% of waste

Source: data collection and expert estimates by members of FPE.

3.2.2.4.2. Extrusion coating

Extrusion coating is similar to the extrusion lamination process, but there is only one substrate which is coated with the molten polymer resin coats and quenched on a chill roll. Energy consumption is primarily driven by the resin melting and extrusion processes, which will vary depending on the chosen resin.

Table 14 contains some indicative data for extrusion coating process.

Table 14 Range specifications to model extrusion coating process

Parameter		Amount	Unit
Substrate losses		5 – 7	% of input substrate
Electricity		15 – 200	Wh/m^2 film
Natural gas		10 – 55	Wh/m^2 film
Molten polymer		10 – 50	g/m^2 film
Substrate waste	Internal recycling rate	0	% of waste
	External recycling rate	60 – 80	% of waste
	Incineration rate	20 – 40	% of waste
	Landfill rate	0	% of waste

Source: data collection and expert estimates by members of FPE.

3.2.2.4.3. Dispersion coating

Dispersion coating is similar to the dispersion lamination process, but there is only one substrate which is coated with a water-based dispersion.

Table 15 contains some indicative data for dispersion coating process. The thickness of substrate and coating, as well as the nature of the substrate, influence the energy consumption, the substrate losses and the recyclability of the resulting waste.

Table 15 Range specifications to model dispersion coating process

Parameter		Amount	Unit	Comments
Substrate losses		4 – 5	% of input substrate	N/A
Electricity		3 – 30	Wh/m^2 film	N/A
Natural gas		20 – 90	Wh/m^2 film	N/A
Dispersion		1 – 10	g/m^2 film	For dry conditions. 2 – 20 for wet condition.
Water consumption		0.1- 0.3	g/m^2 film	N/A
Substrate waste	Internal recycling rate	0	% of waste	N/A
	External recycling rate	60 – 80	% of waste	N/A
	Incineration rate	20 – 40	% of waste	N/A
	Landfill rate	0	% of waste	N/A
Wastewater		0.1- 0.3	g/m^2 film	N/A

Source: data collection and expert estimates by members of FPE.

3.2.2.5. Slitting

Slitting is performed to provide the films in a format that can be used by the customer. The film is cut in sheets or in a reel of smaller width (Leguern et al. 2010). To model the slitting process, following data points should be collected:

- Material consumption (substrate);
- Auxiliary materials consumption;

- Electricity consumption;
- Amount of output film;
- Waste treatment of manufacturing waste (internal or external recycling, incineration and landfill).

Table 16 contains some indicative data for slitting process.

Table 16 Range specifications to model slitting process

Parameter		Amount	Unit
Substrate losses		3 – 5	% of input substrate
Electricity		0.2 – 6	Wh/m^2 film
Substrate waste	Internal recycling rate	0	% of waste
	External recycling rate	80 – 95	% of waste
	Incineration rate	5 – 20	% of waste
	Landfill rate	0 – 5	% of waste

Source: data collection and expert estimates by members of FPE.

3.2.2.6. Shaping

This process shapes bags that can be used by the customer. The film reels undergo a series of folding, welding and cutting depending on the finished product to be manufactured (Leguern et al. 2010). To model the shaping process, following data points should be collected:

- Material consumption (substrate);
- Auxiliary materials consumption;
- Electricity consumption;
- Natural gas consumption;
- Water (to test for punctures);
- Amount of output film;
- Material losses;
- Waste treatment of manufacturing waste (internal or external recycling, incineration and landfill).

Material losses and electricity consumption can vary significantly depending on various factors such as the specified shape of the bag, material in use and batch size.

Table 17 contains some indicative data for shaping process.

Table 17 Range specifications to model shaping process

Parameter		Amount	Unit
Substrate losses		1 – 10	% of input substrate
Electricity		20 – 30	Wh/m^2 film
Substrate waste	Internal recycling rate	0 – 5	% of waste
	External recycling rate	80 – 90	% of waste
	Incineration rate	0 – 5	% of waste
	Landfill rate	0 – 5	% of waste

Source: data collection and expert estimates by members of FPE.

3.2.3. DISTRIBUTION

The distribution stage includes the transport of the packaging material from factory gate to product manufacturers, to be further processed and filled with the final packaged product. This stage includes the transportation of semi-finished and intermediate products between manufacturing stages. If we consider the whole life cycle of flexible packaging, transportation processes usually have a relatively low contribution to climate change due to the high impact of the raw materials phase. Based on this, generic transportation modules shall be applied to all transportation-related activities. Distribution typically uses modes as ship or truck, especially within Europe. However, if specified by the concerned parties, transport by plane or train may be used.

It is recommended to use primary data for location of the supplier and transport mode as well as departure and arrival harbours/airports. In that case, distances can be calculated using:

- Searates for sea, land, air transport;
- distance.to for land and air transport.

In case it is unknown, distance calculation can be done on country-level origin using the CERDI database[8] where distances are available for transport via sea, air, road and multi-modal. If the country of origin is also unknown, default distances and transportation modes for European (intracontinental) or international supply chains are provided in the PEF method (Zampori et al., 2019). Transportation information may also be present in databases like ecoinvent.

3.2.4. USE PHASE

The use phase of packaging material can be broken down into two sub-phases.

First, the resources (e.g. water, energy, equipment) required for the filling of the packaging material with the good it is meant to package/cover/preserve: as this step is specific to the subsequent processing of the material and cannot be predicted, it is not included in the scope of this guidance.

The second stage of the material's use is with the consumer, the end user of the packaged product. This may include refrigeration and transport from retailers to consumers. However, this is depending on the product the flexible packaging contains and cannot be predicted: therefore, this is out of scope of this guidance.

3.2.5. END-OF-LIFE AND RECYCLED CONTENT

The end-of-life of flexible packaging from each life cycle stage shall be included in the overall modelling of the life cycle of the product and reported at the life cycle stage where the waste occurs. This section provides guidelines on how to model the end-of-life of flexible packaging as well as the recycled content.

With regards to burdens of waste treatment for recycling or energy recovery, the common LCA practice used by databases (e.g. ecoinvent) is to apply the cut-off approach, where the waste producer does not accrue the impact of the recycling process and in the 'second 'life' of the material, the material is burden-free but accrues the impact of the recycling process[9]. This approach is more

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[8] https://zenodo.org/records/46822#.VvFcNWMvyjp

[9] https://support.ecoinvent.org/system-models

aligned with GHG Protocol for corporate footprint[10] and best suited for cradle-to-gate comparisons. The PEF method adds an allocation of burdens and benefits of recycling through the Circular Footprint Formula (CFF) approach and is a requirement for PEF compliant studies.

Due to the lack of visibility converters have regarding the regional end markets for specific packages, it is challenging to predict where the waste will ultimately be collected and recycled. This uncertainty is compounded by the highly fragmented nature of waste collection and recycling infrastructure across Europe. In light of these factors, it is recommended to conduct a sensitivity analysis considering both CFF and cut-off approaches, focusing on region-specific default end-of-life scenarios that include recycling, incineration, and landfill processes based on the latest data from each country. To gain a comprehensive understanding of potential environmental impacts, it's also advisable to evaluate additional scenarios that simulate 100% participation in each individual end-of-life activity (recycling, incineration, and landfill). Further details on the CFF formula are available in the PEF method.

3.2.5.1. Pre-consumer scrap or internal recycling

The approach on pre-consumer scrap in this guidance is based on the respective PEF method's guidelines. In this case, the option 2 of the PEF method is recommended for flexible packaging (available at European Commission (2021)):

Any material that circulates within a process chain or pool of process chains is excluded from being defined as recycled content and it is not included in R1. Scrap is not claimed as pre-consumer recycled content.

This means that, scrap that is claimed within the process boundaries where it was generated, will not be claimed as recycled content and the scrap is modelled as part of the production system (burdens associated to scrap treatment included).

3.2.5.2. Recycled content

According to the PEF method, recycled content is defined as the proportion of material in the input to the production that has been recycled from a previous system (Zampori et al., 2019). This guidance

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[10] The GHG Protocol Corporate Accounting and Reporting Standard, https://ghgprotocol.org/corporate-standard

takes inspiration from the PEF method's guidelines for accounting recycled content, with adaptations as necessary.

A supply-chain specific recycled content higher than zero shall be applied if it can be traced and verified, traceability throughout the supply chain is thus necessary. In all other cases, the recycled content should be zero. Following guidelines shall be applied when using supply-chain specific recycled content:

- The supplier information (through e.g. statement of conformity or delivery note) shall be maintained during all stages of production and delivery at the converter;
- Once the material is delivered to the converter for production of flexible packaging, the converter shall handle information through their regular administrative procedures;
- The converter for production of flexible packaging claiming recycled content shall demonstrate through its management system the [%] of recycled input material into the respective flexible packaging structure (see further details below);
- The latter demonstration shall be transferred upon request to the user of the flexible packaging. This shall be stated in the respective LCA study;
- Company-owned traceability systems may be applied as long as they cover the general guidelines outlined above.

Chain of Custody (CoC) models for recycled content are frameworks designed to track and verify the path of recycled materials from their source through to the final product. These models play a role in the supply chain by providing a systematic approach to ensure the integrity and traceability of recycled materials.

In the context of this guidance, following industry-specific guidelines for traceability are recommended:

- For the paper industry: European Recovered Paper Identification System (CEPI – Confederation of European Paper Industries, 2008). This document prescribes rules and guidance on necessary information and steps, with a delivery note that shall be received at the reception of the mill.
- For the plastics industry: EN standard 15343:2007. This standard prescribes rules and guidelines on traceability. The supplier of the recyclate is requested to provide specific information.

Keep in mind that more updates and guidelines may become available in the future, also including additional materials.

There are other certification schemes (refer to ISO 22095:2020 or ISO/TC 308) that can be used to add credibility on specific points such as Chain of Custody (CoC), including International Sustainability & Carbon Certification (ISCC) certification ISCC+, Aluminium Stewardship Initiative (ASI) and others.

Table 18 Chain of custody models.

CoC model	Description	Advantage	Disadvantage
Identity Preservation	Keeps the certified material's unique identity throughout the supply chain.	Ensures purity and traceability of materials.	Logistically complex and costly.
Segregation	Allows mixing materials from different certified sources.	Flexibility in sourcing certified materials.	Requires strict segregation controls.
Mass Balance	Tracks the total amount of sustainable content, allowing some mixing.	Balances sustainability with practicality.	Less direct traceability of sustainable content.
Book and Claim	Companies buy certificates for the volume of sustainable material produced.	Highly flexible and scalable.	No physical traceability in the final product.

3.2.5.3. Recycling output rate

According to the PEF method, the recycled waste is defined as the proportion of the material in the product that will be recycled (or reused) in a subsequent system. This recycling rate shall therefore consider the inefficiencies in the collection and recycling (or reuse) processes, measured at the output of the recycling plant (Zampori et al., 2019).

The product design and composition will determine if the material in the specific product is suitable for recycling. Therefore (and following the PEF method recommendation), before selecting the appropriate recycling output rate, an evaluation of the recyclability of the material shall be made.

In regard with the definition of “recyclable packaging”, this guidance refers to the Packaging and Packaging Waste Regulation (PPWR)[11] which, at the time of writing this document, is still provisional and is expected to be published in 2024. According to the PPWR, packaging can be considered recyclable if it meets the specified requirements. The criteria outlined in the current draft of the Regulation include considerations for design for recycling, as well as factors such as the feasibility of collection, sorting processes, the quality of secondary raw materials, and the scalability of recyclability. For a detailed understanding of these requirements, please refer to the PPWR documentation.

Recyclability disruptors of flexible packaging structures can influence their potential for recycling (CEFLEX, 2020). The recycling output rate from the Annex C of PEF can be used if packaging is designed to be recyclable according to guidelines such as CEFLEX (CEFLEX, 2020), RecyClass (RecyClass, 2022; Recyclass, 2024), 4evergreen (4evergreenforum, 2023), or via third party verification. If the criteria are not met, the recycling output rate should be set as zero. It is expected that European Commission will develop Design for Recycling criteria in line with the Packaging and Packaging Waste Regulation (PPWR). According to the agreed provisional text (April 2024) available when this guidance has been written, design for recycling criteria and grades will be produced by the European Committee for Standardization (CEN) for each material and category on Annex II (which includes flexible packaging). It is recommended to align with these criteria as soon as they are available.

The following procedure shall be followed to select the recycling output rate to be used in case the recyclability has been proven following above criteria:

- Primary data shall be used when available and following the evaluation of recyclability;
- If no primary data are available and the criteria for the evaluation of recyclability are fulfilled (see above), application-specific recycling output rate values should be used depending on the country and selecting the appropriate value available in Annex C of the PEF method:
    - If the value is not available for a specific country, then the European average from the PEF method shall be used;

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[11] Proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0677

- If the value is not available for a specific application, the values of the material to be sorted for recycling shall be used (e.g. materials' average);
- In case no values are available, recycling output rates shall be set to zero.

Recyclability is sensitive to infrastructure development, and with the scale-up of emerging solutions, the recyclability is expected to increase (Hundertmark et al, 2018). Furthermore, the Packaging and Packaging Waste Regulation (PPWR) aims to update the legislative framework and provide adequate support to achieve waste reduction targets, including recyclability targets. For these reasons, it is recommended to use the latest data on end-of-life available at country level.

3.2.5.4. Incineration

Modelling the incineration of waste can be done with third-party datasets. It is important to note that the chosen dataset should fit the different material(s) being incinerated, e.g. consider whether materials are biobased or fossil-based (for the appropriate accounting of biogenic CO2 emissions, for additional information, see section 3.2.6.2 on biogenic carbon), as well as their heating value. Heating values are specific to the material and are often available in commercial databases, like ecoinvent. For innovative materials, not available in databases, they shall be communicated by the suppliers. Any credits for recovered energy (heat, electricity) shall be modelled according to the chosen allocation method (cut-off or CFF) and using relevant datasets (residual mix for electricity). Note that third-party datasets may already include and account for such credits. For solvents, a dataset for incineration of hazardous waste can be used as proxy.

3.2.5.5. Landfill

Similar to the incineration process, modelling landfilling of waste can be done with third-party datasets. It is important to note that the chosen dataset should fit the different material(s) being landfilled, paying attention to biobased and fossil-based materials (for the appropriate accounting of biogenic CO2 emissions, see section 3.2.6.2 on biogenic carbon). Any credits for recovered energy from landfill gas (heat, electricity) shall be modelled according to the chosen allocation method (cut-off or CFF) and using relevant datasets. Note that third-party datasets may already include and account for such credits.

3.2.6. GENERAL MODELLING GUIDANCE

3.2.6.1. Electricity modelling

If specific agreements on electricity supply (e.g. renewable energy certificates) are in place for flexible packaging manufacturing facilities, the impact of these can be accounted for by following the PEF method. The rules to model electricity mixes are based on a hierarchical order that generally consists of:

- Using a supplier-specific electricity product if there is a 100% tracking system in the country or if a specific set of minimum criteria to ensure the contractual instruments are reliable is met (set of minimum criteria is summarized below);
- Supplier-specific total electricity mix if the same set of minimum criteria is met;
- ‘Country-specific residual grid mix, consumption mix’;
- Using the region representative residual grid mix, consumption mix.

A summary of the criteria defined by the PEF method consists of:

- Criterion 1 – Convey attributes: convey the energy type mix associated with unit of electricity produced. Electricity from facilities for which the attributes have been sold off shall be characterized as having the environmental attributes of the country residual consumption mix where the facility is located;
- Criterion 2 – Be a unique claim: the instrument is the only one to carry the environmental attribute claim associated to the quantity of generated electricity;
- Criterion 3 – Be as close as possible to the period to which the contractual instrument is applied.

Further guidance in modelling country-specific residual grid mix is available in the PEF method. The PEF method states that the consumption grid mix shall be used in the use stage, however, use stage is considered to be out of scope of this guidance (see also section 3.2.4).

In the case of modelling **on-site electricity generation**, the guidelines from the PEF method are also adopted. If on-site electricity production is equal to the site own consumption, two situations apply:

- Contractual instruments (e.g. Renewable Energy Certificates (RECs)) have not been sold to a third party: the own electricity mix shall be modelled;
- Contractual instruments have been sold to a third party: the ‘country-specific residual grid mix, consumption mix’ shall be used.

If more electricity is produced than the amount consumed on-site within the defined system boundary and is sold to, for example, the electricity grid, this system may be seen as a multifunctional situation by providing two functions (e.g. flexible packaging and electricity). In this case, following rules apply:

- If possible, apply subdivision to separate a) electricity productions or b) common electricity production based on electricity amounts for own consumption and to the share being sold by the company;
- If not possible, direct substitution shall be used. The country-specific residual consumption electricity mix shall be used as substitution.

For further details, see the PEF method.

3.2.6.2. Biogenic carbon

In general, the carbon uptake in biomass and its release (emissions) must be considered in LCA for flexible packaging, especially when bio-based materials such as paper or biopolymers are used.

The characterization model in the PEF method (based on IPCC) assigns a zero impact to biogenic CO_2 uptake and emissions, in contrast to other methodologies such as ISO 14067 that integrate these elements into their climate change impact assessments. These different approaches are reflected in current LCA software and databases in the datasets for the production and end-of-life stages of bio-based materials, aligning with the various methodological standards.

For a comprehensive analysis of flexible packaging, its biogenic carbon content must be reported in LCA studies. This ensures a transparent accounting of the environmental impact of products made from renewable biological resources. Carbon content depends on the raw biological materials used to produce the packaging (e.g. wood from trees for paper or sugarcane for bioplastics) and it is available in literature. Typically, the carbon content of dry biomass is approximately 45-50% of its weight.

3.2.6.3. Manufacturing losses and waste

For all materials, the input and output amounts should be balanced based on the bill of materials or on the specific weight or grammage of the final product's content and on residual losses (wastes) along the production and value chain.

If the input or output amounts are not known for a process *i*, the amount of required output material (specific weight of the flexible packaging structure) and the waste or losses for each manufacturing process can be used to calculate the amount of input raw materials for each manufacturing stage using the following equation:

$$Amount\ of\ input\ material_i = \frac{Amount\ of\ output\ material_i}{1 - Process\ waste_i}$$

Equation 1

Where the input and output are measured in kg and the waste is measured as a percentage.

Assuming that the amount of input material for process n is equal to the amount of output material for the previous process i-1, the losses are cumulative from the last processing step to the initial step. For example, for an average final product weight of 40 g/m^2 that has undergone extrusion and printing processes, considering a loss of 10% for printing, the amount of input material for printing can be calculated accordingly to Equation 1, resulting in 44.4 g of input film. Then, it is assumed that the output mass of the extrusion process is equal to 44.4 g: therefore, the input mass of the extrusion, if we estimate a loss rate of 5%, it is equivalent to 46.8 g.

Some losses only affect part of the packaging. For example, if only a PET film is printed and then combined with a PE film, the waste rate applies solely to the PET film, not to the entire packaging.

Average losses per manufacturing processes are presented in section 3.2.2 for converting processes, based on industry data and expert judgement provided by the contributing members of this guidance. The loss rates may differ between the substrates and other input materials. For manufacturing processes and materials not available in this guidance and for which the loss rate is unknown, a loss rate of 10% can be used as default.

End-of-life of losses of each process shall be modelled using the CFF as described in section 3.2.5.

3.2.6.4. Solvent waste treatment and associated emissions

Solvents are often used in solvent-based lamination, solvent coating, and printing processes of flexible packaging. Solvents are evaporated during drying process and the evaporated solvents (VOCs) may be recovered for reuse or undergo an air pollution treatment through regenerative thermal oxidizers (incinerated with energy recovery) before being released to the atmosphere. This practice is enforced in European context (EU Directive 2004/42/CE) and other national regulations to limit on the VOCs emissions to atmosphere: however, in some countries where such regulations are not in place or enforced, it is possible that these VOCs are released to indoor air or in the environment untreated. It is recommended to check how VOCs are treated and model them accordingly.

Reference flows of conversion processes should be traced or at least mass balanced to appropriately model the associated emissions, following the approach described in section 3.2.5. See Figure 2 as an example for flexographic printing waste, which outlines a process flow related to waste management and emissions in a printing operation. The numbers used in this figure are taken from Leguern et al. (2010). The printing process starts with the substrate to be printed, fresh ink with a 70% solvent content and a fresh solvent mix. During printing, wet ink is applied to the substrate, the solvents evaporate, and dry ink remains on the substrate. A portion of the solvent evaporated during drying contributes to VOC emissions, a portion is treated by VOC burning leading to CO_2 emissions and a portion (in this example is zero) is recovered for use in the solvent mix. Used cleaning solvents mostly evaporate and are treated as the VOC flow. Wasted ink (not mixed with solvents) is subjected to external incineration and wasted solvents (not mixed with ink) are split equally between incineration and recycling processes.

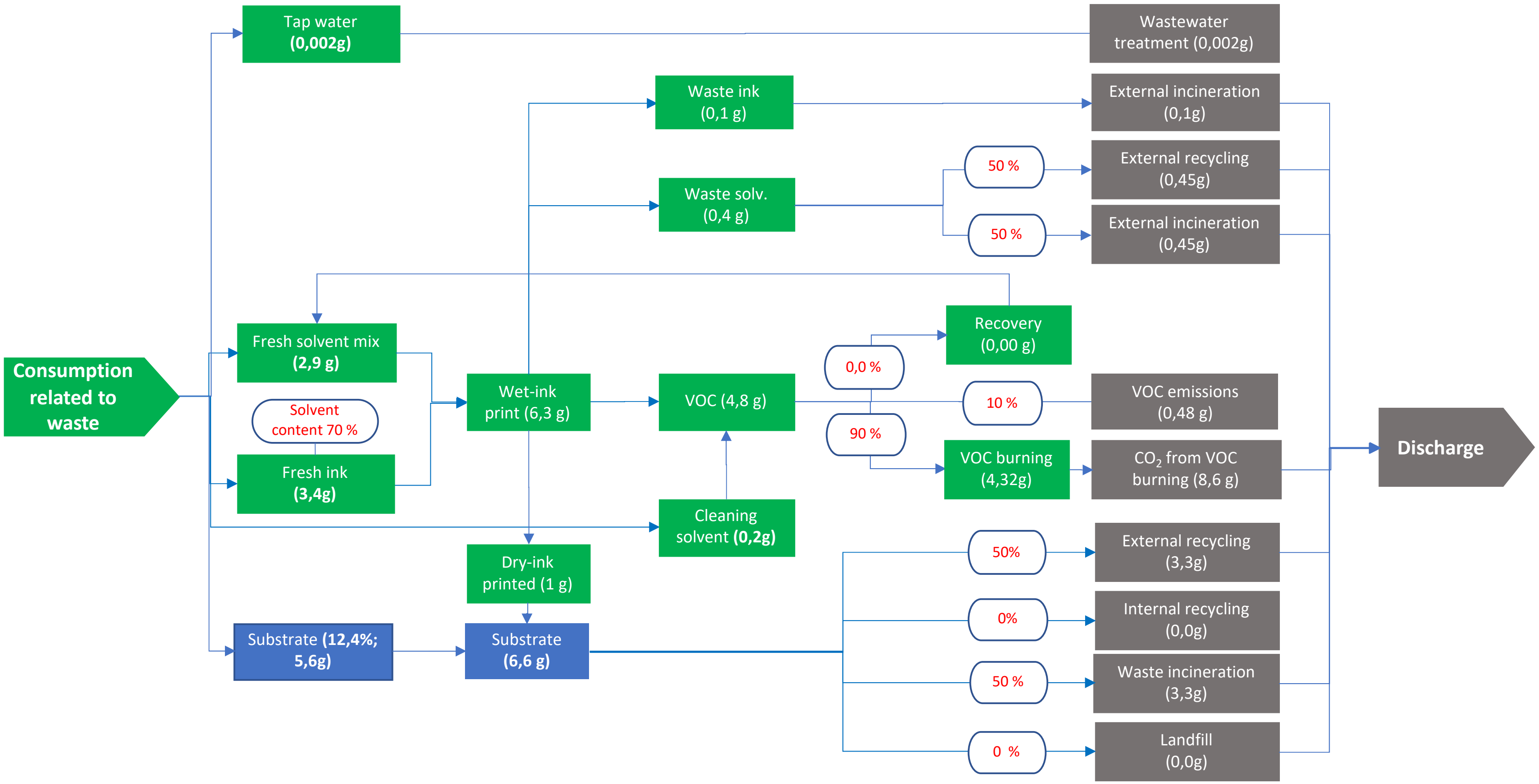

Figure 2 Example reference flows for substrate, ink and solvent waste of flexographic printing. Source: own creation of the authors, with calculations based on numbers reported in Leguern et al (2010) for 1 m^2 film at 46 g/m^2.

To calculate the CO_2 emissions from incineration of solvents, composition of the solvents, molecular weight and the number of carbon atoms in the molecule of each solvent are needed. The number of carbon atoms in a solvent is used to estimate the equivalent CO_2 emissions, using the molecular weight of CO_2 as a conversion key. Table 19 shows an example of the calculation for different solvents. The main assumption is that solvent inks (and often coatings) are purchased on wet basis, with a specific solid and the remainder as solvent content. Solvent adhesives are always purchased in dry basis, e.g. a 100% solid content. Prior to their application onto the substrate, wet inks and the adhesives are diluted with fresh solvent to adjust application viscosity. The precise composition of solvent content of purchased inks is often unknown: however, it is likely a mixture of some of the solvents listed in Table 19. In the printing process, the fresh solvent used for viscosity control is mainly a two to four-component mixture, the composition of which may be available. The emissions are calculated by

a) multiplying the number of carbon atoms in the molecule by the molecular weight of CO_2 (44 g/mol);
b) dividing this by the molecular weight of the solvent;
c) multiplying by the fraction in the solvent in the composition.

The sum of these emissions rates per solvent is equivalent to the emissions rate of the mixture, as they are weighted with their fraction in the solvent mix. Note that some of the solvents are not included in the calculation but are shown to show the molecular weight and chemical formula of some of the commonly used solvents mentioned in this guidance.

It is recommended to inquire always about the solvent used; if it is unavailable, consider using following solvents as proxy:

- ethyl acetate for rotogravure printing;
- ethanol for flexographic printing;
- ethyl acetate for solvent lamination.

By comparing the CO_2 emissions per unit of the solvent mixture to those of the predominant solvent in the mixture (ethanol in the example shown in Table 19), it can be assumed that, in the absence of specific composition details, the emissions of the main solvent may be used to approximate the emissions per unit of the entire solvent mix.

Also, remember to include this solvent in the list of raw materials, even though it is not part of the Bill of Materials (BOM) of the flexible packaging structure.

Table 19 Example calculation of CO_2 emissions from combustion of VOCs.

	A	**B**	**C= (B×44)/A 44 is the MW of CO_2**	**D**	**E= C×D**
Solvent mixture or substance	Molecular weight (g/mol)	# of carbon atoms in molecule	CO_2 emissions per incinerated solvent (kg CO_2e/kg solvent)	Composition of solvent (%)	CO_2 emissions per incinerated solvent in solvent mix (kg CO_2e/kg solvent)
Ethanol (C_2H_6O)	46	2	1.9	76	1.45
Ethylacetate ($C_4H_8O_2$)	88	4	2.0	14	0.28
Isopropylacetate ($C_5H_{10}O_2$)	100	5	2.2	0	0
Ethoxypropanol ($C_5H_{12}O_2$)	104	5	2.1	8	0.17
Isopropanol (C_3H_8O)	60	3	2.2	1	0.02
1-propanol (C_3H_8O)	60	3	2.2	1	0.02
Methyl ethyl ketone (MEK) (C_4H_8O)	72	4	2.4	0	0
Total	**-**	**-**		**100**	**2.0**

Note: totals may not align due to rounding.

3.3. Life cycle impact assessment

After the LCI is completed and the model is created, the results are calculated based on the EF LCIA method. The indicators have to be selected as described in section 3.1.2.6. LCIA results represent potential and not actual environmental impacts. They are relative expressions, which are not intended to predict the final impact or risk on the natural media or whether standards or safety margins are exceeded.

3.4. Interpretation

The results interpretation phase aims to analyse the inventory and impact assessment results in relation to the goal and scope previously defined (ISO 2020b). A hotspot analysis with a focus on climate change (absolute results, relative improvement, and contribution analysis) and the other discussed impact categories (relative improvements and contribution analysis) is presented starting with the contributions of all life cycle stages and following with a deep dive into individual materials, processes, and emissions. As part of this stage, data quality aspects, assumptions, sensitivity analysis, and uncertainty assessment are evaluated, aiming to derive valid conclusions and recommendations for improvements (ISO 2020b). These topics are described in the following sections.

3.5. Data quality assessment

To enhance the credibility of the study and ensure that decisions made within the scope of the LCA are well-informed, the collected data are assessed using the Pedigree matrix by Weidema, B. & Wesnæs, M. (1996) and based on the following set of data quality criteria:

- **Time-Related Coverage:** Refers to the recency and relevance of the data to the time period for which the LCA is intended. It assesses whether the data accurately represents the temporal conditions of the system being studied.

- **Geographical Coverage:** Assesses the degree to which data reflects the geographic location where the product or process is sourced, produced, or consumed. This ensures that local environmental conditions and regulations are appropriately considered.
- **Technology Coverage:** Evaluates how well the data represents the specific technologies or processes used in the product's lifecycle. It looks at the technical specificity and modernity of the data in relation to the actual technology being assessed.
- **Completeness:** Involves checking whether all necessary data is included and whether there are any gaps in the data set that could affect the outcome of the LCA.
- **Reliability:** Concerns the trustworthiness of the data, which depends on the source of the data and the degree of verification or peer review it has undergone. Reliable data is crucial for building confidence in the LCA results.

Foreground processes and data sources are assessed by the practitioner on the basis of time-related coverage, geographical coverage, technology coverage, precision, completeness, representativeness, consistency, reproducibility, reliability of data source and uncertainty of the information as prescribed in ISO 14044. The pedigree matrix can be used for rating inventory data from 1 to 5, with a score of one being most favourable and a score of five being least favourable (refer to section 7.1 Appendix A: Pedigree matrix). A complete discussion of this topic can be found in B. P. Weidema et al., 2013. If the criteria specified for the different scores in Table 20 are not relevant or applicable, the scores can be given comparing the different systems assessed and common sense, but the scores remain quite subjective.

The average data quality rate can be calculated based on the given scores for each criterion and each dataset. This is especially valuable to compare average data quality scores between two or more comparable packaging materials, to evaluate the reliability and robustness of the comparison.

The data quality assessment is to be performed and shown in the study. The score shall correspond to reliability, completeness, temporal correlation, geographical correlation, and technological correlation. The overall data quality rating (DQR) has to be calculated based on the average data scores for each criterion. Table 20 shows the data quality levels for specific data quality ranges.

Table 20
Overall data quality level according to the achieved data quality rating. Source: PEF method.

Overall data quality rating	Overall data quality level
DQR ≤ 1.5	excellent quality
1.5 < DQR ≤ 2.0	very good quality
2.0 < DQR ≤ 3.0	good quality
3.0 < DQR ≤ 4.0	fair quality
DQR > 4	poor quality

3.6. Uncertainty analysis and completeness check

The uncertainty analysis should be at least a qualitative description. It needs to be highlighted that there is uncertainty related to assumptions applied to processing data of different products or omitting parts of the life cycle of flexible packaging, for example the use phase, the transport and the end-of-life because those are based on literature research and assumptions. Furthermore, if data sets were used as proxies, those shall be mentioned in the slide deck presentation.

A completeness check shall be carried out to identify data gaps in the inventory data that could affect the results and the interpretation (ISO 2020b). To avoid issues in meeting the goal and scope of the study, identified data gaps shall be addressed.

3.7. Sensitivity analysis

As part of the interpretation, critical assumptions and/or uncertain data identified with the help of the data quality assessment and the uncertainty analysis shall be explored as part of sensitivity analysis. Some examples are listed below:

- The effect of the electricity source used in the production may be compared through a sensitivity analysis, in particular if there is a possibility of future modification in the energy sourcing for that production facility;

- The effect of different end-of-life parameters in country-specific scenarios may be compared through a sensitivity analysis;
- For comparative LCAs especially, the effect of material quantities and processing needed for the filling of the flexible packaging material compared to other packaging material. Different use approaches are particularly important if they had been modelled based on assumptions;
- The effect of different recycled content shares in packaging;
- The effect of different wastes rates in the manufacturing stage;
- The effect of different paper production datasets, if paper is used in the packaging and no information from suppliers is available.

Choosing the right sensitivity analysis is crucial as it significantly influences the quality of the study. It must be conducted transparently.

3.8. Limitations and conclusions

The LCA limitations shall be identified and reported in the LCA report. The limitations may indicate a need to adjust previous parts of the study, assuring that the goal and scope are successfully covered. Moreover, limitations can highlight future opportunities for improvement (ISO 2020a). The main sources/types of limitations in product/specific flexible packaging LCAs done following this guidance are listed below:

- If the CFF approach is used to assess the end-of-life, the use of the default values of the CFF coefficients. The results and conclusions are only valid for the considered values and can change if the coefficients change;
- The use of European background datasets for other regions;
- The use of a different background datasets (ecoinvent and association data) which are based on different data sources and different modelling decisions.

These limitations apply to all flexible packaging LCAs based on this LCA guidance, related to the manufacturing and use within the European market. As a result, conclusions and statements cannot simply be transferred to other markets. In general, it needs to be highlighted that results obtained for a specific product are valid only for the considered ingredients, packaging details, and considered assumptions.

LCA studies remain valid provided that the materials and technology used in the production process align with those in the models, and the overall potential environmental impacts fall within a ±20% range (% range as mentioned is based on expert judgement). The average validity of a study is between 2 and 4 years. This validity considers regular database updates, updates in the impact assessment methods, and modifications of suppliers.

In the final stage of the LCA study, a comprehensive conclusion synthesizes the key findings from the interpretation of the results. This conclusion highlights the significant environmental impacts and areas for potential improvement, aiming to guide stakeholders toward actionable strategies that promote environmental stewardship and further the development of a circular economy.

4. Critical review

For comparative flexible packaging LCAs, a critical review is recommended. It involves a systematic process aimed at ensuring the credibility and reliability of the study. This process can be summarized into key steps:

I. **Define the review's scope and objectives**, aligning with the comparative LCA's goals.

II. **Select a panel of at least three experts** with relevant expertise, ensuring impartiality, especially for LCAs intended for public disclosure.

III. **Conduct the review process**, which includes evaluating the LCA's methodological consistency with ISO standards, the quality of data and assumptions, comparability between systems analysed, and the study's transparency and completeness.

IV. **Produce a review report** that details findings, limitations, and recommendations for improvement, assessing whether the LCA complies with ISO standards and supports its comparative assertions.

V. **Incorporate feedback and make necessary revisions** to the LCA based on the panel's recommendations.

VI. **Final approval** is given once the panel is satisfied that their concerns have been addressed, enhancing the study's credibility.

This summarized process ensures that comparative LCAs are conducted and reported in a manner that is scientifically robust and unbiased, fostering confidence among stakeholders in the study's findings.

5. Limitations of this guidance

Developing LCA guidance specifically for flexible packaging materials is a valuable initiative that supports sustainability efforts. However, several potential limitations in the guidance itself could affect its effectiveness and application.

Specific limitations identified to data in this guidance are the following:

- We acknowledge that some data are missing in this guidance, for instance data on metallization or biaxial orientation, even if experts of this group recognize their relevance;
- The indicative ranges of data presented in this guidance are sometimes very large and their variability can affect the conclusions of the study.

Additional potential limitations to consider are:

- **Complexity of LCA Concepts**: Simplifying LCA concepts for non-experts without losing the methodological rigor and depth can be challenging. There's a risk that oversimplification might lead to misunderstandings or misuse of the guidance;
- **Data Availability and Quality**: Non-experts might struggle with accessing high-quality, product-specific data for flexible packaging materials. The guidance might not fully compensate for the variability and gaps in data quality and availability, affecting the accuracy of LCA results;
- **Specificity vs. Generality**: Tailoring a guidance to flexible packaging while keeping it broad enough to apply to various products and contexts is difficult. A guidance that is too generic might not offer enough detail for meaningful analysis, whereas a too specific guidance may not apply broadly;
- **Assumptions and Simplifications**: To make the LCA process manageable for non-experts, the guidance may rely on assumptions and simplifications. These could potentially lead to inaccuracies or bias in the LCA outcomes;
- **Software and Tools**: The guidance might recommend specific LCA software or tools which could have their own limitations, learning curves, and costs, potentially limiting accessibility for some users;

- **Interpretation of Results**: Non-experts might find it challenging to interpret LCA results accurately, especially when dealing with trade-offs and uncertainties. The guidance may not fully equip users to handle these complexities;
- **Keeping Current**: The field of LCA and sustainable materials is rapidly evolving. The guidance could quickly become outdated if it does not incorporate the latest methodologies, standards, and scientific findings;
- **Scope of Review**: For comparative LCAs, especially those intended for public disclosure, the critical review process can be complex. The guidance might not fully prepare users for the rigor required in critical review and validation according to ISO 14040/44 standards. Users conducting comparative LCAs need to be prepared for an intensive validation process. This includes being ready to provide comprehensive documentation and justifications for all methodological choices and data sources used;
- **Regulatory and Geographical Variations**: An LCA guidance that overlooks regulatory and geographical variations may offer recommendations that are not applicable or optimal across all jurisdictions or for all flexible packaging applications;
- **Resource Intensity**: Conducting an LCA, even with guidance, can be resource-intensive in terms of time and expertise required. Small organizations or individuals might find it challenging to allocate sufficient resources to conduct a comprehensive LCA.

Addressing these limitations in the guidance itself, through clear communication, providing resources for further learning, and updates to keep the guidance current, can help mitigate some of these issues and improve the utility of the LCA guidance for non-experts.

6. References

4evergreenforum (2023) Circularity by Design Guideline for Fibre-Based Packaging. Version 2. https://4evergreenforum.eu/about/guidelinesandprotocol/

Abeykoon, C. (2022). Sensing technologies for process monitoring in polymer extrusion: A comprehensive review on past, present and future aspects. Measurement: Sensors, 22, 100381. https://doi.org/10.1016/J.MEASEN.2022.100381

Beck, T., Bos, U., Wittstock, B., Baitz, M., Fischer, M., Sedlbauer, K. (2010). 'LANCA Land Use Indicator Value Calculation in Life Cycle Assessment – Method Report', Fraunhofer Institute for Building Physics.

Bos U., Horn R., Beck T., Lindner J.P., Fischer M. (2016). LANCA® - Characterisation Factors for Life Cycle Impact Assessment, Version 2.0, 978-3-8396-0953-8Fraunhofer Verlag, Stuttgart.

CEFLEX (2020). Designing for a Circular Economy (D4ACE) Guidelines. https://guidelines.ceflex.eu/resources/

Dreicer M., Tort V. and Manen P. (1995). ExternE, Externalities of Energy, Vol. 5 Nuclear, Centre d'étude sur l'Evaluation de la Protection dans le domaine nucléaire (CEPN), edited by the European Commission DGXII, Science, Research and development JOULE, Luxembourg.

EPAL (2021). EPAL EURO PALLET (EPAL 1). European Pallet Association e.V. (EPAL) https://www.epal-pallets.org/eu-en/load-carriers/epal-euro-pallet/

Eunomia (2020). Flexible Films Market in Europe State of Play. Production, Collection and Recycling Data. https://www.plasticsrecyclers.eu/_files/ugd/dda42a_ff8049bc82bd408faee0d2ba4a148693.pdf

European Commission (2021). Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. C/2021/9332. http://data.europa.eu/eli/reco/2021/2279/oj

Fantke, P., Bijster, M.,Guignard, C., Hauschild, M., Huijbregts, M., Jolliet, O., Kounina, A., Magaud, V., Margni, M., McKone, T.E., Posthuma, L., Rosenbaum, R.K., van de Meent, D., van Zelm, R., 2017.USEtox®2.0 Documentation (Version 1), http://usetox.org. https://doi.org/10.11581/DTU:00000011

Frischknecht R., Steiner R. and Jungbluth N. (2008): The Ecological Scarcity method – Eco-Factors 2006. A method for impact assessment in LCA. Environmental studies no. 0906. Federal Office for the Environment (FOEN), Bern. 188 pp.

Hundertmark, T., Mayer, M., McNally, C., Simons, T.J., Witte, Christof (2018). How plastics waste recycling could transform the chemical industry. McKinsey. https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry

ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework

ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines

ISO/TS 14071:2014 Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Leguern Y., Petiot C. (2010) Analyse de cycle de vie des procédés de mise en forme d'emballages souples complexes. 141

Mieth A., Hoekstra E., Simoneau C. (2016) Guidance for the identification of polymers in multilayer films used in food contact materials: User guide of selected practices to determine the nature of layers; EUR 27816 EN; doi:10.2788/10593

RecyClass. (2022). RecyClass Design Book. A Step-by-step Guide to Plastic Packaging Recyclability. Brussels: Plastics Recyclers Europe. https://recyclass.eu/wp-content/uploads/2022/06/RecyClass_Design-Book_digital_June-2022.pdf

RecyClass (2024). Design for Recycling Guidelines. https://recyclass.eu/recyclability/design-for-recycling-guidelines/

Seppälä J., Posch M., Johansson M. and Hettelingh J.P. (2006): Country- dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. International Journal of Life Cycle Assessment 11(6): 403-416.

Siever, J. (2020) Gravure Printing in Europe – Status and Trends. Flexo+Tief-Druck, Ebner Media Group GmbH & Co. KG. https://www.flexotiefdruck.de/dossiers/gravure-printing-in-europe-status-and-trends/

Spekreijse, J., Vikla, K., Vis, M., Boysen-Urban, K., Philippidis, G. and M'barek, R., Bio-based value chains for chemicals, plastics and pharmaceuticals, EUR 30653 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-32459-1, doi:10.2760/712499, JRC124141.

Struijs J., Beusen A., van Jaarsveld H. and Huijbregts M.A.J. (2009): Aquatic Eutrophication. Chapter 6 in: Goedkoop M., Heijungs R., Huijbregts M.A.J., De Schryver A., Struijs J., Van Zelm R. (2009): ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition.eUNEP (2016) Global guidance for life cycle impact assessment indicators. Volume 1. ISBN: 978-92-807-3630-4. Available at: http://www.lifecycleinitiative.org/life-cycle-impact-assessment-indicators-and-characterization-factors/

Van Oers L., de Koning A., Guinee J.B. and Huppes G. (2002): Abiotic Resource Depletion in LCA. Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam.

Van Zelm R., Huijbregts M.A.J., Den Hollander H.A., Van Jaarsveld H.A., Sauter F.J., Struijs J., Van Wijnen H.J. and Van de Meent D. (2008): European characterisation factors for human health damage of PM10 and ozone in life cycle impact assessment. Atmospheric Environment 42, 441-453.

Weidema, B., & Wesnæs, M. (1996). Data quality management for life cycle inventories—an example of using data quality indicators. *Journal of Cleaner Production*, *4*(3), 167–174. http://www.sciencedirect.com/science/article/pii/S0959652696000431

Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G. (2013). Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3). St. Gallen: The ecoinvent Centre

World Meteorological Organization (WMO) (2014), Scientific Assessment of Ozone Depletion: 2014, Global Ozone Research and Monitoring Project Report No. 55, Geneva, Switzerland.

Zampori, L. and Pant, R. (2019). Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76- 00654-1, doi:10.2760/424613, JRC115959.

7. Appendix

7.1. Appendix A: Pedigree matrix

Table A- 1: Pedigree matrix used for data quality assessment (Weidema, B., & Wesnæs, M. (1996)).

Indicator score	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g., by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant to the market considered, over an adequate period to even out normal fluctuations	Representative data from >50 of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50) relevant for the market considered or >50 of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Representativeness unknown or incomplete data from a smaller number of sites and from shorter periods
Temporal correlation	Less than 3 years of difference to the time-period of the dataset	Less than 6 years difference to the time-period of the dataset	Less than 10 years difference to the time-period of the dataset	Less than 15 years difference to the time-period of the dataset	Age of data unknown or more than 15 years of difference to the time-period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

7.2. Appendix B: Overview of product footprint methodological standards

This appendix features an overview of three relevant product footprint methodologies for flexible packaging: ISO 14067, PEF and GHG Protocol. The overview should support the choice of an overall methodology for users of this guidance when conducting a product footprint, and it includes a brief description of methodological, compliance and application aspects of each standard.

Table B- 2: Overview of ISO 14067, PEF, GHG Protocol Product Standard.

Feature/Aspect	ISO 14067	PEF (Product Environmental Footprint)	GHG Protocol (Product Standard)
Scope	Focuses on the quantification of carbon footprint of products, including goods and services. Cradle-to-gate and cradle-to-grave assessment possible.	Broadens the focus to the overall environmental footprint, considering various impact categories. Cradle-to-gate and cradle-to-grave assessment possible.	Centers on measuring and managing greenhouse gas emissions across a product's life cycle. Cradle-to-gate and cradle-to-grave assessment possible.
Methodology	Life cycle assessment (LCA) methodology specific to greenhouse gas emissions throughout a product's life cycle.	Comprehensive LCA approach considering a wide range of environmental impacts, not just greenhouse gases.	Uses life cycle assessment approach for quantifying the greenhouse gas emissions associated with individual products.
Geographical Scope and Prevalence	International standard with global applicability. Recognized by industries and organizations globally.	Developed by the European Commission, with a primary focus on products within the EU market, but applicable internationally. Used mostly within the EU.	Widely recognized and used globally for GHG emissions reporting and reduction.

Feature/Aspect	ISO 14067	PEF (Product Environmental Footprint)	GHG Protocol (Product Standard)
Environmental Impact Categories	Specifically, carbon and other GHG emissions.	Multiple (total of 16) impact categories such as water use, pollution, resource depletion, etc.	Focuses on GHG emissions only.
Data Requirements	Specific to carbon footprint; requires data related to GHG emissions. No specific database requirement.	Requires detailed environmental data across 16 impact categories. Specific requirements on primary data, secondary data (as well as their quality) and database.	Requires comprehensive data on GHG emissions. Databases used should align with the methodology and scope of GHG Protocol.
Allocation Rules for Multi-Output Processes	Detailed guidance on allocation procedures.	Provides methods for allocation and system expansion.	Offers multiple options for allocation.
End-of-Life and Recycled Content Requirements	Prescribes the use of either a cut-off approach or allocation methods.	Prescribes the use of the Circular Footprint Formula (CFF)	Allows for cut-off or allocation methods.
Biogenic Carbon Accounting and Characterization	Integrated into the climate change impact assessments	Biogenic CO_2 uptake and emissions are characterized with zero impact. Biogenic content of cradle-to-gate product assessments are reported.	Biogenic CO_2 uptake and emissions are calculated and reported separately