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ORIENTING

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LCSA methodology to be implemented in WP4 demonstrations

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Provisions

Acronyms

AoP	**Area of Protection**
CA	Criticality assessment
CBS	Cost Breakdown Structure
CE	circular economy
CF	characterization factor
cLCC	conventional life cycle costing
CRM	critical raw materials
CTI2.0	Circularity transition indicators version 2.0
EC	European Commission
EI	Economic importance
EF	environmental footprint
eLCC	environmental life cycle costing
EMF	Ellen MacArthur Foundation
GLAM	United Nations Global Guidance for Life Cycle Impact Assessment Indicators
ISO	International Organization for Standardization
JRC	the European Commission's Joint Research Centre
LCA	life cycle assessment
LCC	life cycle costing
LCSA	life cycle sustainability assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
LFI	Linear Flow Index
MCI	Material Circularity Indicator

NPV	Net Present Value
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PSF	Product Sustainability Footprint
PSFR	Product Sustainability Footprint category rules
REE	rare earth elements
RSA	reference scale assessment
SETAC	Society of Environmental Toxicology and Chemistry
S-LCA	social life cycle assessment
sLCC	societal life cycle costing
SOC	soil organic carbon
SR	supply risk
UNEP	United Nations Environmental Programme
WBCSD	World Business Council for Sustainable Development
WP	work package

1. Executive summary

This report describes the draft life cycle sustainability assessment (LCSA) methodology developed in the Horizon 2020 project ORIENTING. The main objective of the project is to **develop a robust, comprehensive, and operational methodology for LCSA of products** (goods and services) to support the transition towards a circular economy. The starting point for the ORIENTING LCSA methodology is the framework proposed by UNEP/SETAC Life Cycle Initiative (UNEP/SETAC Life Cycle Initiative, 2011b). According to this framework, the methodology consists of an approach **combining environmental LCA, social LCA and life cycle costing** (LCSA = LCA + S-LCA + LCC)[1]. In addition to the three pillars addressed in the original LCSA framework, the ORIENTING LCSA methodology also includes indicators and methods that enable a coherent and practical assessment of **product circularity and raw material criticality** in the context of an LCSA study. The LCSA methodology of ORIENTING consists of four main phases: 1) goal and scope definition, 2) inventory, 3) impact assessment and 4) interpretation & integration.

The development of the ORIENTING LCSA methodology is guided by seven **main principles**: i) Adopting a life cycle perspective, ii) Comprehensiveness, iii) Relevance, iv) Interdisciplinarity, v) Consistency, vi) Transparency, vii) Operationality. According to these principles, the methodology aims at a consistent use of different assessment methods, allowing for a comprehensive and integrated assessment of different sustainability topics. However, due to the wide spectrum of topics that could be included in an LCSA, ORIENTING aims at focusing the assessment on topics that are most relevant for specific sectors and/or products. Relevance of a topic can be evaluated based on the outcome of a **materiality assessment**, which can be both a means (to select relevant topics), and an outcome (to validate/identify most important topics) of an LCSA study. A topic may be relevant because of its impacts on any of the sustainability domains, or because it is of interest to the stakeholders.

An important goal of ORIENTING is to help **overcome barriers** hindering the practical implementation of LCSA (such as lack of harmonised guidelines and tools, complexity of the methods, lack of necessary knowledge, and time and budget constraints), which are particularly critical for small and medium-sized enterprises. One of the aids developed in ORIENTING is the provision of a flexible methodological approach, where different options (different levels of LCSA) are defined to take into account the purpose of the assessment (application) and the starting point (previous knowledge, support and resources available for the assessment) of the organisation conducting (or commissioning) the assessment.

Three levels for applying LCSA are proposed in ORIENTING, namely "entry-level", "intermediate level" and "advanced level". Within ORIENTING, LCSA is considered as an iterative process that supports learning related to sustainable development, and that can be used for various purposes. When (getting more) familiar with the methods applied in LCSA, the level of detail and comprehensiveness of the assessment can be increased, and a more thorough understanding of potential sustainability impacts and benefits of a product can be gained. This idea is reflected in the development of the three levels of LCSA methodology.

While three levels are addressed in this report, the **main focus is on the full LCSA methodology (advanced level)**. The methodology will be **tested in five case studies (demonstrations)** starting from May 2022 until December 2022. The case studies are conducted for different types of products, in cooperation with five

[1] We refer to LCC, although it can be noted that the assessment of the economic pillar might not be limited to costing methods only but also embrace other indicators.

companies representing the respective industry sectors (food, pulp and paper, chemical, textile and recycling). Such companies have different size, and levels of experience in the use of life cycle approaches for sustainability assessment (from no experience to experienced users). The aim of the demonstration phase is to test the practical applicability of the methodology in different contexts and to utilise the learnings gained to further develop the methodology.

ORIENTING's LCSA framework in detail

In order to enhance practical implementation of LCSA, ORIENTING aims to **promote harmonisation and builds (as much as possible) on existing initiatives**, guidelines and standards available for the different sustainability domains. Furthermore, ORIENTING makes linkages to on-going developments related to corporate sustainability and EU policy initiatives relating to the implementation of the European Green Deal. Particular attention has been paid to identifying synergies between different approaches, in order to ease the burdens related to conducting a comprehensive LCSA.

The environmental assessment part of the LCSA is based on **life cycle assessment (LCA)**, building on the Product Environmental Footprint (PEF) method of the European Commission (EC 2021). In LCA, ORIENTING improves the impact assessment method presented in PEF for land use impacts. In the updated framework, land use is investigated through three independent indicators: biotic production, biodiversity and soil quality index, the latter one including erosion, mechanical filtration, physicochemical filtration, groundwater regeneration and soil organic carbon. The updated land use framework allows impact assessment on three levels, depending on data availability and relevance of land use impacts in the studied value chain, possibly leading to a regionalized impact assessment.

Beyond assessing resource use in (environmental) LCA, the ORIENTING LCSA framework also proposes the assessment of how market, regulations and socio-political aspects of the supply chain may affect the resource availability in the product system through **Criticality Assessment (CA)**. To this end, the framework also makes use of the Life Cycle Inventory (LCI) information from LCA. The integration of CA is suggested according to a tiered approach from the analysis of the Bill of Materials (BoM) to the analysis of elementary flows (for materials) in the supply chain's inventory. First, the approach suggests the identification of critical raw materials (CRM) according to the latest version of the EU CRM list, followed by a broader assessment of the criticality of materials through characterisation factors (CF) based on the European Commission's CA method and provided in the project. To overcome the limitation of the number of materials characterised, the framework will also test the optional use of the GeoPolRisk method to characterise criticality.

Next to criticality of materials, **circularity** of products is also analysed. In ORIENTING, it is considered that circularity is not an end, but a means toward sustainability. Consequently, circularity should be analysed in the context of an LCSA study, and not as stand-alone topic. The ORIENTING proposal integrates a three-level assessment complexity to encompass companies in various knowledge stages related to circular economy. At the entry level, a qualitative assessment is presented to create inspiration and awareness of the circular economy in products. It also includes a product circularity assessment with a checklist for early-stage design. At the intermediate and advanced levels, a quantitative assessment is proposed using circularity indicators. At the intermediate level, the indicator % Circularity from CTI2.0 (WBCSD, 2021) can measure the input and output flows of a product, mostly evaluating information gathered from a BoM perspective. At the advanced level, a more complex assessment is proposed using the Material Circularity Indicator (MCI) (EMF & Granta, 2015), which also includes considerations about product use and materials' end-of-life. Apart from them, elements leading to the quantification of aggregated circularity indicators (e.g., use of materials, production of waste) are also to be analysed in a system of indicators describing different Circular Economy aspects.

ORIENTING also pursues an alignment between LCC and LCA. There are three main approaches to develop the **economic part of an LCSA**. Conventional LCC (cLCC) aims at considering internalised costs (and benefits) associated with the life cycle of products and that are directly covered by one or more actors in the product life cycle. Environmental LCC (eLCC) also considers externalities relating to environmental issues that are known to be internalised in the decision-making relevant future, whilst societal LCC (sLCC) values all externalities in monetary terms. The ORIENTING methodology provides practical solutions to conduct eLCC of products and align with LCA, as well as account for different stakeholder perspectives, i.e., producers, consumers and policy makers.

One of the developments to ease practical implementation of LCC is the Cost Breakdown Structure (CBS) related to product systems (inventory level). The CBS should be used for materiality assessment, and for the collection and organisation of data. The CBS can also serve as an interface with the environmental LCI, thereby giving visibility to environment-related costs and supporting the quantification of externalities, if needed. At entry level, it can instead serve as a checklist.

The impact assessment framework for LCC is flexible and (depending on the goal and scope) can accommodate costs, as well as potential benefits and not-yet internalised externalities associated with different life cycle stages at different points in time. The methodology proposes four aggregated economic indicators that differ in terms of inclusion of costs and benefits and in their approach to discounting future monetary flows, i.e., total undiscounted cost, total discounted cost, total undiscounted value, and net present value (also referred to as total discounted value).

The **S-LCA methodology** proposed in ORIENTING builds upon the UNEP (2020) Guidelines for S-LCA and the Handbook for Product Social Impact Assessment (Goedkoop et al., 2020). The S-LCA methodology is characterised by a qualitative approach for assessing social performances and risks. Social performances refer to the principles, practices, and outcomes of businesses' relationships with people, organisations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard (UNEP 2020). Both social performances and risks are assessed using the reference scale approach (RSA). A direct implication is that the result of an S-LCA study that uses the RSA consists of information – qualitative or semi-quantitative – on the presence and/or severity of a social performance or risk: these outcomes can be organised per stakeholders' categories, per life cycle stages, and/or per social topics, or could even be further aggregated.

The S-LCA proposed for ORIENTING aims at providing practical solutions to help companies and practitioners in implementing the assessment. These includes a harmonised list of social topics and their definition, building upon the above-mentioned sources and current practice. As a starting point for the ORIENTING case studies, guidelines for the identification of material topics were prepared for the following sectors/products: pulp and paper, chemicals, processed tomatoes, concrete recycling, and technical coats. Since data collection is currently one of the bottlenecks within S-LCA studies, potential levels for implementing the S-LCA have been considered by providing guidance on the type and quality of data to collect for the different levels (from entry to advanced level). Finally, an attempt has been made to align the assessment with some of the concepts and requirements set in latest European legislation (Social taxonomy and sustainability reporting).

In addition to assessments focusing on different sustainability domains and topics, a comprehensive and consistent LCSA also entails the **integrated assessment** of sustainability aspects over the life cycle of products, to support the interpretation of results. This is done in the integration phase, which is a fundamental step of the LCSA methodology of ORIENTING. Addressing all relevant aspects of sustainability over the entire life cycle of products and presenting the results in a comprehensive, clear and transparent manner is a challenging task for which no widely recognised approach exists (at least to date). ORIENTING aims to fill this gap by providing an approach to select adequate methods that allow for the integration, interpretation and communication of multidimensional LCSA information, whilst managing in an operational manner its inherent complexities, such as potential shifts of burdens across impact categories, sustainability topics, life cycle stages, and stakeholders. Alternative approaches/methods for integration will be tested during the case studies, and a dedicated tool for supporting the interpretation and integration phases is developed during the project.

Concluding remarks and next steps

While each of the building blocks of the ORIENTING methodology could be applied individually (as stand-alone-method for specific purposes), **ORIENTING aims at producing a comprehensive LCSA methodology, in which the different assessments are jointly applied in a consistent manner**. This will allow taking advantage of synergies created by the use of methods addressing different aspects of sustainability, but also the identification of potential trade-offs between the different domains and topics, and life cycle stages.

In addition to **practical application and testing of the methodology (May-December 2022)**, feedback for refining the currently proposed methodology is collected during a **stakeholder consultation that takes place in May 2022**. Based on the feedback obtained and the experiences collected during the consultation and implementation phases, a **final version of the LCSA methodology will be published in August 2023**. The methodology will be presented in an LCSA Handbook that will be complemented with training materials, data specifications and a tool for integrating LCSA results from different domains and topics. Finally, a guidance document will be produced for setting the ground to the (future) development of product sustainability footprint category rules (PSFCR) based on the experiences gained in the project.

2. Terms and definitions

This section introduces some of the key terms and definitions that are applied for life cycle sustainability assessment (LCSA) and/or the different sustainability topics and domains. Explained terms are presented in alphabetical order. Currently, the terminology applied in different standards and guidelines relevant for LCSA is not harmonised. Differences in terminology can be found for example between the ISO14040-44 standards for life cycle assessment (LCA) and the Product Environmental Footprint (PEF) method, and in the different guidelines and documents that were the starting points for the assessment of environmental, economic and social topics, as well as circular economy and circularity aspects.

One of the aims of the ORIENTING project is to harmonise the use of terminology within and between different sustainability domains and topics that are included in the assessment. This process is still in an early phase, and some inconsistencies can still be found in the current document. When special terms or definitions are applied, clarifications or references to clarifying documents are provided. Further information and explanations can be added based on the feedback received during the stakeholder consultation. Efforts related to harmonisation will continue throughout the project.

Area of Protection (AoP): a state that is desired to be sustained or protected and is of recognized value to society (UNEP 2020).

Aggregation: refers to the process of combining indicators presenting compatible units into single scores, composite indices and indicators (Gan et al., 2017a); aggregation might include normalisation and/or weighting. Note: aggregation, can be performed at different levels (e.g., individual sustainability domains and sub-domains, areas of protection, overall LCSA); additionally, aggregation can also involve the use of visualisation techniques.

Allocation: partioning the inputs and outputs of a process or a product system producing more than one product between these different products.

Base year: In an economic assessment, a "base year" is the reference year in whose prices costs are expressed. Generally, past costs are updated to the base year considering inflation, while future costs are generally discounted to the base year by means of a certain discount rate.

Bill of Materials (BoM): A bill of materials or product structure (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product(European Commission, 2018)

Characterisation Factor (CF): Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator (ISO 14040).

Co-product: Any of two or more products coming from the same unit process or product system.

Complementary data (LCC context): Data other than cost needed, e.g., in discounting, currency or base year adjustments.

Conventional Life Cycle Costing (cLCC): a stand-alone assessment (i.e. no alignment with environmental LCA) of internal costs (i.e. private cash flows) that is carried out from the perspective of a single stakeholder.

Cost element: a cost that can be classified at least according to economic inventory category, life cycle stage, and stakeholder ("cost bearer"). Further specifications can be useful (e.g., a specific material or energy source within the economic inventory category "Materials/utility costs").

Cradle-to-gate: an assessment that is limited to the life cycle stages "raw material acquisition and pre-processing" (including production of parts and components) and "manufacturing" (production of the main product). Gate means gate of the factory.

Cradle-to-grave: an assessment that covers all life cycle stages.

Critical Raw Materials (CRMs) are defined in ORIENTING as those raw materials of high importance to the economy of a region (e.g., the EU) that are associated with high risk of supply disruption.

Criticality Assessment (CA) is an approach to assess supply risks of resources and the vulnerability (e.g. according to economic importance) of a system (product, company, country or region) to a supply disruption according to its needs. It is intended to provide insights for criticality mitigation plans.

Discounting: process of calculating the present value of future monetary values (taken from ISO-14008, 2019).

Economic inventory category: a set of cost elements which, due to the similar nature, are grouped together. For the purpose of the ORIENTING LCSA framework, the following economic inventory categories are distinguished: A. Capital costs; B. Material/utility costs; C. Personnel cost; D. Transport cost; E. Other operational costs; F. Emission & discharge & waste related costs; G. Soon-to-be-internalised external costs; H. Non-internalised external costs; I. Positive cash flows.

Elementary flow: (a) material or energy flow that has been drawn from the environment without previous human transformation and that enters the system being studied; or (b) material or energy flow that leaves the system being studied and is released into the environment without subsequent human transformation. (ISO 14040).

(Impact category) Endpoint: Attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern (ISO 14040).

Environmental Life Cycle Costing (eLCC): an assessment of internal costs (i.e. private cash flows) and of those environmental externalities that are likely to be internalised in the "decision-relevant future", carried out from the perspective of one or more stakeholders and aligned with environmental LCA (i.e. functional unit, system boundaries, life cycle stages).

Externality: consequence of an activity that affects interested parties other than the organization undertaking the activity, for which the organization is neither compensated nor penalized through markets or regulatory mechanisms (taken from ISO-14007, 2019). If a policy is already in place[2] that will cause for example a release to be priced in the near future (e.g., a CO_2 tax) then this can be referred to as "soon-to-be-internalised externality" (see also eLCC). Note that for the latter case internalisation might not be complete.

Flow property: Property of elementary or product flow such as elemental content or energy content.

Functional unit (FU): Quantified performance of a product system for use as a reference unit (ISO 14040).

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[2] Note that policies under negotiation or intended to be enacted are disregarded.

Hotspot: life cycle stage or process in which significant environmental, economic or social impacts (or risks) can potentially occur, and to which it would be worth to pay specific attention in the future; see also "Social hotspot".

Impact category: Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (ISO 14040), for example climate change or acidification.

Impact category indicator: Quantifiable representation of an impact category.

Impact pathway: Cause-effect chain from life cycle inventory results to impact assessment results (for example from CO_2-emissions to global warming potential to potential damages to human health; see also "Midpoint" and "Endpoint").

Intermediate flow: product, material or energy flow occurring between unit processes of the product system being studied (ISO 14040).

Integration: integrated analysis of the outcomes of LCSA across different sustainability domains (environmental, social, economic), including also the consideration of circularity and criticality aspects.

Life cycle (LC): Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14040).

Life cycle assessment (LCA): compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life cycle inventory (LCI): compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life cycle stage: see life cycle; according to the PEF category rules, the default life cycle stages presented shall be as a minimum: Raw material acquisition and pre-processing (including production of parts and unspecific components); Production of the main product; Product distribution and storage; Use stage (if in scope); End-of-life (including product, recovery / recycling, if in scope) ((European Commission, 2018)).

Life cycle sustainability assessment (LCSA): a life cycle-based assessment (of products) that takes into account all sustainability domains. In the framework of ORIENTING project, LCSA covers relevant life cycle impacts and benefits related to all assessed sustainability domains (environmental, economic and social) and analyses them in relation to each other. ORIENTING's LCSA also addresses the lifetime and circularity of products as well as the criticality of materials.

Materials' criticality: corresponds to the output of a material criticality assessment. It refers to materials that are critical (i.e. critical raw materials, CRMs) to a product system. Criticality is evaluated from the point of view of supply risks. Economic considerations may also play a role.

Materiality assessment: a process to define topics that are important because of their impact on stakeholders/business and/or because they are considered relevant by the target audience who desire to have information on them (ORIENTING, 2021a).

(Impact category) Midpoint: The term 'midpoint' expresses that this point is located on the impact pathway at an intermediate position between the LCI results and the ultimate environmental damage (often referred to as endpoints) (Jolliet et al., 2004)

Net present value (NPV) (or total discounted value): most aggregated economic indicator that is computed using discounting and including both costs and benefits / revenues.

Normalisation: Calculating the magnitude of category indicator results relative to reference information (ISO 14044; ISO/DTS 14074:2021).

Present costs (or total discounted costs): most aggregated economic indicator that is computed using discounting and including only costs.

Primary data: information about a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source. Primary data can also include descriptive, qualitative information concerning the studied processes, life cycle stages, organisations or stakeholders.

Process: Set of interrelated or interacting activities that transforms inputs into outputs (ISO 14040); activity is often used as a synonym.

Product: any goods or service (ISO 14040).

Product circularity: state of a product where value is retained, regenerated, or added within a technical or a biological system whilst benefiting sustainable development (according to current definition of Circular Economy within ISO TC323 WG1).

Product flow: Products entering from or leaving to another product system (ISO 14040).

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (ISO 14040).

Reference flow: measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.

Product utility refers to the perception of the consumer in regard to what the product provides, besides its function (the capacity of a good to satisfy a need). This appreciation is linked with his/her cultural and social values, as well as his/her desires and satisfaction. Product utility can be identified in technical terms (quality, functionality etc.) or in social terms (convenience, prestige, etc.) (UNEP 2020).

Reference unit: Quantified performance of a product system to which LCSA data and impacts are referred.

Secondary data - information obtained from sources other than primary data (databases, literature, etc.).

Social hotspot: the location and/or activity in the life cycle where a social risk is likely to occur (UNEP, 2020).

Social impacts are consequences of positive or negative pressures on social areas of protection, often defined as human dignity and well-being of stakeholders.

Social performances refer to the principles, practices, and outcomes of businesses' relationships with people, organizations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard.

Social risk is a measure of the likelihood of negative effects only (damage, injury, loss) that may be avoided through preventive actions.

Social topic is a generic terminology used to describe more generically *social issues* of concern, both positive and negative. They can include social risks, or can be measured with reference to performances, or give rise to social impacts.

Societal Life Cycle Costing (sLCC): an assessment of internal costs (i.e. private cash flows) and of externalities beyond those that are likely to be internalised soon, carried out from the societal perspective (incl. policy makers) (See Hunkeler, Lichtenvort, & Rebitzer, 2008).

Stakeholder: person or organisation that can affect, be affected by, or perceive itself to be affected by a decision or activity" (ISO 14050:2020).

Total undiscounted costs: most aggregated economic indicator that is computed by disregarding discounting and including only costs.

Total undiscounted value: most aggregated economic indicator that is computed by disregarding discounting and including both costs and benefits / revenues.

Unit process: Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO 14040).

Waste (flow): Substances or objects which the holder intends or is required to dispose of (ISO 14040).

Weighting: Converting and possibly aggregating indicator results across impact categories using weighting factors based on value choices (ISO/DTS 14074:2021). The process converts different indicator results across impact categories into unit formats addressing specific issues (e.g., monetary value) (UNEP/SETAC Life Cycle Initiative, 2011b).

3. Introduction and structure of the report

> ORIENTING is a Horizon 2020 project having the main objective to develop a robust and operational methodology for life cycle sustainability assessment (LCSA) of products (goods and services). The LCSA methodology adopts a life-cycle approach that addresses environmental, social and economic topics in a consistent and integrated way, and considers circular economy and material criticality issues. Methodology presented in this report is a draft version that will be developed further based on feedback received during a stakeholder consultation and the experiences gained from implementing the methodology in practical case studies. The final version of the methodology should be published in August 2023.

3.1 Introduction to ORIENTING LCSA

Life cycle sustainability assessment is a methodology that has been developed for evaluating potential environmental, economic and social impacts of products over their life cycle. The aim of this comprehensive and systematic assessment is to avoid shifting burdens from one life cycle phase, and from one sustainability domain, topic, or impact category, to another. LCSA can find a broad range of uses in market and policy applications. In general terms, it could be used for example:

- As a screening tool to identify hotspots and areas of concerns along the life cycle of products, to avoid burden shifting and to learn how to improve the sustainability performance.
- As a tool to assess the sustainability performance of different product options, potentially in comparison with product options delivering similar functions, or with other benchmarks.

This report describes the draft LCSA methodology developed in ORIENTING. The methodology presented in this report will be tested in five case studies (demonstrations) starting from May 2022. The case studies are conducted for different types of products in cooperation with five companies that represent different industry sectors (food, pulp and paper, chemical, textile and recycling), are of different size, and have different levels of experience in life cycle based sustainability assessment (from no experience to experienced users). The aim of the demonstration phase is to test the practical applicability of the methodology in different contexts and to utilise the learnings gained for developing a methodology that is robust, comprehensive, and operational.

An important goal of ORIENTING is to lower the barriers hindering the practical implementation of LCSA. During the project, special attention is given to development of supporting tools and guidance, and in making the methodology accessible and applicable for those who do not have previous experience about the use of life cycle based tools, or might have limited resources for conducting the assessment. It was recognised that developing a flexible approach to facilitate the implementation of LCSA to users with different levels of expertise or resources (e.g., SMEs vs. multinationals) is a critical need to consistently operationalise LCSA. Consequently, ORIENTING aims at providing methodological options (different levels of LCSA), which are defined considering both the purpose of the assessment (application) and the starting point (previous knowledge, support and resources available for the assessment) of the organisation conducting (or commissioning) the assessment.

Three levels for applying LCSA are proposed in ORIENTING, namely entry-level, intermediate level and advanced level. In this report, we will propose an approach to be followed at the entry level, but the main focus will be the full LCSA methodology (advanced level), which will be applied during the case studies. One of the aims of the case studies is to explore alternative ways for refining, as well as streamlining, the advanced level methodology to increase its applicability and lower entry barriers. For this purpose, potential options for streamlining the methodology are presented already in this report.

In addition to practical testing of the methodology, feedback for the currently proposed methodology is collected during a stakeholder consultation that will take place in May 2022. Based on the feedback and experiences collected during the consultation and implementation phases, a final version of the LCSA methodology will be published in August 2023. The methodology will be presented in an LCSA Handbook that will be complemented with a proposal for developing future product sustainability footprint category rules (PSFCR), training materials, data specifications and a dedicated tool for integrating LCSA results from different domains and topics.

3.2 Report structure and how to best make use of it

The first part of the report introduces the background and the main idea of the ORIENTING LCSA methodology. It explains terms and definitions (Chapter 2), the building blocks (Chapter 4) and the main principles (Chapter 5) of the methodology. Potential applications for the methodology are presented in Chapter 6, while Chapter 7 introduces the proposed three levels of the LCSA methodology (entry, intermediate and advanced). The approach to be applied for the entry-level assessment is presented in Chapter 8.

Actual LCSA methodology description starts from Chapter 9 which is focused on the first phase of an LCSA study, the **goal and scope definition**. Chapters 10-15 describe the LCSA **inventory phase**, for environmental assessment (Chapter 11), circularity (Chapter 12), criticality (Chapter 13), economic assessment (Chapter 14) and social assessment (Chapter 15).

The **impact assessment** phase for an LCSA study is presented in Chapters 16-22, starting from environmental assessment, which is introduced in Chapter 17. Impact assessment for circularity is introduced in Chapter 18 and for criticality in Chapter 19. The economic impact assessment phase is presented in Chapter 20. The main idea of the process to be followed for assessing social performance is shortly explained in Chapter 21.

The final phase of an LCSA study, namely the **interpretation and integration** phase, is described in Chapter 22. This chapter introduces several methods and approaches that could be used for aggregating the results either within or between the different domains of LCSA. Alternative approaches for integration are tested during the project. Finally, Chapter 23 briefly summarises the next steps of ORIENTING project.

If you do not have previous experience from LCSA, we recommend you to focus on **the first part of ther report until the entry-level assessment** (Chapter 8). Especially Chapters 7 and 8 are recommended. However, Chapters 4 & 5 introducing the building blocks and the main principles of the methodology are also important.

If you are familiar with the idea of LCSA and the life cycle-based methods, it is recommended to first have a look at the LCSA **building blocks and principles in Chapters 4 and 5**. The description of the comprehensive (advanced level) **LCSA methodology starts from Chapter 9**. Use of normative language and provision boxes that give concise instructions is explained in the following Chapter 3.3.

3.3 Using normative language and displaying of provisions

LCA practitioners are generally well familiar with normative language, for example, from experience with following the ISO LCA standards (ISO-14040, 2006; ISO-14044, 2006), the Product Environmental Footprint (PEF) guidance (2021), the International Reference Life Cycle Data System (ILCD) Handbook (EC-JRC, 2010). However, the proposed ORIENTING LCSA methodology is not a standard but rather a recommendation for conducting an LCSA study on products. While acknowledging the merits of using normative language in terms of clarity about what is absolutely required, merely recommended or allowed, it has not been applied consistently in this document, as described next.

A more comprehensive and harmonised use of prescriptions and normative language is expected for the final version of the methodology (which will be presented in ORIENTING D2.9). Nevertheless, some examples of how this will take place are already reported in D2.3. Wherever there are chapters with provision boxes/tables (i.e., chapter **Error! Reference source not found.** on goal and scope and chapters on the economic environmental and assessments, i.e., chapters 11, 14, 17 and 0), requirements, guidance (recommendations) and options (permissions without the need for further justification) are given by using the terms “shall”, “should” or “may”, respectively. The word “can” points at possibilities or capabilities. The provision boxes are intended to provide concise summaries for those who are already familiar with the different methods and approaches used for LCSA, and related terminology.

In the other parts of the document, the following definitions for the terms “shall”, “should”, “may” and “can” are used:

- Word “shall” indicates a requirement that has to be followed in order to be compatible with the principles and the principal idea of the proposed methodology.
- Word “should” indicates a recommendation that an organisation or commissioner of the study shall at least test or consider doing or including as part of the assessment, whenever relevant and possible.
- Words “may” or “can” indicate an option that could followed when possible, for example if willing to go deeper in the analysis.

4. Building blocks of ORIENTING LCSA methodology

The starting point for the ORIENTING LCSA methodology is the framework proposed by UNEP/SETAC Life Cycle Initiative (UNEP/SETAC Life Cycle Initiative, 2011b). According to this framework, the ORIENTING LCSA methodology consists of an environmental LCA, a social LCA and a life cycle costing approach (**LCSA = LCA + S-LCA + LCC**)[3]. In addition to the three pillars included in the original LCSA framework, the ORIENTING LCSA methodology includes indicators and methods that enable a coherent and practical assessment of product circularity and raw material criticality in the context of an LCSA study. This chapter briefly introduces the building blocks of the ORIENTING LCSA methodology.

The potential environmental impacts of human actions on quality of natural environment, availability of natural resources and human health are assessed with **life cycle assessment (LCA)**. The assessment of the impacts along the value chain of products[4] is internationally standardised through the life cycle assessment (LCA) methodology (ISO-14040, 2006). Since the ISO standards do not fully prescribe specific methodological details, the European Commission has created the Product Environmental Footprint (PEF) (European Commission, 2021a) method to harmonize the environmental assessments of products in EU. The environmental assessment part of the LCSA in ORIENTING uses the PEF method but supplements the assessment with new indicators for land use, biodiversity and biotic production.

Striving for the political target of a Circular Economy (CE), as exemplified in the2nd Circular Economy Action Plan published in 2020 by the European Commission (EC), different circularity indicators have been developed that are used in a variety of contexts. In ORIENTING, which is focused on the assessment of products, CE and circularity are intended to promote the extended and/or cyclical use of products, their parts and materials. Furthermore, within ORIENTING, **circularity is considered as a means to achieve sustainability**. Thus, circularity is not an impact per se. In ORIENTING's, two circularity indicators have been detailed and discussed. While the two indicators alone are not yet sufficient for describing all the different aspects of circularity, they can mostly be calculated based on data that is collected for the quantification of the environmental life cycle inventory. Selected indicators are the % Circularity from Circularity Transition Indicators (CTI2.0) and Material Circularity Indicator (MCI)[5]. In ORIENTING, it is considered that circularity should be assessed together with other indicators as part of an LCSA study, in order to capture potential sustainability impacts

Next to circularity, **criticality of materials** is another CE topic of focus for ORIENTING. Raw materials are essential for the production of a broad range of goods and services and for the development of eco-efficient technologies (e.g. batteries, renewable energies). The high dependency on raw materials imports (e.g. into the EU) and the increasing global demand for those materials highlight the concerns over the risks of supply disruption. In ORIENTING, "critical raw materials" (CRMs) are defined according to European Commission

[3] We refer to LCC, although it can be noted that the assessment of the economic pillar might not be limited to costing methods only but also embrace other indicators.
[4] Product in ORIENTING LCSA generally refers to good or service
[5] The Product Circularity Indicator (PCI) was another promising indicator under consideration by the ORIENTING team (see deliverable D1.6 of ORIENTING). This is based on MCI and include a more detailed overview of materials circularity. However, it was not proposed for two main reasons: (1) it cannot be used with biobased products and (2) the rigorous quantification of some parameters may be complex and make its operationalization difficult.

(2017b) as those "raw materials of high importance to the economy of the EU and whose supply is associated with high risk". Thus, the two main parameters considered here to determine criticality are economic importance (EI) and supply risk (SR). As economic importance is context- and scope-dependent, the criticality of materials is most commonly defined in terms of factors influencing supply risk. These factors are associated with physical/technical/geological availability, to economic/strategic/market reasons, regulatory reasons, and political stability/governance of supplying countries (Dewulf, Blengini, Pennington, Nuss, & Nassar, 2016). Two criticality approaches are proposed as part of ORIENTING LCSA framework: the European Commisions's Criticality Assessment (EC-CA) and the GeoPolRisk.

Life Cycle Costing (LCC), as the economic pillar of LCSA, is a methodology for calculating the costs (and, if extended, also benefits) over the *life cycle*[6] of a product directly borne by one or more actors involved (supplier, producer, user/consumer, end-of-life actor). When applied at product level, LCC generally aims to estimate costs associated with the production, commercialisation, use, and end-of-life, i.e. by default extending beyond the producing firm's own boundaries.

One advantage of conducting an LCC study is to be able to differentiate product-related cost elements by life cycle stages/processes, by actors, and by type of costs. Compared to conventional cost accounting and cost management methods, LCC conducted at the product level allows for much higher granularity and for adopting a system perspective. LCC is also an essential link to connect environmental and social concerns with core business strategies and detect synergies between the three pillars that can allow moving towards sustainable development. Furthermore, LCC can be used to integrate certain environmental and social costs that are not reflected in current prices (i.e. so-called externalities).

The evaluation of the potential social impacts and benefits will be carried out with the **Social LCA (S-LCA)** methodology. S-LCA aims to assess social performances and risks of products along their life cycle, including those that are at remote stages of the value chain in which companies are involved. The ultimate goal of the assessment is to improve human dignity and wellbeing. S-LCA is rooted in the stakeholders' perspective: stakeholders are those who experience and are affected by the behaviour of organizations (manufactured products), and at the same time they can affect the product life cycle with their own behaviour.

Within ORIENTING, the S-LCA focuses on understanding and assessing social performances and risks, using the reference scale approach (RSA). In RSA, social performances are evaluated based on pre-defined, specific reference points of expected activity. The approach does not establish a direct link between the activity and long-term impacts but rather estimates the likely magnitude and significance of potential impacts in the assessed product system (UNEP, 2020).

A simplified overview of the LCSA methodology is presented in Figure 1. According to the recommendation from the Life Cycle Initiative (Valdivia et al., 2021), the LCSA methodology follows the four main phases described in ISO14040 and 14044 (2006; 2020) (i.e., Goal and scope definition, Life Cycle Inventory analysis, Life Cycle Impact assessment, and Interpretation). The content of the phases can be adapted to serve the specific needs of the each of the assessed sustainability domains and/or topics, and the purpose of the study. With the circulating arrows on the right-hand side, the figure highlights the iterative nature of the LCSA

[6] Life cycle costing can address a product's entire life cycle or (a) selected stage(s) or periods of interest thereof.

process. In practice, this means that results and learnings gained in each of the phases can affect the following phases or lead to further adjustments of decisions made in earlier steps.

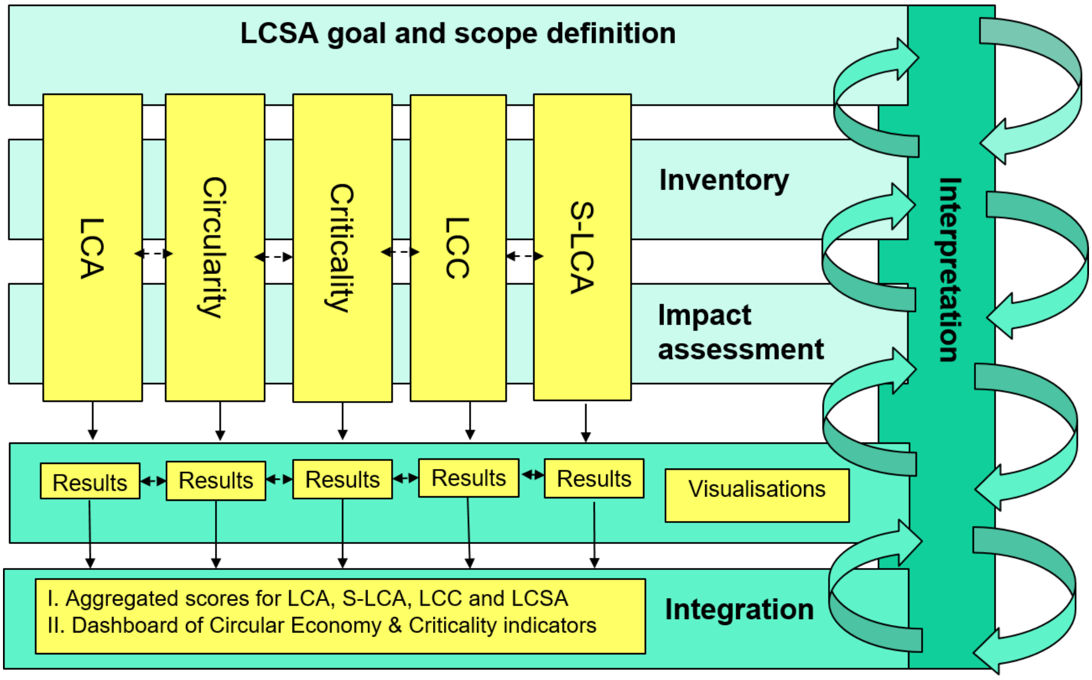


Figure 1 Simplified illustration of the ORIENTING LCSA in its current state of development

Furthermore, it must be highlighted that, while each assessment could be applied individually (as stand-alone-method for specific purposes), ORIENTING aims at producing a comprehensive LCSA methodology, in which the different **assessments are jointly applied and integrated in a consistent manner**. Options for **integrating and aggregating** the results from an LCSA study are discussed in Chapter 22. A dedicated tool for supporting the interpretation and integration phases will be developed and tested during the project.

Finally, LCSA is considered as a process that supports learning related to sustainable development, and that can be used for various purposes. When getting more familiar with the methods applied for LCSA, the level of detail and comprehensiveness of the assessment can be increased, and a more thorough understanding of potential sustainability impacts and benefits of a product can be gained. This idea is reflected in the development of the three levels of LCSA methodology, which are more thoroughly described in Chapters 7-8.

5. Principles of LCSA

The development and implementation of the ORIENTING LCSA methodology are guided by seven main principles: Adopting a life cycle perspective, Comprehensiveness, Relevance, Interdisciplinarity, Consistency, Transparency and Operationality. The principles were drafted taking into account existing standards, guidelines and frameworks relevant for the ORIENTING LCSA methodology.[7] Updates and modifications to the principles will be made upon need, based on the feedback received and the experience gained during the project.

5.1 Adopting a life cycle perspective

The ORIENTING LCSA methodology covers the entire life cycle of a product[8]. Any deviations need to be explained and transparently communicated (ISO-14040, 2006; UNEP/SETAC Life Cycle Initiative, 2011b; Valdivia et al., 2021). The life cycle perspective spans from extraction of resources, production of materials and parts, manufacturing, logistics, use, maintenance, repair/refurbishment, reuse, until the final disposal of the products for the recovery of parts and materials. The benefit of performing a full LCSA study is its system perspective and the identification of potential trade-offs between life cycle stages, as well as sustainability aspects and stakeholders.

5.2 Comprehensiveness

In the context of the ORIENTING LCSA methodology, comprehensiveness means that relevant impacts and benefits related to all assessed sustainability domains (environmental, economic and social) (UNEP/SETAC Life Cycle Initiative, 2011b) and topics (circularity and criticality) are covered and analysed in relation to each other (UNEP, 2017; Valdivia et al., 2021).

5.3 Relevance

The ORIENTING LCSA methodology is intended to serve the decision-making needs of the identified stakeholders by producing sustainability information that is relevant for the dedicated decision-context and for the stakeholders using that information (adapted from UNEP/SETAC Life Cycle Initiative, 2011a; UNEP, 2017; Valdivia et al., 2021). In addition to previous studies and available product category rules, materiality assessment as well as stakeholder input may be used for identifying what is relevant. In this context, materiality is defined as a topic that is of such relevance and importance that it could substantially influence the conclusions of the study, and the decisions and actions based on those conclusions (UNEP, 2020). In order to remain relevant, results need to be revisited during the LCSA (iterative approach) and the LCSA might need

[7] Key references were the principles presented within the UNEP/SETAC Framework for life cycle sustainability assessment (2011b), ISO14040 (2006) for life cycle assessment, UNEP (2020) Guidelines for Social LCA, Global Guidance Principles for Life Cycle Assessment Databases (UNEP/SETAC Life Cycle Initiative, 2011a), the Product Environmental Footprint method (European Commission, 2013a), the Guidelines for Providing Product Sustainability Information (UNEP, 2017) and the principles for the application of LCSA recently proposed by the Life Cycle Initiative hosted by UNEP (Valdivia et al., 2021).
[8] Product refers to any good or service, similarly to ISO14040 (2006).

to be updated from time to time in order to adjust the assessment to new contexts, insights and/or targets. This will also help a continual improvement of products from a sustainability point of view.

5.4 Interdisciplinarity

Interdisciplinarity refers to a research approach where representatives of different disciplines work together in a coordinated manner, studying different aspects of a same research problem (Pohl & Hirsch Hadorn, 2008). The ORIENTING LCSA methodology includes methods that originate from different disciplinary backgrounds. Thus, it acknowledges that both objective and subjective knowledge elements may be present within a sustainability assessment, and may use both quantitative and qualitative methods and data. While the environmental LCA relies on methods and data derived from fields of natural science and engineering, methods and approaches originating from the fields of economics and social sciences are necessary for assessing other elements of sustainability, and for supporting the interpretation of the results.

Eventually, the methodology could be developed towards transdisciplinarity (Sala, Farioli, & Zamagni, 2013)*, once the level of integration between the assessment and stakeholder involvement become more developed. Transdisciplinarity differs from interdisciplinarity in its level of integration and stakeholder involvement. Transdisciplinarity has been defined as a research approach in which methods and epistemologies originating from different disciplines are used in an integrated manner for studying a joint research problem, and involving different stakeholders in the research process* (Lang et al., 2012; Wickson, Carew, & Russell, 2006)*.*

5.5 Consistency

Consistency ensures the non-contradictory use of methodologies, models, data, and assumptions to allow for meaningful integration and interpretation of results over time (European Commission, 2013; UNEP/SETAC Life Cycle Initiative, 2011a; UNEP, 2020). In practice, this also means applying best available science and related methods and information for the production of as accurate as possible results. The principle of consistency shall be in particular followed when defining the goal and scope for the assessment, the system boundaries, the life cycle stages and the data sources and methods to use for each of the assessments. Thus, similar principles shall be followed for the different assessments, to ensure consistency in the overall sustainability results. When deviations are necessary (in order to keep the information relevant and the work manageable), these will need to be explained and reported.

5.6 Transparency

Transparency ensures an open, comprehensive and understandable presentation of information (ISO-14040, 2006) and values behind the assessment, as well as limitations (Valdivia et al., 2021). Transparency allows others to understand the assessment and to reproduce it (Valdivia et al., 2021). Due to the inherent complexity of LCSA, transparency is an important guiding principle in executing LCSAs in order to ensure proper interpretation of the results (ISO-14040, 2006).

Transparency intends to aid stakeholders in assessing the robustness and reliability of the assessment (EC, 2013). Thus, the principle of transparency shall be supported by accurate use of both methods and data to ensure robustness of the results. Additionally, it requires use of appropriate measures for handling and *communicating uncertainty. Dedicated measures for verification, critical review or peer review will be developed during the project, and will support implementing the principle of transparency in practice.*

5.7 Operationality

One of the main goals of the ORIENTING project is to make the LCSA methodology operational so that it can be applied in practice, and with a reasonable effort. In ORIENTING, operationality is supported via various means that will be studied and developed further during the project.

Firstly, operationality can be put into practice by addressing the compatibility of the ORIENTING LCSA methodology with (selected) existing and widely used guidelines, methods, indicators, tools and datasets applied for (life cycle) sustainability assessment and corporate sustainability (when relevant), and by further developing tools and practical approaches.

Secondly, LCSA implies the interaction of an integration tool with various information types and formats, and with simulation software tools used within a company. This means not only having access to methods, tools and datasets for performing a LCSA study, but also exploiting digital opportunities, such as ontologies, to enable fluent use of different databases and datasets, to support automation of calculations, and to foster interoperability between information sources (e.g., databases) and software tools.

Thirdly, operationality also means exploring some level of flexibility, depending on the purpose of the application (e.g. internal use for process improvement v. external communication) and expertise of the users in order to ease the implementation of the methodology. For example, newbies and less experienced users of LCSA could familiarise first with a streamlined approach (observing that this cannot match the same applications of a more rigorous approach), and be guided towards a full ORIENTING-compatible LCSA through progressive steps. This would allow a gradual, broad diffusion of LCSA since the early phase of implementation of the ORIENTING LCSA methodology, avoiding that only front-runners are able to apply it. However, while doing so, it must be acknowledged that the overall target of the methodology is to pursue a full LCSA (following the above-mentioned principles). Any limitations due to simplifications deviating from the full LCSA need to be transparently reported. For example, comparative claims about life cycle sustainability impacts of a product shall not be made based on streamlined approaches only.

Finally, operationality means the application of ORIENTING LCSA methodology will be supported by the development of dedicated handbook (including practical guidelines) and training materials.

6. Potential uses of LCSA

LCSA and LCSA results can be used for different types of applications or purposes with the overall aim of pursuing environmental protection and regeneration, sustainable economic growth and social equity.

Potential initiators of LCSA studies include:

- **Business**, which can use LCSA for “internal” and/or “external” purposes (e.g., targeting an improvement and/or communication of its sustainability performance).
- **Public administrators**, which can use LCSA results in their efforts to improve the sustainability performance of their activities, including the definition of green and sustainable public procurement (GPP, SPP) criteria, and the further selection of products through tendering processes.
- **Policy makers**, which can use LCSA results to correct market failures and inform the development, implementation and monitoring of policies for products.

Furthermore, other relevant actors involved in the above applications include:

- **Analysts, consultancies and universities**, who can support those requesting or conducting an LCSA via the provision of tools and training (to develop LCSA capacity), or can produce - LCSA information.
- **Non-govermental organisations,** which may either produce or use information from LCSA studies for informing consumers, authorities and other actors in making more sustainable decisions
- **Consumers**, who can base their purchase decisions on LCSA information provided by other actors (e.g., business or NGOs).

Consequently, LCSA can find a broad range of uses and applications in different market and policy applications, which might be targeted to different audiences. Potential LCSA applications for companies and within policy contexts are presented in Chapters 6.1 and 6.2.

In ORIENTING it is considered that different types of applications can present different methodological requirements and needs, while companies and other actors involved in the application can present different levels of resources and experience in LCSA. The methodology and tools developed within ORIENTING aim at considering these aspects. Chapter 7 presents the three levels of ORIENTING methodology, which aim at taking into account both the availability of resources and prior knowledge for conducting the assessment, but also the intended application and audience for the study. Methodological requirements for the applications presented in Chapter 6 are sketched out in Chapter 7.

6.1 Company uses

Within companies, LCSA can be applied in different ways and for different purposes. Broadly, applications for companies can be classified as internal (e.g., product development) or external (e.g., sustainability communication, regulatory compliance). While it is acknowledged that companies exist in many legal or organisational forms and sizes (e.g., from large multinationals, to SMEs and start-ups), and as a result the applications of LCSA can vary, this section aims to generalize LCSA applications for companies. Within the following sections, the applications have been categorized according to the main target audiences that could be either internal (Table 1) or external (Table 2) to the company.

Table 1. Examples of potential internal applications of LCSA

Purpose for which LCSA information is used	Description	Target audience
Learning about sustainability		
Understanding sustainability issues along the life cycle of a product, also to inform **sustainability strategies**	A study is done to understand, and/or learn how to assess, sustainability issues along the life cycle of products. Such information could also inform the analysis of the sustainability performance of an organisation. This may be followed by new studies aimed at increasing the comprehensiveness and accuracy of information and/or achieving more specific purposes.	Internal to the organisation (e.g., CEOs, managers, R&D, employees)
Managing and improving sustainability of products		
(A) Process/product design improvement & optimisation	Understanding sustainability issues in the value chain of products and accordingly modifying the design of processes and products to improve and optimise their sustainability performance (e.g., switching to circular business model, using more sustainable materials, improving manufacturing efficiencies, interacting with users, influencing end of life fate).	Internal to the organisation (e.g., CEOs, managers, designers, R&D)
(B) New technology development	Understanding sustainability issues associated with new technologies, processes and products under development, and improve their design accordingly.	Internal to the organisation (e.g., CEOs, managers, designers, R&D)
(C) Life cycle management	Understanding sustainability issues in the life cycle of products manufactured by a company and accordingly modifying upstream processes (e.g., selection of suppliers) and downstream processes (e.g., product distribution and reverse logistic) to improve the sustainability performance.	Internal to the organisation (e.g., managers, procurers, designers), but also external (suppliers)

Table 2 Examples of potential external applications of LCSA

Purpose for which LCSA information is used	Description	Target audience
Reporting of product sustainability information		
(A) Reporting of information on products, without comparative statements	Assessment and provision of (auditable) information about the sustainability of invidual products (e.g., for value chain transparency and collaboration, policy compliance).	External to the organisation: value chain partners, customers, competitors, regulators, other stakeholders.
(B) Reporting of information on products, with strict comparative requirements	Communication of auditable and comparable sustainability information to customers for marketing purposes (e.g., via the PEFs, EPDs and other sustainability certification schemes).	External to the organisation: customers (incl. public administrations)

6.2 Policy linkages/policy support

European environmental policy requires that sustainability information is provided in a transparent, understandable, and reliable way to avoid green- and social-washing as also reflected in recent initiatives such as Sustainable Product Initiative (European Commission, 2022a), Safe and Sustainable-by-Design initiative (European Commission, 2022c). This is even a more important issue now that policy makers urge to accelerate the transition towards a sustainable economy, which will also imply significant investments (European Commission, 2022b). In this context, LCSA can find practical use in a number of policy applications, as described in the following and summarised in Table 3.

LCSA could help ensure that products in the EU market effectively contribute to the achievement of sustainable development, in line with the objectives of the European Green Deal. However, the transition towards sustainability is far from proceeding autonomously through the free will of companies and consumers, potentially basing their purchase decision on LCSA information. Effective assessment and verification procedures, governance/control by independent third-party organisation(s) and policies are necessary to correct and/or to boost market evolution.

Furthermore, LCSA could be used to evaluate and monitor the effects of such policies. This is particularly relevant now that sustainability aspects must be systematically integrated into policy initiatives to enhance the promotion of sustainable consumption and production patterns.

LCSA can be integrated in policymaking, also building on the experience gained in the EU with the Environmental Footprint (European Commission, 2021a) and, more in general, the increasing consideration of LCA and life cycle thinking for policy purposes (Sala, Amadei, Beylot, & Ardente, 2021). In particular, LCSA information can directly be used in the development of sustainability criteria in sustainable product policy tools (e.g., Ecodesign, Energy Label, Ecolabel, Green Public Procurement), as well as the activities covered by the EU Taxonomy. Prospectively, LCSA could be also integrated in Level(s) (Dodd, Donatello, & Cordella, 2021)), the EU framework of indicators to assess the sustainability performance of buildings, potentially expandable to other construction works and urban systems.

In fact, LCA/PEF is already used in sustainable product policy tools (Cordella et al., 2020) in combination with the broader analysis of legislative, techno-economic and social aspects (e.g., product quality, inherent safety of materials), to understand impacts associated with design options and policy scenarios, identify hotspots, and develop sustainability criteria referring to different life cycle stages. However, while guidelines and procedures for environmental LCA are well-established, procedures and guidelines for other sustainability topics need to be defined. Finally, LCSA can also have synergies with current standardisation work (e.g., ISO/TC 323 on circular economy and ISO/TC 207/SC5 on social life cycle assessment), which can support market and policy applications of LCSA itself.

Table 3 Examples of potential policy uses of LCSA

Purpose for which LCSA information is used	Description	Target audience
Development of sustainability requirements for categories of products (	Developing mandatory/voluntary requirements about the sustainability of products (e.g., ecodesign and ecolabel, Product environmental footprint, Product sustainability footprint)	Stakeholders representing the entire society (business, governments, NGOs, …)
Monitoring, evaluation and assessment of the impacts of sustainable product policies	Policy makers monitor, evaluate and assess the impacts of sustainable product policies.	Stakeholders representing the entire society (business, governments, NGOs, …)

7. Implementation options and levels of the LCSA methodology

According to the principle of operationality, some level of flexibility in conducting LCSA is explored in ORIENTING for supporting a broad implementation of the LCSA methodology. For this purpose, three levels for applying LCSA are under consideration in ORIENTING, namely "entry-level", "intermediate level" and "advanced level". While the entry-level and advanced level are in the focus of this report, the intermediate level will be defined after gathering input from stakeholders through a public consultation process (May 2022), and gaining experience from the practical testing of the methodology with companies involved in demonstrators (May-December 2022)

Figure 2 presents the ORIENTING approach for arriving to a flexible and operational LCSA methodology that would match with dedicated needs of the users and requirements related to specific applications of LCSA.

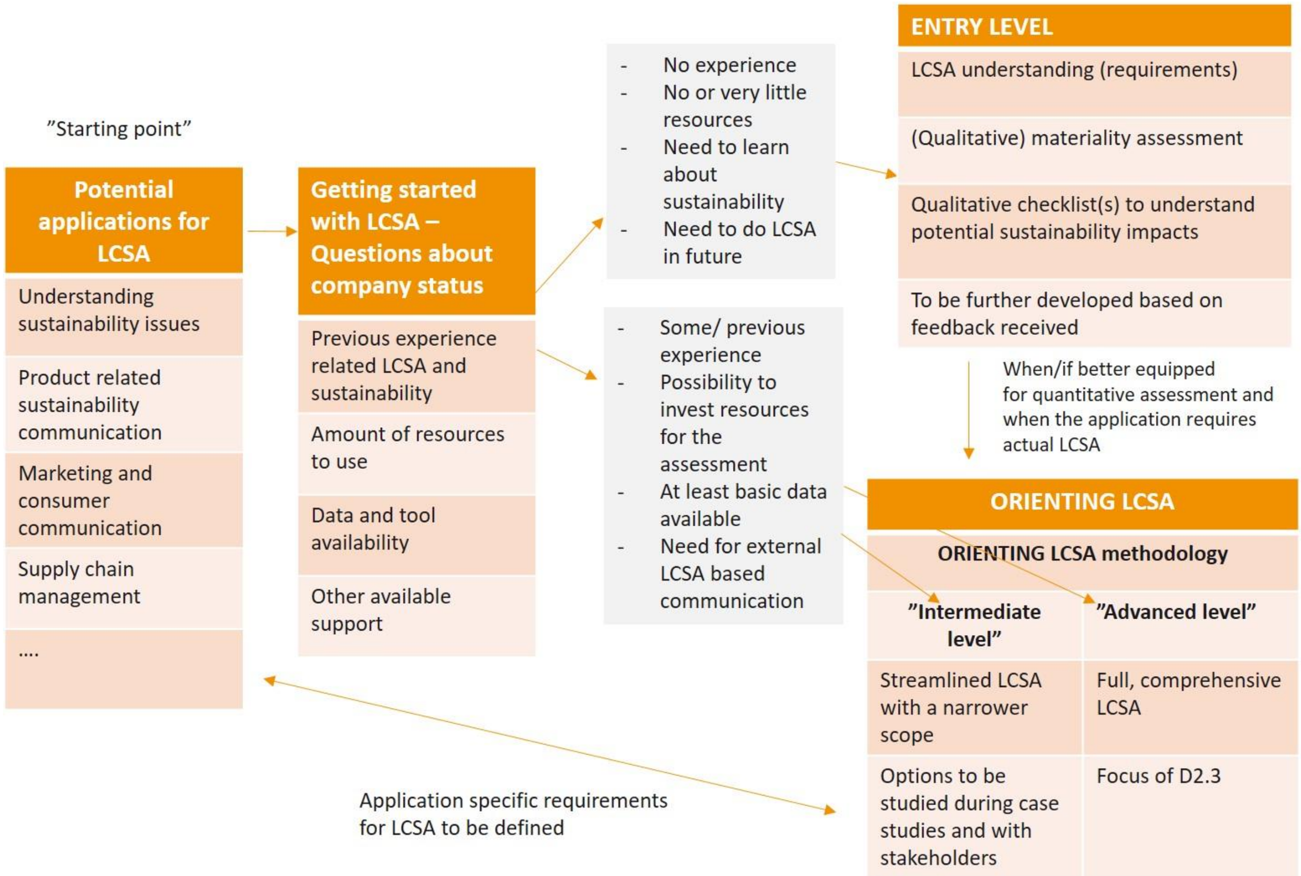


Figure 2. ORIENTING approach with different implementation options for LCSA

The initial step of the approach, common to all the levels, consists of identifying the intended LCSA application, which can be internal (e.g., product design improvement, value chain management) and/or external (e.g., communication to customers). This is followed by an evaluation of related needs, available resources and the level of experience. In general, correct level could be identified also by considering the level that the organisation has within its sustainability journey:

- **Advanced** = already experienced with quantitative sustainability assessment and life cycle approaches for all pillars/topics of LCSA
- **Intermediate** = previous experience from LCA and/or other life cyle approaches, gaps exist for some pillars/topics of LCSA → Start from the intermediate level. Entry-level may be used for getting familiar with new sustainability pillars/topics
- **Beginner** = only conceptual knowledge, or no knowledge at all → Start from the entry-level

A list of additional questions that could be used for identifying the correct level for the assessment is proposed in Table 4. Estimations regarding resources (e.g. amount of working hours) required for conducting the LCSA at different levels will be provided by ORIENTING after the methodology has been implemented and tested in the case studies.

Table 4 Getting started with LCSA: list of questions for identifying the correct level of assessment

Question	Comments and details
Purpose of the assessment	
What is the intended application (or purpose for the study)?	
Are you planning to use the information collected from the assessment for external purposes (e.g., marketing or consumer communication)?	*If yes, then it is necessary to get familiar with the intermediate or advanced level methodology.* *Please note that these levels are recommended also for some internal purposes (e.g. product design optimisation).* *If you have not used any life cycle based methods before, you should start from the entry level assessment.*
Previous knowledge about LCSA and/or other sustainability assessments	
Have you conducted (or commissioned) an LCA or PEF study for any of your products before?	*In case there is no (or only very little) previous experience, we recommend starting from the entry-level assessment.* *If you have experience in LCA, it might be easier to get started with other domains of LCSA, and we recommend applying the advanced (or intermediate) level methodology.*
Have you conducted (or commissioned) studies for the other aspects of LCSA (LCC, S-LCA, circularity, criticality)?	*If not, you can get familiar with the topics by checking the questions for the entry-level assessment.* *If yes, we recommend applying the advanced (or intermediate) level methodology.*
Have you conducted sustainability reporting or used any sustainability methods that focus on the level of organisation?	*If yes, this experience and data is most likely useful, but extra efforts are usually needed for collecting product-based data for the LCSA. You might be able to start from intermediate level. Entry-level might be useful for getting to know life cycle thinking.*
Amount of resources available for the assessment	

Is your company small and medium sized?	*If yes, you might want to start from the entry-level. Later on, you might be able to move towards intermediate level assessment for specific topics, but most likely need external support (or service providers) for conducting the assessment.*
Do you have dedicated personnel involved in sustainability assessment of your products or responsible for sustainability topics in general?	*If yes, their input will be helpful for identifying relevant topics to include in your study and for collecting the data needed for the assessment* *If no, there might be a need for external support or services for conducting the assessment.* *Entry-level assessment can be conducted autonomously to see, what type of information would be needed, and how well you already know your product's life cycle.*
Are you using external expert services for the assessment?	*If yes, you can consider starting from the intermediate or advanced level assessment.* *Entry-level might still be useful as a starting point for understanding the type of amount of data needed for the study.* *Even if you are using expert services, several days will most likely be needed for defining the goal and scope of the study and collecting the data that is needed for a comprehensive LCSA study.*
Data and tool availability	
Do you regularly collect or report environmental, economic or social information at product level?	*If yes, it is recommended to start from the comprehensive LCSA (advanced level)*
Do you collect or report sustainability information at the level of a product group, business line or whole company?	*If yes, this information will be helpful for your study. You are most likely able to start from intermediate or advanced level LCSA, but some efforts are needed for collecting product level data.*
Have you collected or tried to collect environmental, economic or social information from your value chain (e.g., from your suppliers or customers) before?	*If not, this is usually quite slow and requires time. It is recommended to start data collection from suppliers with whom you have close or established relationships.* *Consultants who provide LCA, S-LCA, LCC or LCSA services usually have licences to databases that can provide additional data sources for the study. These can be used for covering those parts of life cycle that are under the control of your organisation.*
Do you have access or license to any LCA software or database or any other commercial datasources (e.g., Ecovadis, Datamaran, IEA emission factors database) that could be used for LCSA modelling (environmental, economic or social assessment)?	*If yes, this can ease the data collection process and the assessment process.* *If you foresee a regular need for LCSA studies, you might want to consider purchasing same databases for your own use.*

Proposed levels of ORIENTING LCSA and their compatibility with potential LCSA applications (as discussed in Chapter 6) are summarised in Table 5. The approach to be used for the entry-level assessment is presented in Chapter 8, while the advanced level is presented starting from Chapter 9 that introduces the Goal and Scope definition for an LCSA. Chapters 10-22 already introduce some implementation options, which are to be tested and developed further during the ORIENTING case studies, and based on the feedback received during the consultation.

As described in Table 5, the entry level assessment would be rather similar for most of the applications purposes. Although the idea is to have it available for all applications, for some applications it may be only a starting point. Entry-level can be by-passed if users already hold the necessary experience.

An **entry-level** allows beginners and less experienced users of LCSA (including organisations that are only at the beginning of their sustainability journey) to familiarise themselves with product-based sustainability assessment and life cycle thinking (LCT), relevant sustainability topics and impact categories, potential impact improvement strategies (through qualitative approaches) and interpretation of results. Thus, the entry-level assessment facilitates progressing towards more comprehensive, quantitative LCSA studies. It provides exploitable outcomes and values to the organisations, in line with the defined goal. The entry-level assessment is expected to lower some of the burdens currently hindering the development of more in-depth LCSA studies.

However, the entry-level assessment alone does not yet suffice for all the applications discussed in Chapter 6, and cannot be considered as an LCSA study. The intention of the entry-level is also eventually to guide the users towards more comprehensive LCSAs, possibly starting from streamlined approaches (intermediate level), and moving towards the advanced level, when more experience is gained, and when the requirements related to comparability and verification of provided sustainability information increase. For example, comparative claims about life cycle sustainability impacts of a product shall not be made based on entry-level assessments only. Furthermore, independently from application and level of complexity, it is fundamental to ensure critical interpretation and transparency of LCSA information, and fulfil requirements associated with intended purposes (e.g., standardised rules are needed for comparative claims in future). Compared to the entry level, both intermediate and advanced levels are characterised by increased details on data (quality and type), modelling of life cycle impacts, interpretation and reporting requirements.

The **advanced level** is the most ambitious level and the main target of the LCSA methodology in ORIENTING. However, some adaptations also within the advanced level could be made depending on the purpose of LCSA. Compared to the advanced level, the **intermediate level** would represent a more streamlined version of LCSA. In Table 5, potential foreseen differences between the levels are highlighted with bold font. In practice the intermediate level could include a flexible or narrower scope (e.g., focusing on a smaller number of indicators and/or life cycle stages), less strict data requirements, taking the purpose of the assessment into account. Options for the intermediate level are not defined in detail in this report, as they will be studied further during the ORIENTING case studies.

Table 5 Levels of ORIENTING LCSA and their compatibility with different business applications of LCSA

Purpose for which LCSA information is used	**Main features**		
	Entry level	**Intermediate level**	**Advanced level**
1) **Understanding sustainability issues** along the life cycle of a product, also to inform sustainability strategies	Understanding what is needed for LCSA and goal and scope definition Materiality assessment and identification of hotspots (e.g., based on literature review) LCT checklists (e.g., guiding through improved design options).	Entry level + more specific goal and **flexible** scope **+** quantitative LCSA results for some topics + Normalisation & Weighting (e.g., **internal** rather than external benchmarks) + Interpretation (e.g., hotspot and scenario analysis) **+** Showing outcomes with support of digital tools	Entry level + **more specific goal and comprehensive scope** + quantitative **LCSA results for all topics** + **Normalisation & Weighting (e.g., external** rather than internal benchmarks) + Interpretation (e.g., hotspot and scenario analysis) **+** Showing outcomes with support of digital tools
2) Managing and improving sustainability of products (A) Process/product design improvement & optimisation (B) New technology development (C) Life cycle management	See (1)	See (1)	See (1) Not applicable for (B)
3) Reporting of product sustainability information (A) Reporting of information on products, without strict comparative requirements (B) Reporting of information, with strict comparative requirements	3(A): see (1), where needed. 3(B): not applicable. 3(C): see 3A/3B	See (1) + **data issues** (transparency, quality & verification issues) **+** aggregated/disaggregated LCSA results for **some quantified impacts** **+** Based on **PSFCR (especially relevant for 3(B)).**	See (1) + **data issues** (transparency, quality & verification issues) **+ aggregated/disaggregated LCSA results for all topics** + Based on **PSFCR, to the extent available** See (1) + **data issues** (transparency, quality & verification issues) **+ aggregated/disaggregated LCSA results for all topics** + Based on **PSFCR (especially relevant for 3(B)).**

8. Entry level – getting-to-know LCSA and understanding materiality

The entry-level assessment aims to guide companies (and other users interested in LCSA) towards a preliminary identification and understanding of potentially relevant sustainability topics and impacts in the product life cycle, as well as improvement options. In this regard, materiality assessment is a key component of the entry level, as it guides the identification and evaluation of what could be relevant from a sustainability perspective for the analysed product, and what should be included in a future sustainability assessment or studied further. This type of assessment can be based on literature, own estimations, and stakeholder consultations.

In addition to learning about potential sustainability impacts of a product, an important goal of the entry level assessment is to understand which sustainability topics the company (or other organization conducting the assessment) is currently following or measuring, and where potential data and knowledge gaps exist. Data gaps can relate to different phases of the life cycle, specific sustainability domains or topics, or other actors and organisations involved in the life cycle.

The entry-level introduces the organisations to the idea of life cycle thinking (LCT) and includes elements that are similar to a goal and scope definition, which is the first phase of an LCSA study (Introduced in Chapter 9). In addition, it covers and introduces in qualitative terms all the sustainability domains and topics that are assessed during an LCSA.

The United Nations Environmental Programme's Life Cycle Initiative defines LCT as '*going beyond the traditional focus on production site and manufacturing processes to include environmental, social, and economic impacts of a product over its entire life cycle. The main goals of LCT are to reduce a product's resource use and emissions to the environment as well as improve its socio-economic performance through its life cycle.*'[9] Similarly, with the basic idea of LCSA, LCT includes, but is not limited to, the following elements:

- Having an objective to reduce the overall adverse sustainability impacts of the product while still considering other relevant aspects such as product quality.
- Identifying the significant sustainability aspects of the product.
- Considering potential trade-offs between different sustainability aspects and life cycle stages.
- Identifying improvement options.
- Implementing necessary measures, methods and tools for achieving improvements.

The four main phases of the entry-level assessment are presented in Figure 3. The phases are adapted and modified from the materiality assessment and principles included in the GRI standard (See GRI, 2021). Thus, **companies who have conducted a materiality assessment for the purposes of sustainability reporting using the GRI standards could use the same materiality assessment as a starting point, but reviewing it** (and where necessary extending it) **from the point of view of the assessed product and its life cycle**. However, it is possible to do the assessment without previous experience related to sustainability or materiality assessment.

[9] https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

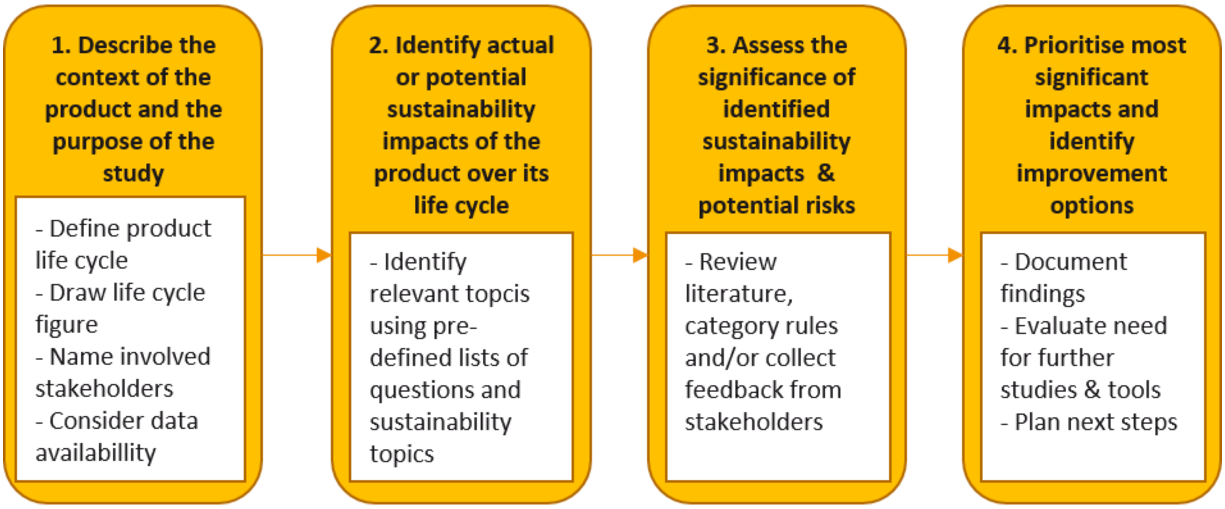


Figure 3 Four main phases of the entry level assessment (adapted from GRI-3; 2021)

As presented in Figure 3, the four main phases of the entry level assessment include:

1. Describing the life cycle of the product (and the context of the organisation conducting the assessment) and defining the purpose for carrying out the study.
2. Identifying actual and potential sustainability impacts of the product.
3. Assessing the significance of potential impacts based on available information.
4. Prioritising most significant impacts and identifying preliminary improvement options.

A short description of the phases together with examples of questions that could be answered in each phase are presented below.

Phase 1 – Describe the life cycle of the product and define the purpose for carrying out the study

The first step of the assessment is to define the product, related functions and its whole life cycle, starting from raw material acquisition until the use phase and the product's end-of-life. This phase includes similarities with the general questions that need to be defined during the goal and scope definition of an LCSA study (presented in Chapter 9).

One of the most important steps conducted during this phase includes defining all the life cycle stages along the product's value chain, their (assumed) locations, and other organisations or stakeholders involved in each stage. In case some of these phases are not known, related data gaps should be documented.

As part of this phase, a figure of the product life cycle should be drawn (for an example, see Figure 4 in Chapter 9.2). Examples of questions that should be answered during the first phase include:

- What is the purpose for conducting the assessment?
- Are the results intended to be communicated to internal and/or external stakeholders? Which ones?
- What are the life cycle stages related to the product in question?
- Which organisations are involved in the different life cycle stages?
- Where are these life cycle stages (and/or related organisations) located?
- Which stakeholders are involved in different life cycle stages? (E.g., workers in the production plant, local community, consumers, children). Please consider that these stakeholders might be present at any step of the life cycle.
- Which of the processes are run or controlled by your organisation?

- Which circularity actions are in place to retain the value of the product, its parts, or materials (e.g., through reuse, refurbish, remanufacture, or recycle)? (For more questions and additional information, please see: Box 1 on Product Circularity in this section, and Table 10 in chapter 9.4)
- What type of data, tools or knowledge is available from the processes run or controlled by your organisation? Data includes information about material and energy flows and costs in each life cycle stage, and the policies and practices that organisations have implemented for ensuring and promoting social responsibility. Data includes also the availability of environmental and/or social and/or sustainability certifications, such as ISO 14001, Environmental Prduct Declarations (EPDs), cradle to cradle, recycled content, SA8000, carbon/water footprint (and other footprints too), sustainability certifications for bio-based products, just to mention some.

For the purposes of the assessment, it is recommended that the company aims to check data availability and to collect information from at least those processes that are run by the company itself. These processes could be located in one or several life cycle stages. They do not need to be supported by evidence at the entry level, but it is important that efforts are made to ensure that all available information is collected and data gaps identified. For the other processes not run by the company, risk-related information can be used, retrieved from both commercial or freely available sources (see Phase 3 of the entry-level assessment for more details).

Availability of relevant information for each of the sustainability domains and topics can be reviewed using dedicated templates that include questions about data availability[10]. For example, economic information for life cycle costing purposes can be evaluated by testing the ORIENTING cost breakdown structure (introduced in section 14.2.1), which covers the whole product life cycle and describes the information needs for the economic assessment. Such excercises provide a good starting point if (or when) the company moves towards an LCSA study later.

BOX 1: Considering product circularity as part of the entry-level assessment

Supporting the approach for determining material topics from a circularity perspective, an initial “Product Circularity Assessment” (PCA) can be used to assess the potential of a product to contribute to the circular economy, later referred to as “product circularity” (PC). Conducting a PCA is especially recommended at the early stages of the design and development phase of a new product, or when redesigning an existing product. PCA can be helpful for identifying which aspects of circularity are relevant for the product in question, in order to promote sustainability. It is recommended to pay some extra efforts on PCA, as part of the entry-level assessment, also to understand how different circularity strategies might affect different sustainability domains (see Phase 2 of the entry-level).

For entry-level users, it is recommended to start the PC journey by identifying the product(s) to improve. A product might be selected for example, based on having previously been through an environmental LCA, where the implementation of PC strategies (or broader eco-design strategies) and potential hotspots have been identified. However, the assessment can also be started without previous experience by considering the list of questions presented here.

Initially, different PC strategies should be identified that are relevant (or material) to the selected product. Strategies can be identified by answering questions such as the following for each strategy presented in (See Table 10 in Chapter 9.4). As a consequence, it might be necessary also to consider the implications of any of the strategies for the product functions.

[10] Dedicated checklists for each Sustainability domain and topic will be made available by ORIENTING.

For example:

- Is it possible to reduce the use of virgin materials, e.g. by alternative designs and/or use of recycled material (of adequate quality) without affecting the functionality of the product?

- Is it possible to increase the use of reused parts without affecting the performance or aesthetics of the product?

- Can waste flows for the selected product be reduced?

- Can the product be designed for disassembly (without increasing cost, reducing safety, affecting the aesthetics, visual communication, etc of the product)?

Once relevant PC strategies have been identified, different scenarios for design improvements should be identified, followed by an identification of the data requirements necessary to evaluate PC performance related to each strategy. An important phase of the assessment is also to identify, which business function(s) and/or external stakeholder(s) might hold the data that is needed for assessing potential impacts. Some of this data is most likely similar to data required for an LCSA study.

Conducting an entry-level PCA can thus assist organisations in

1) identifying potential improvements for the PC performance;

2) identifying sustainability impacts related product circularity over the life cycle;

3) understanding data needs and potential gaps in current knowledge.

As the user increases awareness and knowledge with regards to circularity and sustainability, it is recommended to move towards testing the quantitative assessment methods as part of an LCSA study. First step may include an intermediate level LCSA or LCA study, which is extended with circularity indicators introduced in chapter 12

Phase 2 - Identify actual and potential sustainability impacts of the product

The second phase of the entry-level assessment consists of identifying actual and potential sustainability impacts related to the product life cycle. Potential impacts could be identified based on previous studies, and existing product or sector specific guidelines and reports. Additionally, lists of pre-defined environmental, social, circularity and criticality related topics prepared by ORIENTING can be used for this phase, for making a first list of potential sustainability topics and impacts that could occur during the life cycle of the product.[11]

Examples of questions that should be answered during the second phase of the entry-level assessment include:

- What are the raw materials included in the product's life cycle (including packaging materials)?
- What is the origin of those raw materials?
- Are any of the raw materials critical according to the European Commission's list of Critical Raw Materials (CRMs)? (See the list of critical raw materials inTable 6)
- Do you have any data, measurement or quantified knowledge of circularity actions in place that retain the value of the product, its parts, or materials?

[11] These lists will be provided by the ORIENTING project as separate templates, some of which were tested during the first half of the project. For an example, see Annex B for the list of social topics and their definitions.

- Do you know what type of environmental, economic and social impacts are or could be related to different life cycle stages?
- Do you have any measured information, data or other evidence or knowledge about the impacts that might take place in other stages of the life cycle? Is it possible to collect such data from suppliers, other actors or from statistics?
- What type of environmental, social or economic risks could be related to the different life cycle stages? Are there any processes or measures in place for mitigating such risks?

For considering the criticality of used raw materials, a list of raw materials applied (e.g. based on bill of materials if available) can screened against the EC's last updated list of CRM, i.e., the 2020 list of critical raw materials, as provided in Table 6. Raw materials not included in that list can be considered as non-critical (see Annex A for the full list of materials assessed).

Table 6 List of CRM arccording to the latest study on the EU's list of Critical Raw materials (2020)

Antimony	Europium	Natural graphite	Samarium
Barytes	Fluorspar	Natural rubber	Scandium
Bauxite	Gadolinium	Neodymium	Silicon metal
Beryllium	Gallium	Niobium	Strontium
Bismuth	Germanium	Palladium	Tantalum
Boron/Borate	Hafnium	Phosphate rock	Terbium
Cerium	Ho, Tm, Lu, Yb	Phosphorus	Titanium
Cobalt	Indium	Platinum	Tungsten
Cooking Coal	Iridium	Praseodymium	Vanadium
Dysprosium	Lithium	Rhodium	Yttrium
Erbium	Magnesium	Ruthenium	Samarium

The list of social topics developed in ORIENTING, structured according to stakeholder types, and available at Annex A, can support you in the evaluation of the type of risk or impact, considering the whole life cycle but also looking at the single stages. Additional topics can be added to the list upon need. For more templates and supporting tools for the social assessment, see Chapter 15.5.

<u>Phase 3 - Assess the significance of potential impacts based on available information</u>

The third phase of the assessment consists of evaluating the significance of the topics identified during the previous phase. Significance, or materiality, of the topics could be evaluated at the entry level based on own expertise and information available in different literature sources. A combination of different data sources is recommended. Collected data can be complemented with expert interviews. If a materiality assessment has already been carried out by the organisation, this is the starting point, to be further broadened with the considerations raised by the guiding questions.

This phase could also reveal important knowledge gaps that should be addressed in future studies or by implementing dedicated sustainability tools (such as environmental or social policies and standards and lables, chain of custody certifications, code of conduct or supply chain due diligence practices).

Similarly to the process presented in the GRI guidelines (GRI, 2021) input and/or feedback collected from stakeholders can be applied in phases three and four of the assessment in order to understand which sustainability topics and/or life cycle stages are most important or significant, or how the topics should be prioritised when planning next steps. Signficance of topics is evaluated using the (so-called) double-materiality principle (European Commission, 2019). This means that issues can be significant (or material) either for financial reasons, or concerning their importance for any of the sustainability domains or topics. A topic might become significant also because it is of interest to the stakeholders. Later on, the findings from the materiality assessment can be used as a starting point for defining the goal and scope of an LCSA study.

If enough data or knowledge is available, this phase will deliver the identification of hotspots. Hotspots are life cycle stages or processes in which significant environmental, economic or social impacts (or risks) can potentially occur, and to which it would be worth to pay specific attention in the future. This might involve (for example) conducting a dedicated study for acquiring more information, or taking other measures. Hotspots can consist of processes, which are outside the direct control of the organisation, emphasising the importance of having knowledge of the whole product life cycle. However, in case of limited availability of data, it is likely that a more thorough assessment (e.g., LCSA or dedicated LCA or S-LCA studies) is needed in future for identifying the hotspots. Often, data from commercial databases, or freely available data (e.g., on social performance and risks), is required for covering life cycle stages that are outside the control of the company (or other organisation) conducting the assessment.

Phase 4 - Prioritise most significant impacts and identifying preliminary improvement options

The fourth phase of the entry-level assessment consists of prioritising the impacts identified (taking their estimated significance into account), and planning of next steps which could include follow-up studies, data collection efforts etc.

Examples of questions that should be answered during this phase include:

- In which life cycle stages do the identified impacts occur?
- Are the identified potential impacts under the control of or run directly by the organisation whose product is analysed?
- If not, are there relationships in place with the actors in the life cycle stage responsible for the identified impact(s) that allow for example to collect information on those stages and processes in a further step of the analysis?
- Is there a need for further studies in order to understand potential impacts or risks?
- What type of data would need to be collected in future in order to fill in the identified knowledge gaps?
- What kind of reporting systems, assessments, or knowledge would be needed in future for making improvements or setting targets for future improvements?
- Which actions could be taken to improve the sustainability of the product system?

Based on information gathered during the entry-level assessment, an organisation should be better aware of potential sustainability impacts that might be relevant for the assessed product (over its life cycle). In addition, organisation should have better understanding of data availability and gaps in current knowledge. If considered useful and/or necessary (depending of the purpose of the study), the organisation may then move towards an LCA, LCC, S-LCA or LCSA study (including circularity and criticality assessments), for conducting a more systematic quantitative assessment of those impacts that are considered most significant. Guidance and requirements for such a study are presented from Chapter 9 onwards.

9. LCSA goal and scope definition

The definition of goal and scope is the first phase of an LCSA study. This section guides the definition of goal and scope for the intermediate and advanced level of LCSA. If an organisation has previously carried out an entry-level assessment, the goal and scope definition consist of going deeper into the topics already addressed, fine-tuning the level of detail and improving the accessibility and availability of data.

9.1 Introduction

During goal and scope definition the main purpose for carrying out the LCSA study and the intended audience are defined. The following chapters present lists of questions that need to be responded when defining the goal and scope. These questions help in defining what will be studied during the LCSA study and what type of data and information needs to be collected for the assessment. Data and information collection and their elaboration will be part of the following phase, Inventory (introduced in Chapters 10-15).

The definition of the goal includes describing the **intended application of the study** (for examples see Chapter 6), explaining the reasons for carrying out the study and describing the audiences to whom the results will be communicated (ISO 14044). If the goal of the study is to make comparative claims about sustainability impacts of a product for public communication purposes, this will need to be specifically mentioned. In such a case, verification, transparency and quality of the results are very important.

Firstly, **the definition of the scope** includes describing the **product system** under study and its **functions** (performance characteristics) (ISO14044, 2006). Product system means describing the combination of all the processes and activities that take place during the life cycle of the product, and that are needed for producing the intended function related to that product (adapted from ISO14044). In an LCSA study, product system includes also the description of the organisations and stakeholders involved in each life cycle stage.

In ISO14044, the **functional unit** is defined as "quantified performance of a product system, used as a reference unit" for the assessment. The same functional unit shall be applied to the LCSA as a whole. The functional unit can then be quantified with the reference flow, i.e., the amount of product needed to deliver the defined function. However, the quantified performance of the function(s) (or services) needs to be extended with qualitative information describing the utility of the product. Utility describes the perception that the consumer may have about the product, in addition to the function (quality, convenience, etc.) (Valdivia et al., 2021).

Secondly, the **system boundaries** of the analysis shall be defined. It is important to note that sustainability impacts might not be related only to the function delivered by a given product, but also to the behaviour and activities of organisations across the life cycle of the product. This is often the case in the context of social impacts. Thus, the scope of the study might be expanded accordingly. This requires defining:

- The **life cycle stages** included in the study
- **Processess** considered and their **geographic locations**.
- The **organisations involved** in the product life cycle and the type of relationships established among them (e.g., supplier with long-lasting agreement)
- The **stakeholders** along the product life cycle. Stakeholder groups include workers, local community, users/consumers, small scale entrepreneurs, value chain actors, society and children.

The aim of LCSA is to cover the whole life cycle of a product, from the cradle (raw material production) to the grave (e.g., end of life reuse, recycle, recovery, or disposal in landfill). In case there are life cycle stages or processes excluded from the study, the reason for their exclusion needs to be justified and it should be acknowledged that this may have an impact on the possible uses of the study.

According to the principle of consistency, the system boundary used for the whole LCSA shall be consistent between different domains and topics. Consistent does not mean that they are exactly equal: in fact, the level of detail and the focus of the assessment might differ between the assessed sustainability domains and topics, and different life cycle stages.

Important part of goal and scope definition process is also the definition of **methods and indicators** used in the study, and the consequent requirements related to data sourcing, gathering and processing. In the context of LCSA, both quantitative and qualitative data are typically used for the assessment, and data may be collected from different sources using varying methods that originate from different disciplines (e.g., engineering, environmental sciences, economics, social sciences, humanities). Definition of methods and indicators for the LCSA can be made after getting to know what to measure and the methods and indicators presented as part of the of the Goal and Scope (this Chapter) and Inventory phase (Chapters 10-15).

Another important aspect to consider during the goal and scope definition phase is the **temporal coverage** (which past and future years will be considered in the assessment) and the way in which past and future burdens and benefits are considered (e.g., if costs and benefits are discounted and how). Temporal considerations also involve considering the lifetime of the product, and how the different choices made during the life cycle may affect product life cycle, product circularity and related sustainability impacts. Furthermore, from the point of view of economic assessment, it is also important to consider if and how externalities are included in the assessment.

According to the principle of relevance, a **materiality assessment** (see Chapter 9.9) is conducted to support the identification topics, life cycle stages and/or stakeholder groups that should be included in the study due to potential significance of impacts, or specific interest from the stakeholders.

According to the principle of **Operationality,** the idea of different levels of LCSA will be tested during the ORIENTING case studies. This means in practice that while the goal of ORIENTING is to apply the advanced level LCSA methodology in all the case studies, the methodology can be adapted taking into account the starting point of each company and the targeted application for the study. Sector specific characteristics are considered as well. These experiences will then be used for defining the methodology for the intermediate level. All adaptations will be documented, respecting the main principles of LCSA

9.2 General questions and aspects for LCSA goal and scope definition

This chapter presents and summarises questions and aspects that are common for the LCSA as a whole (summarised in Table 7), and provide the starting point for the study. For defining the purpose and intended audience of the study, applicaptions and potential target audiences discussed in chapter 6 may be used as examples. Both, the intended audience and the purpose of the study have some implications for the methodology to be applied during the LCSA study.

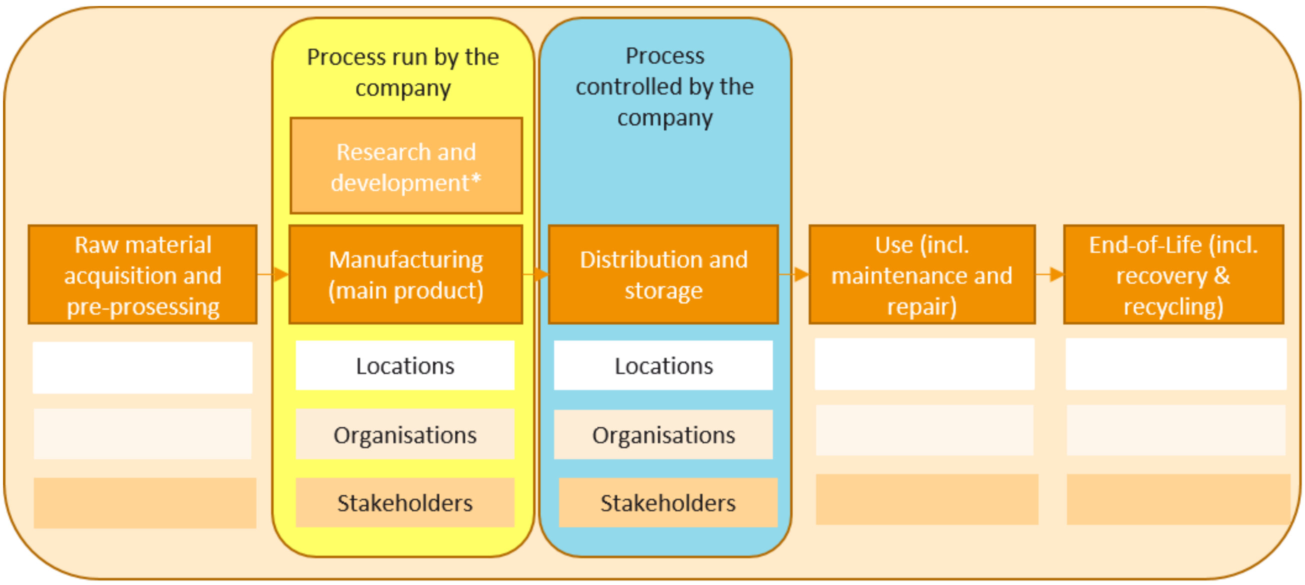
For defining the functional unit of the study, both the functions and the utility provided by the studied product (or service) have to considered. In order to define the functional unit, following questions can be considered: *"What?", "How much?", "How long?", "How well?"* Thus, the function and the utility of the product could be described as follows: "*to paint 10 m^2 of wall with an indoor-use paint that can ensure a satisfactory level of quality for 2 years".* If the intention of the study is to highlight potential sustainability aspects and benefits of product circularity, questions presented in Table 9 (in Chapter 9.4) can provide useful ideas on things to consider when defining the functional unit and the utility of the product.

For defining the scope of the study, a flow chart or an illustrative scheme of the system boundaries shall be made to visualize the life cycle stages (and related processes) considered. Figure 4 provides an example of a life cycle of an illustrative generic product. According to the recommendations of the PEF method (2021), the least the following five life cycle stages shall be included in the study:

1. raw material acquisition and pre-processing (including production of parts and components);
2. manufacturing (production of the main product);
3. distribution (product distribution and storage);
4. use;
5. end of life (including product recovery or recycling).

If needed, the five main stages can be splitted to more specific phases and more phases can be added. Also the naming of the life cycle stages can be adapted to suit the context of the study.

The relevance of the life cycle stages shall be considered from the point of view of each sustainability domain and topic. The level detail and the focus of the assessment might differ between the assessed sustainability domains and topics, and different life cycle stages. For example, the life cycle stage of design and research and development (R&D) is usually not relevant from the environmental point of view as it implies a negligible consumption of physical resources for its execution, and it is then excluded from the environmental LCA. However, decisions made during R&D typically have significant impacts for the product life cycle, and especially for the product end of life. However, from an economic perspective, R&D investments are needed for new product development and related costs might be relevant for inclusion. That stage can also be relevant in a S-LCA study (e.g. gender balance issues). In Figure 4, R&D is separated as an additional life cycle phase in addition to product manufacturing. From a circularity perspective, specific attention might need to be dedicated to aspects such as reliability, maintenance and repair or re-use.



* The design of a given product will have upstream (e.g., procurement) and downstream consequences (e.g., use and End-of-Life)

Figure 4 An example of a flow chart that illustrates the life cycle stages included in the study (system

For each life cycle stage included within the system boundary, data regarding material and energy flows, costs and social performance has to be collected. In addition, companies and/or organisations involved in those life cycle stages (and related processes) shall be listed and their locations specified. Stakeholder groups involved in each life cycle stage are defined for the purposes of the S-LCA. Stakeholder categories are presented as part of specific questions related to S-LCA (Chapter 9.7).

The company conducting (or commissioning the study) needs to collect primary data and/or information at least for those processes that are run by the company itself. These processes may locate in one or several life cycle stages. In addition, it is recommended that the company would make efforts for collecting data also from those processes, where the company has some control over, or from processes or companies, with which the company has established relationships. For the processes run by other companies, data from literature, interviews, statistics or available databases can be collected and applied (so called secondary data). More information on the type of data and their source is provided in the Inventory chapters (10-15). Dedicated spreadsheets are provided for the case study companies to ease data collection.

General questions that need to be addressed for defining the goal and scope of an LCSA study are presented in Table 7. In addition to these general questions, more specific questions from the point of view of each sustainability domain and topic are presented in the following Chapters 9.3-9.8. Like LCSA as a whole, the definition of the goal and scope is an iterative process. Choices made during the goal and scope definition may be adjusted during the study, when more knowledge about the studied sustainability domains and topics is gained.

Table 7 General questions for defining the goal and scope of the LCSA

Question	Details and examples
What is the intended application for the study?	For example: product development or sustainability communication
What are the intended target audiences for the study?	Specify intended audiences and if they are internal or external for the company (e.g. employees, R&D personnel, customer companies, consumers, authorities)
Will the assessment be used for making comparative sustainability claims/benchmarking with other products?	If yes, the study shall follow available guidelines for making sustainability claims (e.g. PEFCR and UNEP 2017). In future, dedicated, sector specific product sustainability footprint catecory rules might be created for such purpose).
Short description of the product (good or service) to be assessed	
Is the product an intermediate product? Is the product a consumer product or a business-to-business product? Is the product already on the market or on an early design phase?	This aspect has different implications in the environmental and social assessment (as described in the dedicated sections). The definition of the FU can be more difficult for intermediate products due to the multiple optional functions in the product life cycle, and thus the declared unit should be typically mass or volume based.

	For product not yet on the market, data requirements will be less demanding, and more assumptions will be needed.
What is the function provided by the product?	Provide a qualitative description and indicate if the product has a social role[12]–
What is the functional unit used in the study?	The functional unit and the reference flow of the study shall be defined on a detailed enough level to answer the questions "What?", "How much?", "How well?" and "How long?". Thus, it should describe the function(s) provided by the product, the extent of the function, the expected quality of the function, and the duration or lifetime of the product
What was the reason for selecting this functional unit?	
Which life cycle stages and processes are included in the study?	See also Figure 4
Are some life cycle stages or processes excluded from the study?	If yes, explain reasons for their exclusion
What is the role of the organisation within the product life cycle?	For example, which of the life cycle stages are run/controlled by the company whose product is assessed? For these stages/processes, primary data shall be collected.
What are the locations for the processes and organisations included in the study?	It is important to specify the geographical location of activities since social risks are also context specific. For more information, see the Chapter 9.7 for S-LCA) Country-specific secondary data may be used for processes not run or controlled by the organisation.
What is the temporal coverage of the study?	For example, from which years will the data be collected?

When questions from all chapters (9.2-9.8) have been considered, a materiality assessment (see Chapter 9.9) can be conducted for focusing the study to most relevant life cycle stages and topics, taking into account both the purpose and intended use of the LCSA results and the resources available for conducting the assessment. System boundaries, life cycle stages and materiality should be considered first at the level of the LCSA as a whole, then making necessary specifications from the point of view of each assessment and topic. It is important to note for example, that applying a cut off criterion for environmental assessment does not automatically exclude a specific flow or process from other assessments. Thus, the final system boundaries

[12] Social goods and services sectors that provide: (i) goods and services for basic human needs; and (ii) basic economic infrastructure of direct relevance to the right to an adequate standard of living (Final Report on Social Taxonomy Platform on Sustainable Finance February 2022)

might have some differences between the assessments, and these will need to be documented. Guidance for materiality assessment is provided in chapter 9.9.

9.3 Specific aspects and questions for the environmental assessment

Since the environmental assessment builds on the Product Environmental Footprint (PEF) method (European Commission, 2021a), a key question for the environmental assessment is whether a Product Environmental Footprint Category Rules (PEFCR) document is available for the studied product. The PEFCR document gives specific guidance for how functional unit and system boundaries should be defined for the LCA, and how the product life cycle should be modelled. The PEFCR guidance shall be followed for LCA. In its absence, reference is made to the general PEF recommendations.

Note, however, that the methodology of ORIENTING is not fully aligned with PEF, as it extends PEF in impact assessment on land-use impacts and biodiversity. Furthermore, some deviations might be justified due to the terms and conditions of PEF, which only apply to actual Environmental Footprint (EF) studies and not to research projects dealing with the matter. This means that PEFCR and PEF are the starting point but not the end of studies developed according to the ORIENTING LCSA methodology. Deviations on e.g. data used, documentation, completeness or other aspects shall be documented for the environmental assessment (as specified in ORIENTING deliverable 1.1).

When defining the system boundary for the LCA study (see also Figure 4), the processes included in the study need to fulfil the cut-off rule set by PEF, i.e. max. 3% cumulative exclusion of mass and energy flows as well as the level of environmental significance on single score level. In addition, the relevant environmental impacts need to be defined in the goal and scope definition. Each cut-off needs to be justified and made explicit regarding its overall environmental relevance (European Commission, 2021a). As the ORIENTING land use impact assessment goes beyond the EF framework, the overall impact on biodiversity and soil quality is also considered in the EF single score.

The environmental impacts studied as part of the LCA are following the PEF recommendations. In addition to the PEF recommendations, the LCSA of ORIENTING shall include an updated version of the LANCA model for the SQI and new impact categories on biodiversity and biotic production. While the updated SQI is jointly developed with the JRC and is expected to replace the current SQI CFs at the end of the EF transition phase, the indicators on biodiversity and biotic production go beyond the current scope of EF and are therefore added as further impact categories. The recommended impact categories for ORIENTING LCA are presented in **Table** 8.

Table 8 Recommended impact categories for the environmental assessment. Compared with PEF, updated land use impact categories are highlighted with green color.

Impact category	Unit	Description
Acidification	mol H^+ eq.	Describes impacts due to acidifying substances in the environment. Emissions of NOx, NH3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralised. 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.
Climate change, total	kg CO_2 eq	All inputs or outputs that result in greenhouse gas emissions, which increase average global temperatures and sudden regional climatic changes. The greatest contributor is generally the combustion of fossil fuels such as coal, oil and natural gas. Climate change is an impact affecting the environment on a global scale.

Ecotoxicity, freshwater	CTUe	Potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem. Some substances have a tendency to accumulate in living organisms. Eco-toxicity is an impact which predominantly affects the environment at local and regional scale. Measured as Comparative Toxic Unit for ecosystems (CTUe).
Particulate Matter	disease incidence	The adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO2). Usually, the smaller the particles are, the more dangerous they are, as they can go deeper into the lungs. Measured as kilogram of Particulate Matter 2.5 equivalent (kg PM 2.5 eq).
Eutrophication, marine	kg N eq	Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). As a rule, the availability of one of these nutrients will be a limiting factor for growth in the ecosystem, and if this nutrient is added, the growth of algae or specific plants will be increased. If algae grow too rapidly, it can leave water without enough oxygen for fish to survive and limit growth in the original ecosystem. For the marine environment this will be mainly due to an increase of nitrogen (N). Nitrogen emissions are caused largely by the agricultural use of fertilisers, but also by combustion processes. The most significant sources of Phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. Eutrophication is an impact which affects the environment at local and regional scale.
Eutrophication, freshwater	kg P eq	
Eutrophication, terrestrial	mol N eq	
Human toxicity, cancer	CTUh	Describes adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – cancer category insofar as they are related to cancer, and the non-cancer category insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation. Human toxicity is an impact predominantly affecting people at local and regional scale. Measured as Comparative Toxic Unit for humans (CTUh).
Human toxicity, non-cancer	CTUh	
Ionising radiation, human health	kBq U235 eq	The exposure to ionising radiation (radioactivity) can have impacts on human health. Here only emissions under normal operating conditions are considered (no accidents in nuclear plants are considered).
Land use, Soil Quality	Dimensionless (pt)	Describes the impacts on soil quality, biotic resources and biodiversity related to land occupation and transformation land due to agriculture, roads, housing, mining or other purposes. All Land Use Impact categories build on the LANCA® framework. Soil Quality includes the impact on erosion, soil organic carbon, physichochemical filtration and groundwater regeneration. Biotic resources are calculated through Human Appropriation of Net Primary Production (HANPP), and the impact of land use on Biodiversity on species richness and abundance is calculated usiung the BioMAPS method. The methods are developed in ORIENTING and further described in the Annex A. All indicators are normalized based on their global distribution and thus dimensionless.
Land Use, Biotic Resources	Dimensionless (pt)	
Land Use, Biodiversity	Dimensionless (pt)	
Ozone depletion	kg CFC-11 eq	The degradation of stratospheric Ozone (O3) layer is caused by emissions of long-lived chlorine and bromine containing gases. The stratospheric ozone protects us from hazardous ultraviolet radiation (UV-B). Its depletion can have dangerous consequences in the form of increased skin cancer cases in humans and damage to plants. The stratospheric ozone depletion is an impact affecting the environment on a global scale.

Photochemical ozone form–tion - human health	kg NMVOC eq	While stratospheric ozone protects us, ozone on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ("summer smog") is present in cities. Photochemical ozone formation is an impact which affects the environment at local and regional scale. Measured as kilogram of Non-Methane Volatile Organic Compound equivalent (kg NMVOC eq).
Resource use, fossils	MJ	The earth contains a finite amount of fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. For example, the depletion of fossil fuels may lead to the non-availability of fossil fuels for future generations.
Resource use, minerals and metals	kg Sb eq	This environmental footprint impact category addresses the use of non-renewable abiotic natural resources (minerals and metals).
Water use	m^3 world eq of deprived water	Water use represents the relative available water remaining per area in a watershed, after demand from humans and aquatic ecosystems has been met. It assesses the potential for water deprivation, to either humans or ecosystems, based on the assumption that the less water remaining available per area, the more likely it is that another user will be deprived. Measured as cubic metres (m^3) of water use related to the local scarcity of water.

Furthermore, the consideration of additional environmental and technical information is specified in the goal and scope. On additional environmental information, the EF recommendation is limited to biodiversity. The recommendation can be followed in addition to the ORIENTING biodiversity indicator if identified as significant, and to complement information on biodiversity impact beyond land use impacts. Furthermore, if seen as relevant, the comprehensive land use impact assessment can be chosen to be considered. Regarding additional technical information, the data requested from other sustainability domains should be provided depending on the applied methods and tools.

As part of additional information to be collected, the Bill of Materials (BoM) is a list of the raw materials, parts and components and their quantities needed to manufacture the product in scope. It can be used as a starting point for data collection for the studied product and can be provided as an additional technical information, also supporting the LCC, circularity and criticality assessments. In practice, the BoM includes a list of materials/ingredients (substance names) with their units and quantities used in the studied product.

Specific questions to be answered for the environmental assessment as part of the goal and scope definition are summarised in Table 9.

Table 9 Specific questions to be considered for the environmental assessment as part of the goal and scope definition

Question	Details and examples
Is a PEFCR document available for the studied product?	If yes, then the following questions should be answered considering the guidance provided in the PEFCR document.
Which environmental impacts will be included in the study?	A) The proposed minimum scope are the 16 environmental impact categories specified in the PEF method (see Table 9) as well as an

	updated land use impact assessment including soil quality, biotic resources and biodiversity. B) Are there other potentially relevant environmental impacts (or benefits) that should be considered or described in the study?
Which deviations from PEF are expected?	Deviations related to the background database and the documentation are expected. Further deviations shall be stated and explained as well.
Are impacts related to land-use and/or biodiversity potentially significant topics for the case product?	This is the case for product system with significant contributions from land using activities such as agriculture, forestry or mining.
If land-use and/or biodiversity are significant – do you have knowledge of your primary production site location and conditions?	Besides the area required the location as well as soil composition can be considered to robustly assess the actual land use impacts.
Are you interested in the relevance of land management practices for your land use impact?	Improved management practices could help reducing the environmental impact from land use to soil quality and biodiversity.
Is it possible to include all relevant processes along the product life cycle as part of the study?	A) Use a cradle to grave system boundary with a cumulative 3% cut off rule for material and energy flows and justify exceptions B) For intermediate products, the distribution, use and end of life shall be excluded
Which data and tools do you have available for LCA?	Bill of materials (BOM), databases (e.g. ecoinvent), LCA tools (e.g. SimaPro, GaBi, SULCA)

9.4 Specific aspects and questions for circularity

In ORIENTING, circularity shall be treated as means towards sustainability, and not as a final objective. A practical starting point for circularity assessment shall rely on the BoM, which is collected as part of life cycle assessment (See Chapter 9.3). At the entry level (described in Chapter 8), BoM can provide information for the specific questions asked in **Table 10**. BoM shall also be used in the intermediate and advanced level as the quantitative analysis require this information. In this sense, the boundary of circularity is “cradle-to-gate” at the entry and intermediate level and "cradle-to-grave" at the advanced level.[13] However, while LCA fully addresses foreground and background systems[14], the circularity assessment in ORIENTING focuses on the foreground system. The possibility of quantifying circularity indicators using a full life cycle modelling (i.e., up to elementary flows) could be discussed.

In the goal and scope definition phase, a series of questions (see Table 10) can be made to aid the qualitative and quantitative assessment of the circularity of products, including the use of the quantitative circularity indicators mentioned in Chapter 12 of this document. Although these questions are qualitative, they can be translated into quantitative information in the inventory phase of the assessment. This list of questions is non-exustive and intended to provide an inspiration in the proposition of more circular produts. Furthermore, this list is grouped in strategies according to Potting et al (2017), but here, the questions are not ordered to imply preferability or hierarchy of strategies.

Table 10: Non-exhaustive list of questions that can aid the use of circularity indicators

Strategy	Questions	Details and examples
Smart product use and manufacturing (e.g. refuse, rethink and reduce)	- Does the product present multifunctionality properties during use?	Product multifunctionality may avoid the production of other new products.
	- Was the product designed to use fewer materials (or less quantity)	e.g., lightweight can reduce the use of raw materials
Extend the lifespan of product and parts (e.g. reuse, repair, refurbish, remanufacture)	- Was the product designed to retain its function for longer? What is the product's lifetime in relation to similar products?	e.g., higher durability may decrease the need for new products providing the same functions
	- Is product reuse promoted as strategy for the users or consumers?	e.g., reusing a product may avoid the production of new products
	- Are reused parts or components used in the production, manufacturing, or assembly of the product?	e.g., reusing parts or components may decrease the need of virgin feedstock
	- Is the product designed to improve the repairability (or remanufacturing or refurbishing)?	e.g., availability of repair manuals or provision of spare parts may increase the product lifetime
	- Does the product support upgrades/updates?	e.g., supporting extended software updates or product upgrades to meet user expectations can extend the life of a product by decreasing the need for product replacement.
	- Are recycled materials used?	e.g., the amount of recycling content may reduce the dependency of virgin materials

[13] The boundary of the so-called "cradle-to-cradle" is not discussed here as it is not mentioned in ISO 14040/44. Moreover, "cradle-to-grave" may include end-of-life treatment and recycling, as mentioned in the LCA standards. We assume that other circularity strategies, such as reuse or refurbishing, can also be included in a "cradle-to-grave" boundary.
[14] Foreground system is specific to the scope of the study (i.e. own operation and fixed suppliers). The background system includes the processes upstream or downstream to the foreground system (ILCD, 2010). For example, in the production of a PVC bottle, the plastic pebbles may be at foreground system, but the extraction of oil needed for the production of the PVC will possibly be at background system.

Useful application of materials (e.g. recycle, recovery)	- Can the product's materials be recycled? Or was the product designed to be more recyclable?	e.g., this can enhance the possibility of recycling materials
	- Are biobased (renewable) materials used?	e.g., the use of renewable materials may decrease the need for non-renewable materials resources
	- Are other by-products / waste materials used in as feedstock?	e.g., wool from sheep not originally purposed for producing textiles
	- Which waste treatment infrastructures are in place in the different parts of the life cycle?	specific waste infrastructure may be essential for waste streams that cannot be currently treated by existing waste infrastructure (e.g., composting plants for biodegradable products)
	- Does the production, manufacturing, or assembly process is optimised to decrease generate waste?	Waste generation can be decreased in several steps of a product life cycle.
	- Does the upstream production of feedstock generate waste? - Do downstream processes generate waste?	Procuring materials with lower circularity impact may influence on the overall circularity of the product.
	- Are there hazardous materials in the product?	e.g., the use of hazardous materials can hamper recycling, or reusing of the product/parts
	- Are materials biodegradable (in technical facilities) at the end of the product's life?	e.g., degradability of materials may require specific composting plants
	- Are actions in place to promote correct product collection for recycling/reuse at the end of life?	e.g., reverse logistics can increase product circularity

9.5 Specific aspects and questions for criticality

Each product, economic activity and region rely on resources, some of each being "critical". Criticality is commonly assessed based on the risk of supply disruption of raw materials taking into account "the probability of supply disruption resulting from geopolitical and market factors" and "the vulnerability of a user to supply disruptions"(Sonderegger et al., 2020). The condition of criticality is thus context dependent. In fact, the assessment is carried out from a demand vs. supply perspective, from the user perspective (a company, a region – e.g., the EU –, or the global market) in relation to market suppliers (a company, a region, and/or the global market). Different criticality assessment (CA) methods allow for different scopes of analysis determined. For example, EC-CA considers the demand and importance of raw materials in the EU's economy and the potential risks of supply disruption according to EU' suppliers or global suppliers (depending on data availability). GeoPolRisk instead considers a country or region's demand of a raw materials and the geopolitical risks of its suppliers.

CA methods support decision makers from industry and governments, and policy-makers by: a) providing information regarding raw materials supply and demand dynamics; b) identifying bottlenecks throughout the supply chain; and c) identifying opportunities to promote risk-mitigating measures (European Commission, 2020b, 2020a). Users of methods might restrict the goal of the study according to the scope of raw materials for which they want to assess criticality and implement risk-mitigating strategies.

“Natural resources” in LCA encompasses land and sea area, energy sources, water, air, natural biomass (i.e., flora and fauna), minerals, fossil fuels, metallic ores, and nuclear ores (Dewulf et al., 2015). The scope of materials characterized in ORIENTING is limited to those raw materials analysed by the “Study on the EU’s list of Critical Raw Materials” (2020) and nuclear ores (Dewulf et al., 2015). (see Annex A for the detailed list of raw materials to take into consideration).

Thus, this document addresses criticality of non-metallic minerals, metals and other ores, as well as fossil fuels and natural biomass. It is an open issue in ORIENTING whether there is a need to characterize criticality for materials other than the ones included in the EU’s study. This would introduce further LCSA challenges because of the associated data needs, which relevance of being addressed will be assessed during the project according to results and feedback from case studies as well as based on from stakeholders’ consultation. Alternatively, at the most advanced level of application, companies might assess the criticality of other raw materials in their products and supply chain through the GeoPolRisk formulae. Data requirements for this application are described in Chapter 13.

As presented in Figure 5, CA methods usually take into account three main stages of the life cycle to analyse the availability of (primary or secondary) raw materials in the market: the extraction of natural resources (e.g., where the output is the raw materials content in ore bodies); the processing of those into primary raw materials (i.e., a “ready-to-use” form of the raw material); and the end-of-life (e.g., secondary raw materials coming from EoL circular strategies – mitigating criticality). Although other stages such as the production of components can present risks of supply disruption as well, it is likely that this stage has a higher supplier diversity. Meanwhile, the mining and processing stages are subjected to reserves and resource and suppliers' concentration. In ORIENTING, this rationale applies to the criticality characterization model in the Impact Assessment phase.

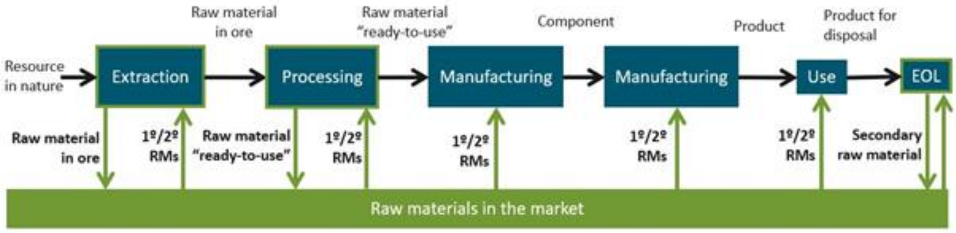


Figure 5 Life cycle stages that provide information of availability of (primary or secondary) raw materials in the market in criticality assessments.

System boundaries of the analysis of criticality at a product level are limited to “cradle-to-gate”, considering that criticality indicators communicate resource availability impacts in a production system (See Figure 6). The scope of analysis may vary according to the raw materials to be analysed. The assessment of effects of LCSA’s EoL scenarios, specific recycling and reusing rates or recycled content in the system is out of the scope of the application of the criticality assessment in ORIENTING since the characterization model already accounts for the availability of secondary raw materials in the market as a mitigating parameter.

Making an analogy with LCA, they can be raw materials in the bill-of-materials (BoM) of the product; or all the materials in the life cycle foreground and background systems. For example, if a company/organisation wants to know the risks of supply disruption of those materials in its final product, the assessment can be carried at BoM level. On the other hand, if a company/organisation wants to know any potential supply risks in the value chain that can affect the manufacturing process, the assessment should be conducted considering all materials in the LCI. Additionally, considering the market competition and price fluctuation due to the demand, a third option might be considered: to analyse the materials contained in the BoM through its direct use in the product and indirect use in the supply chain (both based in foreground and background data). Besides, the quantities of materials losses throughout the supply chain might be included.

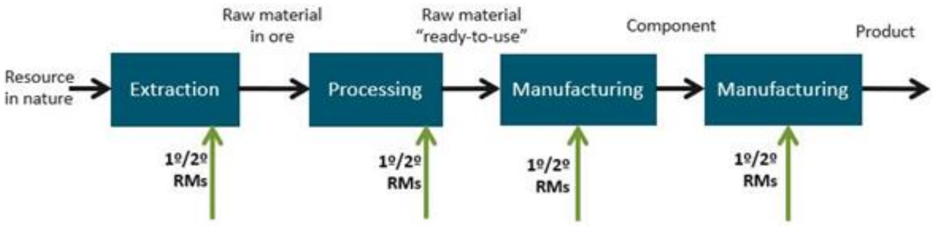


Figure 6 System boundaries of criticality assessment from an LCSA perspective.

Table 11 presents a list of questions that might be helpful for planning the use of criticality indicators as part of an LCSA study.

Table 11 Non-exhaustive list of questions that can aid the use of criticality indicators

Question	Details and examples
What are the raw materials present in the final product (including packaging)?	BoM - gives an overview of the minerals, metals, fossil fuels and natural biomass;
What is the origin of those raw materials?	This will help understanding issues of availability - social and geopolitical issues and concentration of reserves
Is this material critical according to EC list of CRM?	"Yes" or "No" list according to the EC list (See Table 6 and/or Annex A)
What are the raw materials present in the life cycle of the product? (cradle-to-gate)	This information will came from the LCA inventory. No additional information is needed; Scope of RM analyzed can be limited to BoM (direct) or not (all RM)-; Goal of the study can be (but not limited to): 1) To have an overview of the bottlenecks in the supply chain; 2) To have an overview of relevant raw materials in the foreground and background system e.g. that can affect packing or electricity supply;
Which of those materials can be substituted (by other materials or secondary raw materials)?	

9.6 Specific aspects and questions related to the economic assessment

Within an LCSA, the goal and scope of the economic assessment should be as far as possible aligned with the social and environmental assessment, with the system boundaries set accordingly. In general, the economic dimension often requires extending the inventory beyond those elements needed for environmental or social LCA. For example, production plant related investments or the purchase of equipment are often key elements to be considered in the economic evaluation, while they are generally outside the scope of the social or environmental LCA counterpart. In addition, as cost data is often considered as confidential, efforts for data collection may be high and special approaches may be needed for handling the cost data.

When applied at product level, LCC generally aims to estimate the costs associated with the production, commercialisation, use, and end-of-life, i.e., by default extending beyond the producing firm's own boundaries. Therefore, some of the key questions for practitioners concern the choice of relevant life cycle stages/processes, stakeholder perspective and types of costs to be included in the assessment, as further explained in the following and summarised in Table 14.

One main difference of LCC compared to environmental LCA is that LCC studies are often carried out from a certain stakeholder perspective corresponding, for most cases, to the target audience, resulting in approaches that differ in scope and elements to consider. A few examples illustrate this:

- Consumers/users of a product are mainly interested in costs related to ownership (total cost of ownership, TCO), including costs for acquisition, use and disposal of a product, but ignoring, for example, details on the manufacturing costs;
- Producers/providers/manufacturers of the product (businesses) are typically interested in a thorough understanding of the manufacturing costs, including the supply of raw materials or intermediate products and potential product disposal costs, whilst usually not directly interested by costs incurred in the use phase;
- Policy makers/NGOs are likely to be more interested in the wider societal and environmental effects related to the same product, extending the scope to the entire life cycle and also considering externalities (at least to some degree).

This variety in uses is also reflected in international standards for LCC (IEC-60300-3-3, 2017; ISO-15663, 2021; ISO-15686-5, 2017) and in the three main variants of LCC proposed by Hunkeler et al. (2008), i.e., conventional, environmental and societal LCC (abbreviated by cLCC, eLCC and sLCC, respectively). For a short characterisation of these variants, see Table 12. Here, the main distinguishing elements are the stakeholder perspective, consideration of externalities and alignment with environmental LCA (notably in terms of the functional unit, technical, spatial and temporal system boundaries and distinguished life cycle stages). Whilst a producer is more likely to choose conventional or environmental LCC and a policy decision-maker is more likely to choose societal LCC, this choice is ultimately defined by the goal of the analysis. Societal LCC is considered here as an LCSA framework of its own in which environmental and social impacts are weighted in monetary terms to the extent possible. As a result, the decision to adopt a societal LCC approach concerns mainly integration (Chapter 22) and not primarily the economic assessment (Chapters 14 and 0).

All three variants of LCC could be extended to also include positive cash flows (e.g., revenues). Table 12 is limited to LCC in its strict sense and positive cash flows are not mentioned.

Table 12 Characteristics of conventional, environmental and societal LCC

	Conventional LCC	Environmental LCC	Societal LCC
Main features	Stand-alone, single stakeholder perspective (e.g., producer or consumer), only internal costs (i.e., private cash flows)	Alignment with LCA promoted, some externalities considered	"LCSA with monetised impacts", all externalities, long term perspective
Typical stakeholder perspective	Consumers or producers (businesses)	Consumers (including public administrators, producers (business), policy makers	Consumers (including public administrators), producers (businesses), policy makers
Criteria:			
Internal costs (i.e., real cash flows, including already internalised externalities)	Yes	Yes	Yes
Externalities, soon-to-be-internalised	No	Yes	Yes
Externalities, beyond those already or soon-to-be-internalised	No	No	Yes

Another guiding question in LCC concerns the approach to follow for calculating an aggregated indicator (Table 13). The choice is governed by the intended application and involves decisions regarding whether or not to differently value cash flows or externalities occurring at different points in time (discounting) and the inclusion (or not) of benefits or positive cash flows (e.g. revenues). See chapter 0 for further details.

Table 13. Distinguishing characteristics of aggregation indicators in the economic assessment

	No discounting (rate equal to 0%)	**Discounting (rate unequal to 0%)**
Considering costs only	Total undiscounted cost	Present value or Total discounted cost
Considering costs and benefits	Total undiscounted value	Net Present Value (NPV) or Total discounted value

Table 14 summarizes the key questions to define the goal and scope that shall be addressed when carrying out an LCC study as part of a wider LCSA, while Figure 7 shows an example of how the goal and scope definition can influence the way in which the economic evaluation is carried out.

Table 14 Specific questions to be considered for the economic assessment as part of the goal and scope definition

Question	Details and examples
Audience and perspective	
Q1: From which perspective is the economic assessment intended to be undertaken?	Three perspectives are distinguished: 1) consumers, 2) producers and 3) policy makers/NGOs (societal perspective). Which perspective is taken depends on the intended application (see chapter 6). Company-internal applications usually take the producer's perspective. Company-external applications can take either perspective. The choice of the perspective will have implications on the degree to which the Cost Breakdown Structure will be filled, the chosen discount rate(s) and which final aggregation indicator is calculated (see sections 14.2, 20.2 and 20.1, respectively).
Choices concerning items to be included in the assessment	
Q2: Will only costs be considered or also benefits or positive cash flows (e.g., revenues)?	If only costs, the aggregation indicator to be selected is either total undiscounted cost or Present value / Total discounted cost; if also positive cash flows, the aggregation indicator would be either total undiscounted value or Net Present Value (NPV) / Total discounted value (see Table 13; regarding data, see sections 14.1 and 14.2 for more details).
Q3: Will only private effects be considered or also external effects? If so, in which way will they be monetised?	Private (or internal) effects are reflected in the costs borne by consumer or producer. External effects are largely due to emissions or discharges of pollutants or use of resources (see section 25.3.1 for more details on how to monetise these, thereby, largely relying on environmental LCI data).
Q4: Can available, but confidential data be used?	From a company's perspective, the extent to which confidential data can be used depends on the intended application (internal or external) and the level of detail provided (e.g., it is expected that there is no issue with communicating confidential data externally if they are aggregated into (and thus hidden in) one final LCC indicator).
Choices concerning the temporal dimension	
Q5: Which time horizon is considered?	Consideration of past, present, or future years

Question	Details and examples
Q6: Is discounting of future cash flows (and also externalities) envisaged?	Discounting of future cash flows or externalities can be done with a private or social discount rate (see section 20.2)
Choices concerning the spatial dimension and product system boundaries	
Q7: What is the spatial coverage (system boundaries) of the economic assessment?	By default, the assessment will cover the whole value chain. An alignment with the overall LCSA framework and notably with the environmental assessment would be preferable (see section 9.2).
Q8: Which Life Cycle stages are intended to be distinguished?	By default, an alignment with the overall LCSA framework and notably with the environmental assessment would be preferable, while noting that the proposed Cost-Breakdown-Structure also suggests Life Cycle stages (see section 14.2)

The example provided in Figure 7 reflects a situation in which the economic assessment is carried out from the producer perspective (Q1). In this sense, all the life cycle stages relevant to the producers are considered in the analysis, including the EoL stage as the company is also responsible for product "take-back" and disposal (Q8). By contrast, the use and maintenance phase of the product are excluded as in this case they are not relevant from the producer perspective. The example also assumes the inclusion of revenues next to the costs (Q2) and externalities (Q3).

As a result of Q1, Q2, Q3 and Q8 decisions, the cost breakdown structure employed for the life cycle inventory is modelled accordingly. Afterwards, the company can identify and classify each cost element by selected life cycle stages and types of costs. During the economic inventory analysis phase, depending on Q4 and data confidentiality risks, sensitive prices can be retrieved from literature or public databases.

Once the economic inventory is finalised, economic indicators are calculated considering the time horizon (Q5) and the use of discounting (Q6). In this case, the example considers both discounted and non-discounted costs and presents the results in granular form (by cost element), aggregate form and by life cycle stage.

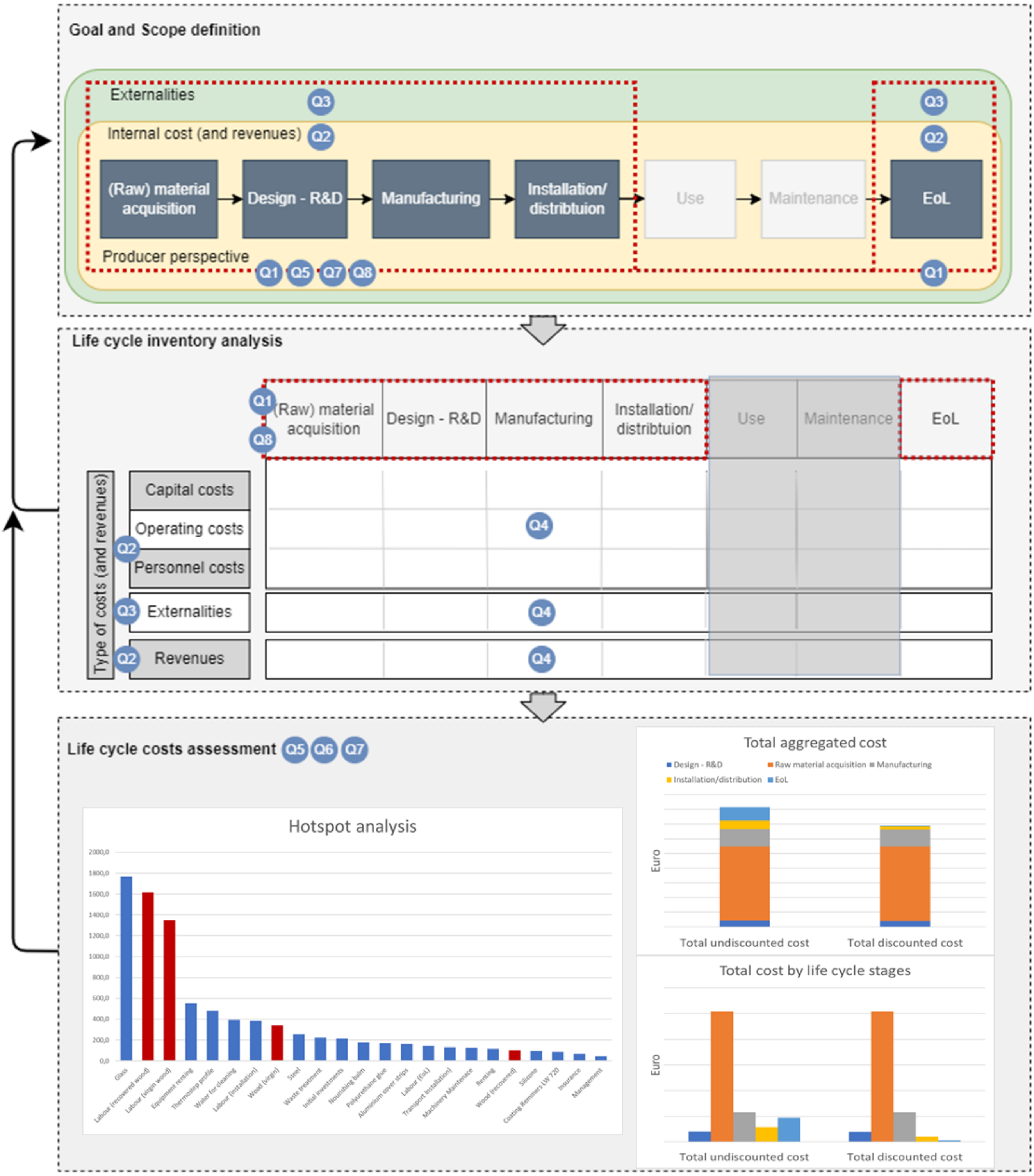


Figure 7 Phases and elements of LCC

9.7 Specific aspects and questions for social assessment

S-LCA aims to assess positive and negative social impacts, performances and risks of products along their life cycle, with the ultimate goal of improving human dignity and wellbeing. Building upon the UNEP Guidelines for Social Life Cycle Assessment (UNEP, 2020) and the Handbook for Product Social Impact Assessment (Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020), within ORIENTING, the methodology focusses on social ***performances*** and ***risks***, which are assessed with the use of the Reference Scale Approach (RSA). According to RSA, social performances in the product system are evaluated based on pre-defined, specific reference points of expected activity. The approach does not establish a direct link between the activity and long-term impacts but rather estimates the likely magnitude and significance of potential impacts in the assessed product system (UNEP, 2020). A direct implication is that the result of an S-LCA study that uses the RSA consists of information – qualitative or semi-quantitative – on the presence and/or severity of a social performance or risk: these outcomes can be organised per stakeholders' categories, per life cycle stages, and/or per social topics, or be further aggregated.(Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020), within ORIENTING, the methodology focusses on social ***performances*** and ***risks***, which are assessed with the use of the Reference Scale Approach (RSA). According to RSA, social performances in the product system are evaluated based on pre-defined, specific reference points of expected activity. The approach does not establish a direct link between the activity and long-term impacts but rather estimates the likely magnitude and significance of potential impacts in the assessed product system (UNEP, 2020). A direct implication is that the result of an S-LCA study that uses the RSA consists of information – qualitative or semi-quantitative – on the presence and/or severity of a social performance or risk: these outcomes can be organised per stakeholders' categories, per life cycle stages, and/or per social topics, or be further aggregated.

Social performances "refer to the principles, practices, and outcomes of businesses' relationships with people, organizations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard" (UNEP, 2020). An example of social performance for the social topic "discrimination and equal opportunities" is whether (and of which kind) the organisation has in place formal policies on equal opportunities. The degree to which this aspect is implemented is then evaluated with the RSA.

A social risk measures the likelihood and magnitude of negative effects only (e.g., damage, injury, loss) that may be avoided through preventive actions. It is however not meant to be quantified as a rigorous combination of probability and severity (as the conventional concept of risk does), but it mainly focusses on probability. For example, health & safety can be a social risk for workers involved in sector X, presenting high probability of occurrence in country Y. Risks are usually measured at country, sector or company level, and the location of the social risk along the life cycle where it is likely to occur represents a social hotspot. The relationships among social perfomrances, risks and impacts, and their contribution to area of protection is illustrated in Figure 8.

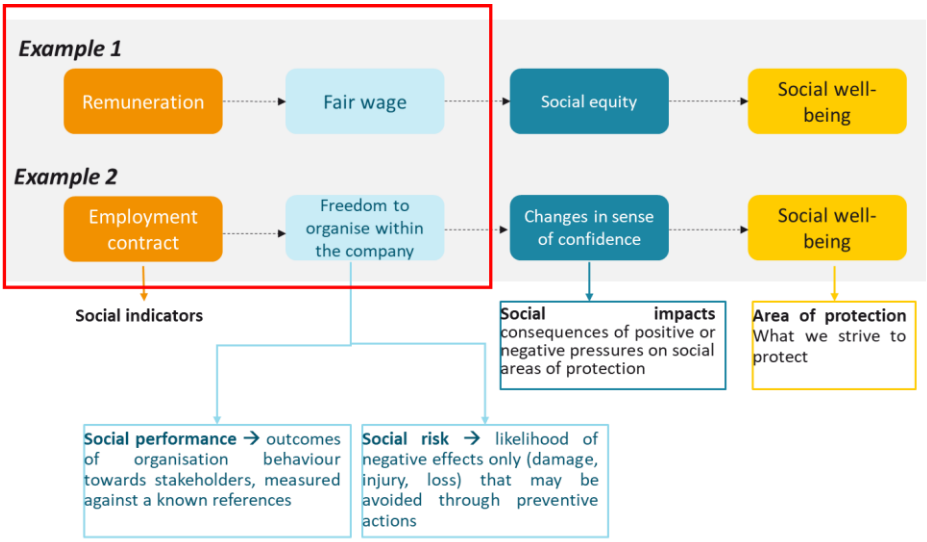


Figure 8 Examples to illustrate the concepts of social indicators, performance, risk and impact. The red box highlights the focus of the S-LCA developments in ORIENTING.

In addition to the aspects addressed as part of the LCSA as a whole (described in Chapter 9.2) the following elements shall be defined for evaluating social performances and risks as part of S-LCA. These include stakeholder categories, social topics, social indicators and materiality assessment. Table 15 summarises all the aspects and questions that shall be considered for S-LCA goal and scope definition. More guidance and examples for answering the questions are given in this chapter (below Table 15).

Stakeholders' categories

A stakeholder category is a group of people that can be affected by the activities of organizations involved in the life cycle of the product under consideration. The list of stakeholder categories has been defined by harmonising those accounted for in the Social LCA Guidelines and the PSIA Handbook, namely: workers, consumers/users, local communities, society, children, value chain actors and small-scale entrepreneurs. In needed, other stakeholder categories can be defined.

Social topics

Social topics are defined as issues of concern from the social perspective and include both performances and risks. The list of social topics has been developed by harmonising the lists from the Handbook and the S-LCA Guidelines in terms of terminology and definitions. Particular attention was given to providing definitions and examples in a structured way for all the topics. Topics were aggregated in a way to avoid overalps as much as possible (a complete independence among topics is not possible since some of them are inherently linked). The final list results in 27 topics which, in some case, differ in term of broadness of the theme: some topics are more specific (e.g., working hours) while others are more general (e.g., contribution to economic development). This aspect will be further deepened in the project based on results of consultation process and demonstrators. The social topics are linked to stakeholders: the same social topic might be relevant for more than one stakeholders. Table 16 shows social topics and their relations with stakeholder groups. A detailed description of social topics in terms of "what the social topic is about", "what we want to measure" and "example/s" is reported in Annex B.

Materiality assessment

Materiality assessment is aimed at identifying and evaluating those social aspects (including information, data, topics, stakeholder groups) that are most important for the product system and the organisation under study. Material aspects are then those that can have an impact, positive or negative, on stakeholders and/or the product system, and also those that are considered relevant by the audience of the S-LCA study.

Social indicators, used to determine the performance on the reference scale

The RSA is qualitative and semi-quantitative, and will not make use of the activity variable, i.e., social topics will not be attributed to the product in relation to variables such as work hours or value added. This implies that while the S-LCA study will require the definition of the FU like for the other sustainability domains, it will not necessarily work with the reference flow.

Table 15 Specific questions to be considered for the social assessment as part of the goal and scope definition

Question	Details and examples
Which are the organizations involved in the different processes of the product system? Please, consider the whole life cycle when identifying the organisations.	In addition to the product system described for the LCSA (as part of Chapter 9.2), describe the system also in terms of organizations, indicating i) their role (e.g., supplier, distributor) and location (represented by blue boxes in the figure); ii) the level of relationship with the organisation. If there are established relationships in place, this can imply e.g., capabilities of go to the supplier and ask for information
Draw the system boundaries by using the same flow diagramme as for the LCSA and add – at each step – the organisations identified in the previous point, with their role and level of relationship.	System boundaries shall be defined as consistently as possible (considering the environmental and economic assessments.) In this case, system boundaries shall be defined both in terms of unit processes (as in LCA and LCC) and in terms of organizations and stakeholders.
Which are the material/relevant social topics?	It is important to identify which social topics to include in the study, and related stakeholders. The topics included should be relevant for the product at hand, in line with the goal of the study. Two situations can occur: A) the product analysed is one of those for which a list of material social topics has been provided by ORIENTING. In this case, the organisation will check for their completeness. The lists of material social topics for processed tomatoes and technical coats is provided (as examples) in Tables 18-21. B) the product is not addressed by ORIENTING. It is then required to carry out a materiality assessment. If materiality has been already addressed within the organisation as part of e.g., sustainability reporting initiative, this represents the starting point.

	For both situations, the minimum number of social topics is represented by those included in the Social Taxonomy, which are aligned with the forthcoming requirements in the Corporate Sustainability Reporting Directive(European Commission, 2021c) (see Chapter 15 on social inventory for details).
Which are the stakeholder groups that might be affected by the product system?	Stakeholder are groups of people affected (positively or negatively) by the product life cycle according to social topics stemmed from materiality assessment (See Table 16)
What can be included and excluded from the system boundaries?	Overall, a cradle to grave scope is recommended, however, it may be necessary to reduce the breadth of the system boundaries and of the processes accounted for for practical reasons. Even within a reduced scope, it might be necessary to apply some cut-offs for making the analysis practicable. The cut-off criteria defined for the environmental analysis and based on mass and environmental significance cannot be adopted as such, as in S-LCA thresholds exist and the presence of a social tooic in many cases is enough for generating an impact, no matter how much. Social significance should be considered, however e.g., the production of crude oil used for electricity production, used in the manufacturing process could be left out as it is a too big topic to be addressed when approaching an S-LCA study for the first time, despite its relevance from the social perspective. It is then important to transparently report any choice done when limiting the breadth and depth of the processes and scope considered in the study, and (qualitatively) evaluate the potential consequences from excluding them.
Which impact assessment method will be applied?	The S-LCA in ORIENTING allows evaluating both social performances and social risks. Depending on the goal, both can be part of the outcomes.

Figure 9 provides an example of the elements to be included when drafting the flow diagramme and the system boundaries for S-LCA.

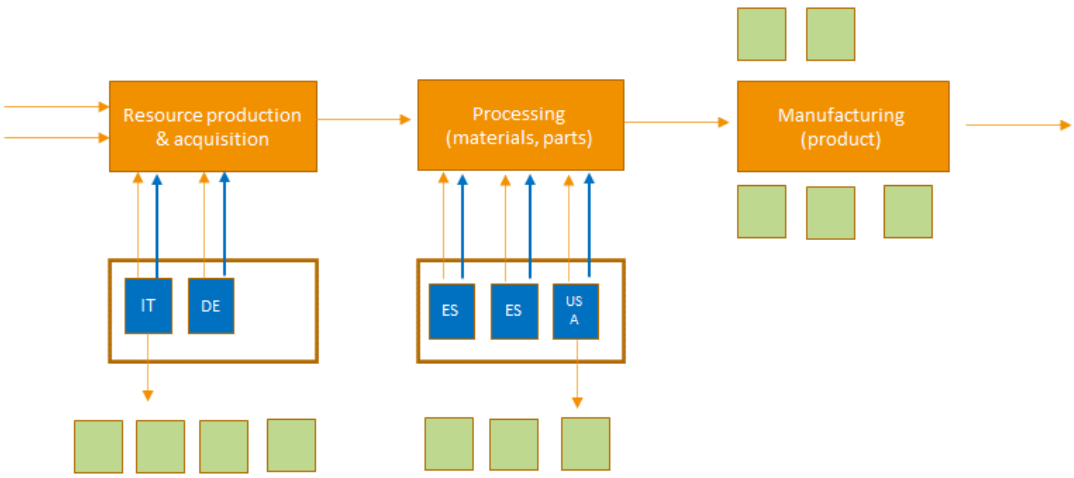


Figure 9 Example of what to account for when drawing the flow diagramme in S-LCA (Zanchi, Delogu, Zamagni, & Pierini, 2018)

In the Figure 9, an example on how to draft the flow diagramme and the elements to consider is provided, considering a limited set of life cycle stages. The green boxes represent stakeholders interacting with the organisations and the technological system; the blue boxes represent the organisations in the value chains, located in different contexts (e.g., IT Italy, DE Germany, ES Spain). The orange arrows represent the exchanged physical flows, which are accounted for and drawn also in the environmental assessment; the blue arrows represent the social performance (or potential risks) of the organisation the company (carrying out the study) has relationships with, related to the analysed product.

An overview of social topics and concerned stakeholders is presented in Table 16. This list can be helpful for considering the goal and scope. A more thorough description of all the social topics and related details can be found from Annex B.

Table 16 ORIENTING list of social topics and concerned stakeholder groups (highlighted with yellow).

No	Social topic	Stakeholder groups						
		Worker	Local community	User/consumer	Small scale enterpren	Value chain actors	Society	Children
1	Access to material, immaterial resources and cultural heritage		X					
2	Accessibility			X				
3	Affordability			X				
4	Child labour	X			X			X
5	Community engagement		X					
6	Contribution to economic development (including local employment)		X					
7	Corruption						X	
8	Delocalization and migration		X					
9	Discrimination and equal opportunities	X			X			
10	Effectiveness and comfort			X				

11	End of life responsibility			X	X	X		
12	Ethical treatment of animals						X	
13	Fair competition				X	X		
14	Forced labour	X						
15	Freedom of association and collective bargaining	X						
16	Health and safety	X	X	X	X	X		X
17	Prevention and mitigation of armed conflicts						X	
18	Privacy			X				
19	Promoting social responsibility and public commitment to sustainability issues					X		
20	Remuneration and social benefits	X			X			
21	Respect of indigenous rights and land rights		X		X			
22	Respect of intellectual property rights					X		
23	Responsible communication and feedback mechanisms			X				
24	Skill development and technology development		X				X	
25	Supplier relationships and fair trading				X	X		
26	Women's empowerment				X			
27	Work life balance and working hours	X			X			

Tables 18-21 report those social topics that have been identified as material within ORIENTING for the following products: processed tomatoes and technical coats. Thus, the tables can be used as starting points for the social assessment during the case studies. Material topics were identified at the level of the overall life cycle and per life cycle stage. The level of materiality or importance has been defined according to a five-point Likert scale, presented in Table 17.

The identification of material social topics was carried out combining two approaches:

- desk review of social aspects pointed out in sector-specific literature and policy papers
- participative techniques, to elicit the views and needs of the industrial stakeholders in the ORIENTING consortium.

Note	This first identification of material topics and of their level of relevance will be refined during the project, and it is open for comments during the consultation process. Feasiblity of the approach will be tested for all the products studied within the project.

Table 17 Scale used for identification of material social topics for the case studies

(grey)	Not important
(light yellow)	Slightly important
(light orange)	Moderately important
(orange)	Important
(green)	Very important

Topics that are labelled as “important” and “very important”in shall be included in the study. Other topics should be further scrutinized by the organisations and evaluated on a case-by-case basis. It is important to consider that social topics are context-dependent, i.e., they become relevant or not according to e.g., cultural aspects, policy initiatives in place, beliefs and many other factors that need to be evaluated on a case-by-case basis. Thus, the importance migt change (for example) according to the location in which the organisation operates or in which the different life cycle stages take place.

In addition to the social topics reported in the tables 14-22, the following shall be included in the assessment (for all levels of LCSA):

- labour rights and working conditions
- social protection and inclusion
- non-discrimination
- the right to health care, housing, education and food
- assistance in the event of unemployment, self-employment, and old-age
- consumer protection including data protection
- peaceful and inclusive societies
- fighting corruptiom and tax evasion.

These social topics are the ones considered as being part of the draft objectives of the European Social Taxonomy (Platform on Sustainable Finance, 2022) and are aligned with the recommendation of the EFRAG’s European Lab Project Task Force on preparatory work for developing EU sustainability reporting standards.

Note	Many of the social topics reported above overlap with the topics already included in the tables 15-23 as relevant: an alignement of terminology and a check of overalps and synergies will be carried out in the next steps of the ORIENTING project.

Table 18 Relevant social topics for tomato products

Social topics	**Entire life cycle**
4. Child labour	Very important
6. Contribution to economic development (including local employment)	Very important
9. Discrimination and equal opportunities	Very important
13. Fair competition	Very important
19. Promoting social responsibility and public commitments to sustainability issues	Very important
20. Remuneration and social benefits	Very important
1. Access to material, immaterial resources and cultural heritage	Important
7. Corruption	Important
10. Effectiveness and comfort	Important
11. End-of-life responsibility	Important
14. Forced labour	Important
15. Freedom of association and collective bargaining	Important
16. Health and safety	Important
22. Respect of intellectual property rights	Important
23. Responsible communication and feedback mechanisms	Important
25. Supplier relationships and fair trading	Important
27. Work life balance and working hours	Important
3. Affordability	Moderately important
21. Respect of indigenous rights and land rights	Moderately important
5. Community engagement	Slightly important
8. Delocalization and migration	Slightly important

12. Ethical treatment of animals	Slightly important
17. Prevention and mitigation of armed conflicts	Slightly important
24. Skill development and technology development	Slightly important
26. Women's empowerment	Slightly important
2. Accessibility	Not important
18. Privacy	Not important

Table 19 Relevance of social topic along the life cycle stages for tomato products

Social topic	1. Raw material acquisition	2. Design - R&D	3. Manufacturing	4. Installation / distribution / retail	5. Use	6. Maintenance, repair, refurbishment of the product in question	7. End-of-life
1. Access to material, immaterial resources and cultural heritage							
2. Accessibility							
3. Affordability							
4. Child labour							
5. Community engagement							
6. Contribution to economic development (including local employment)							
7. Corruption							
8. Delocalization and migration							
9. Discrimination and equal opportunities							
10. Effectiveness and comfort							
11. End-of-life responsibility							
12. Ethical treatment of animals							
13. Fair competition							
14. Forced labour							
15. Freedom of association and collective bargaining							
16. Health and safety							
17. Prevention and mitigation of armed conflicts							
18. Privacy							
19. Promoting social responsibility and public commitments to sustainability issues							
20. Remuneration and social benefits							
21. Respect of indigenous rights and land rights							
22. Respect of intellectual property rights							
23. Responsible communication and feedback mechanisms							
24. Skill development and technology development							
25. Supplier relationships and fair trading							

26. Women's empowerment							
27. Work life balance and working hours							

Table 20 Relevant social topics for technical coats

Social topic	Relevance for the entire life cycle
1. Access to material, immaterial resources and cultural heritage	Very important
4. Child labour	Very important
6. Contribution to economic development (including local employment)	Very important
7. Corruption	Very important
9. Discrimination and equal opportunities	Very important
11. End-of-life responsibility	Very important
12. Ethical treatment of animals	Very important
14. Forced labour	Very important
15. Freedom of association and collective bargaining	Very important
16. Health and safety	Very important
20. Remuneration and social benefits	Very important
23. Responsible communication and feedback mechanisms	Very important
26. Women's empowerment	Very important
27. Work life balance and working hours	Very important
2. Accessibility	Important
3. Affordability	Important
5. Community engagement	Important
8. Delocalization and migration	Important
10. Effectiveness and comfort	Important
19. Promoting social responsibility and public commitments to sustainability issues	Important
24. Skill development and technology development	Important
25. Supplier relationships and fair trading	Important
13. Fair competition	Moderately important
17. Prevention and mitigation of armed conflicts	Not important
18. Privacy	Not important
21. Respect of indigenous rights and land rights	Not important
22. Respect of intellectual property rights	Not important

Table 21 Relevance of social topic along the life cycle of technical coats

Social topic	1. Raw material acquisition	2. Design - R&D	3. Manufacturing	4. Installation / distribution / retail	5. Use	6. Maintenance, repair, refurbishment of the product in question	7. End-of-life
1. Access to material, immaterial resources and cultural heritage							
2. Accessibility							

3. Affordability							
4. Child labour							
5. Community engagement							
6. Contribution to economic development (including local employment)							
7. Corruption							
8. Delocalization and migration							
9. Discrimination and equal opportunities							
10. Effectiveness and comfort							
11. End-of-life responsibility							
12. Ethical treatment of animals							
13. Fair competition							
14. Forced labour							
15. Freedom of association and collective bargaining							
16. Health and safety							
17. Prevention and mitigation of armed conflicts							
18. Privacy							
19. Promoting social responsibility and public commitments to sustainability issues							
20. Remuneration and social benefits							
21. Respect of indigenous rights and land rights							
22. Respect of intellectual property rights							
23. Responsible communication and feedback mechanisms							
24. Skill development and technology development							
25. Supplier relationships and fair trading							
26. Women's empowerment							
27. Work life balance and working hours							

9.8 Specific aspects and questions for integration

In ORIENTING, **integration** is defined as the (integrated) analysis of the outcomes of LCSA across different sustainability domains (environmental, social, economic), including the consideration of circularity and criticality aspects. ORIENTING provides steps to perform the integration within the LCSA framework, guiding LCSA practitioners in the selection of adequate methods that allow for the integration, interpretation and use of multidimensional LCSA information, whilst managing in an operational manner its inherent complexities, such as potential shifts of burdens across impact categories, sustainability topics, life cycle stages, and stakeholders.

In doing so, general questions and aspects defined for the overarching LCSA goal and scope are intrinsically related also to the purpose and outcomes of integration, particularly those related to intended application (e.g., ranking options and/or obtaining numerical scores against a benchmark). However, there may be some specific questions to answer to better address the integration phase and identified possible operational options, as presented in Table 22. It should be observed that it might be possible to provide a more consolidate answer only after performing the impact assessment phase, when LCSA results will become available.

Table 22 Examples of specific questions to be considered as part of goal and scope when selecting an approach to be used for integration of LCSA results.

Question	Details and examples (*)
Is the purpose of integration to obtain numerical scores?	Scores may be created at the level of sustainability domains (environmental, economic and social), or at the level of LCSA as a whole.
Ist the purpose of integration to rank options (e.g. amongst different product/service alternatives or with an external reference)?	Assessment to be conducted for analysed options and reference case(s). The reference could be external or one of the options.
Is the purpose of integration to include the perspective of different stakeholders in weighting the results?	Identify which stakeholders to contact in order to have a panel that would be representative and suit the purpose?
Does the ingration aim at inclusion of all sustatainability topics and priorisation among them?	Make sure that the study is comprehensive enough and includes all relevant sustainability domains and topics (See also Chapter 9.9 on materiality assessment).

(*) For more info, see Chapter 22.

Alternative approaches/methods for integration will be tested during the case studies, and a dedicated tool for supporting the interpretation and integration phases is developed during the project. Further information about approaches and methods for integration are presented in Chapter 22.

9.9 Guidance for materiality assessment in LCSA

Materiality assessment is defined as a process to define topics that are important because of their impact on stakeholders/business and/or because they are considered relevant by the target audience who desires to have information on them (ORIENTING, 2021a). In an LCSA study, a key issue is that materiality (considered from different perspectives) may be related to different life cycle stages, processes, topics or stakeholder, depending of the sustainability dimensions. Thus, it has to be considered from the point of view of each dimension.

Doing a materiality assessment is both a mean and an outcome of a LCSA study: in fact, it helps in narrowing down the scope of the assessment, by highlighting which aspects matter the most. The practitioner can then just focus on them, because the identified topics are good descriptors of the behaviour of the product system analysed. For example, the PEFCRs of the Product Environmental footprint identify the most relevant environmental impact categories for a defined product group, and also life cycle stages and processes: the practitioner can then focus a PEF study only on those aspects, limiting the efforts of a study without neglecting important aspects.

In addition, the materiality might be an outcome too of an assessment, e.g., for identifying what matters the most and then prioritizing the improvement actions accordingly. The depth and breadth of how the materiality assessment is carried out and the indented goal is the key distinguishing factor between the entry, intermediate and advanced level. Doing a materiality assessment for a LCSA study requires to account for all potentially relevant aspects from the environmental, economic, social, criticality and circularity point of view. For the environmental assessment, the PEF method (and the PEFCR's) provides the materiality assessment. For the social and economic assessment, approaches are proposed in this report. All aspects of materiality and the materiality assessment approach as a whole will be tested and developed further during the ORIENTING case studies

9.10 Conclusion with provisions

Provisions 1. General goal and scope considerations

It shall be stated in the documentation

- for which purpose (intended application) the assessment is conducted and for which target audience (e.g. business, public administrators and other consumers, and policy makers: see chapter 6). Examples of purposes are given in Chapter 6).
- if the goal of the study is to make comparative claims about sustainability impacts of a product for public communication purposes, in which way and by whom (person and organisation) the LCSA results have to be verified. Note that requirements related to reporing and verification of an LCSA study are not addressed in this document
- the intended audience and the stakeholders to be involved in which part of the assessment.
- the product system under study and its functions (performance characteristics including e.g. its lifetime).
- the functional unit and a qualitative descrption of product utility. A motivation for its selection should also be provided. If the same functional unit is not used in the LCSA as a whole, this shall be justified in the documentation.
- the life cycle stages included (and distinguished) in the study and the geographic locations where the different processes take place, including a brief description. If the considered life cycle stages are not consistently applied throughout the LCSA, this shall be stated and justified in the documentation. If the whole life cycle of a product, from the cradle (raw material production) to the grave (e.g., end of life reuse, recycle, recovery, or disposal in landfill), is not covered, this shall be justified in the documentation.
- the geographical boundaries. If the geographical boundaries are not consistently applied in the LCSA as a whole, this shall be justified in the documentation. Where needed, individual life cycle stages may be analysed in more detail for one sustainability pillar (e.g. social LCA).
- the time horizon for which the assessment is relevant. This can also include the future (so-called decision-relevant future). If different time horizons are used (for example environmental aspects and impacts considered into the future differing from the costs over a product's life cycle), this shall be stated and justified in the documentation.
- the methods and indicators used in the LCSA study. If they deviate from the requirements or recommendations given in this document, this shall be justified in the documentation.
- the choices made regarding the questions raised in sections 9.2 to9.9 (See Provisions 2).

Any limitations regarding the applicability of the results should be stated in the documentation.

For requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

Provisions 2. Setting the goal and scope for the specific building blocks of the LCSA

Chosen approach to environmental LCA

- The LCA shall follow the general provisions of the LCSA
- The PEF(CR) guidance shall be followed for LCA and the deviations shall be justified and documented

- The cut-offs shall be documented
- If no PEF(CR) is available, the general PEF recommendations shall be followed and each deviation shall be documented and justified
- All impact categories shall be assessed, including the new land use, biotic production and biodiversity indicators. Deviations shall be justified.

Chosen approach to social LCA

It shall be stated and justified in the documentation:

- The social topics included in the study and the related stakeholders
- The mapping of the organisations along the product life cycle, their role and the type of relationship among them
- If a cut-off has been applied, which criteria have been applied and what has been excluded from the study
- If the study is aimed at mapping potential risks or at assessing social performances

Chosen approach to Life Cycle Costing and the related aggregation indicator

It shall be stated and justified in the documentation:

- which approach to Life Cycle Costing is followed (see Table 12).
- which aggregation indicator is used in Life Cycle Costing (see Table 13).

Chosen approach to material criticality

It shall be stated and justified in the documentation:

- if the scope of raw materials is limited to BoM (supply chain) or all raw materials (foregraound and background system e.g. that can affect packing or electricity supply)

Chosen approach to evaluate circularity

It shall be staged and justified in the documentation:

- If circularity is a relevant topic for the product in question
- Which circularity indicators (see Chapter 12) and at which level (intermediate or advanced) they are assessed.

Chosen approach to integration

It shall be staged and justified in the documentation:

- What is the main purpose of integration?

Chosen approach to assess materiality

It shall be stated and justified in the documentation,

- which approach and what data sources are used for assessing the materiality of different sustainability domains and topics.
- if and how materiality affected scope definition

For requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

10. Inventory

The life cycle inventory (LCI) phase consists of modelling the product system and collecting all the data and information that is needed for conducting the LCSA. Data needs and requirements for the data to be collected depend of the goal and scope of the assessment and the specific topics that will be included in the assessment.

Data needs for the different sustainability domains and topics are described under respective chapters of this section. Data requirements might differ depending of the purpose of the assessment and of the level at which LCSA is implemented (intermediate/advanced). Some implementation options are presented in the following chapters introducing the inventory phase.

Chapter 11 introduces the inventory for environmental assessment (LCA.) Following the requirements of the PEF method, primary data (i.e., specific data collected on site, typically referring to activities under the direct control of a company) will be collected as much as possible. For the environmental assessment, this means gathering information about the material and energy sources used in a manufacturing process, as well as the emissions and waste generated. The input and output flows (resources and emissions) needed for LCA constitute a starting point also for other the circularity (Chapter 12) and criticality assessments (Chapter 13).

For the economic assessment (focusing on LCC), the inventory builds on the environmental LCI results as far as material and energy procurement across the product's value chain is concerned. Depending on the goal and scope definition, further cost data and potentially benefits or revenues need to be collected (e.g., overhead and labour cost). The inventory for the social assessment (introduced in Chapter 15) builds on the product system, but requires collecting another layer of data and information. This consists of information concerning affected stakeholders and the relations among them, as a result of the activities carried out by the organisation providing the analysed good/service. Specific advice for collecting the data that is required for assessing social performances and risks is provided in Chapter 15.

In principle, data and information for LCSA should be collected for the whole life cycle. However, practical availability of data usually diminishes across the life cycle when going beyond the processes run by the company or on which the company has direct control (see Figure 4). In these cases, secondary data acquired from available databases, statistics and literature sources can be applied. Potential data sources are introduced for each sustainability domain and topic. Sometimes also expert estimations can be used to complement for the data gaps. In all cases, evaluation of data quality is an important part of the assessment, and sources of data (even if data itself would be confidential) including their evaluation shall be documented. Behavioural studies and statistics are also a valuable resource to model the use phase and the following end of life stage.

Existing LCA standards and the PEF guidelines provide recommendations on cut-off criteria, which means rules for including or excluding certain processes or raw materials from the assessment. For the social and for the economic assessments, materiality is the main cut-off criterion to define and apply during the goal and scope and inventory steps, as it allows to limit the data and information collection only to the relevant stakeholders and topics. More information is provided in Chapters 9, 14 & 15. Since LCSA is an iterative process, it might be that the definition of materiality changes during the assessment, and consequently the data requirements may change as well. Further strategies might need to be developed for assisting the data collection efforts, as well as assessing the quality of such information.

11. Environmental inventory

11.1 Introduction

For the purposes of a PEF study, a life cycle inventory (LCI) of all inputs (e.g., resources) and outputs (e.g., products and emissions) of the assessed product system shall be compiled. This includes the inventory of material, energy and waste flows, as well as emissions into air, water and soil, occurring in each life cycle stage. The data needs to be collected from raw material acquisition and pre-processing, manufacturing, distribution, use stage and end-of-life, including possible maintenance, repair, recycling or recovery of products and materials. Each stage is made of processes/activities, which are interconnected through material and/or energy flows from the raw material acquisition until the end of life, as shown in Figure 10

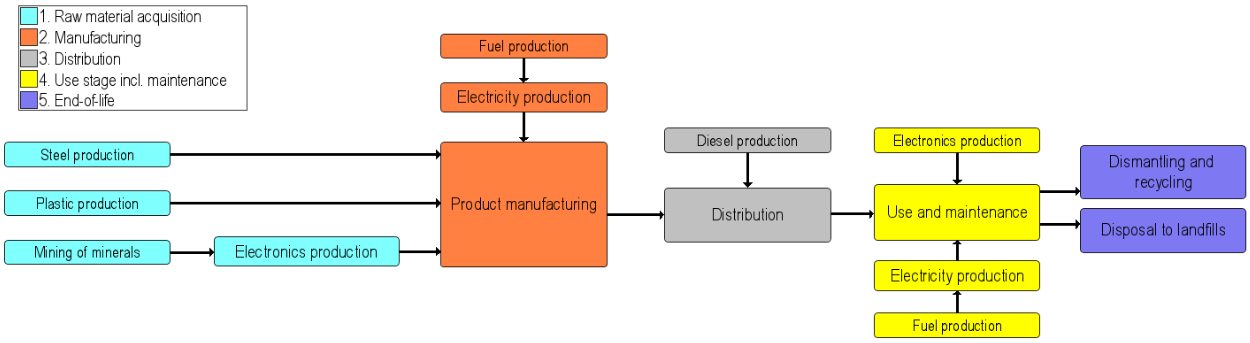


Figure 10 An illustrative example of a flowchart and processes included in its life cycle stages.

11.2 Data needs

The data collection and modelling of the life cycle starts from the manufacturing process(es) controlled by the company. This shall be based on company-specific primary data, also described as activity data. Activity data means information about the direct flows in the process, i.e. amounts and types of raw materials and chemicals used in the production, amounts of waste created, direct emissions released and amounts and types of energy needed during the assembly of the materials/components of the product in scope) as shown in Figure 11 below. This information can be collected with the support of dedicated spreadsheets, reporting inputs and outputs during a certain period with respect to a dedicated calculation basis (e.g. the production volume in one year). For ORIENTING purposes, a data collection template will give more instructions on how to define the outputs as products, by-products, recyclable waste and non-recyclable waste. Once the company specific data is collected, the value chain can be built and completed with secondary data from public data sources, as will be explained later.

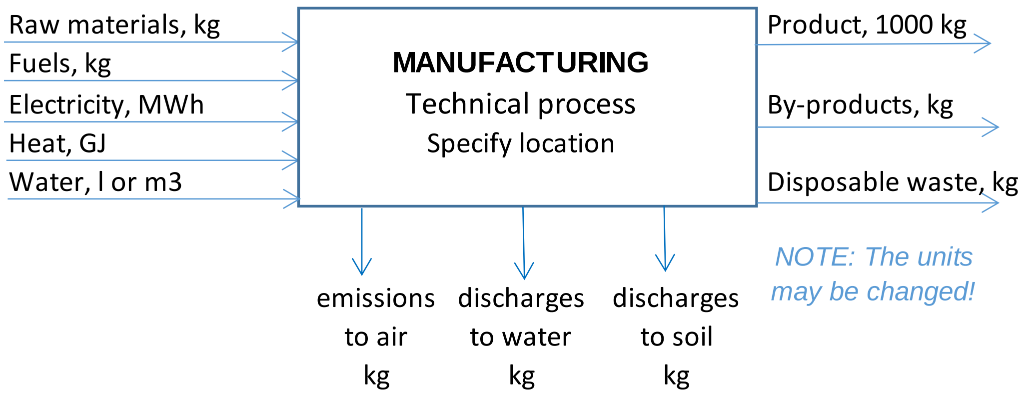


Figure 11 An example of data collection needs for a process in a life cycle assessment study

In case PEFCR document exist for the studied product category, the document includes a definition of the mandatory company specific data and data collection templates, which shall be applied in the environmental assessment. If no PEFCR exist, the data requirements are presented in Table 23. Required data can be collected with the help of a dedicated spreadsheet which will be provided for the case companies.

Table 23 Data requirements for a study without PEFCR[15]

Situation	Option	Data requirements
1. Process run by the company	Option 1	- Provide company-specific data (both activity data and direct emissions); and - Create a company-specific dataset
2. Process not run by the company but with access to specific information	Option 1	- Provide specific data (both activity data and direct emissions); and - Create a specific- dataset
	Option 2	- Use an Environmental Footprint (EF)-compliant secondary dataset; and - Apply company specific activity data (e.g., for transport distance); and - Substitute the sub-processes used for electricity mix and transport with supply-chain specific EF compliant datasets, where possible
3. Process not run by the company and without access to specific information	Option 1	- Use an EF-compliant secondary data set in aggregated form
	Option 2	- Use an ILCD compliant secondary data set in aggregated form

[15] Table adapted from: https://ec.europa.eu/environment/eussd/smgp/pdf/Training%20DNM%20Webinar%202019-12-04%20Final.pdf and https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf

When the full life cycle is considered as a cradle-to-gate or cradle-to-grave system, also the indirect flows need to be considered. This means that the LCI modelling needs to be done up to elementary flow level. Elementary flows refer to material or energy *entering* the system that has been drawn from the environment without previous human transformation (e.g., aluminium in ground, kinetic energy in wind) or *leaving* the system that is released into the environment without subsequent human transformation (e.g., nitrogen dioxide emission to air, ammonium ions to water). Such modelling is typically carried out with the support of datasets from public or commercial databases, reporting elementary flows associated with processes/activities. For the demonstrations, the ecoinvent v3 database (www.ecoinvent.org) is available but also other public ILCD compliant databases can be used.

Additional data related to land using activities will only be required if the improved land use assessment framework as additional environmental information is wanted to be implemented. This includes soil quality index, biotic production and biodiversity beyond the current land use framework, which only allows to use country average characterisation factors using a limited list of land use flows. For land use assessment, three levels of detail to model and assess land using activities will be specified, whereas the latter two go beyond the current EF framework (see also Annex A):

1. The first level refers to and complies with the general rules for inventory modelling and the current land use impact assessment practice, providing country average CFs. It does not require additional information compared to the EF framework.
2. For the second level, spatial information (latitude and longitude) is added to the model, allowing the quantification of CFs from geospatially differentiated sources (GIS based model based on generic data).
3. For the third level, the standard values provided as input to the CF calculation can be adapted by modifying the input data to the land use assessment models to represent the specific conditions on local level (e.g. allowing to calculate SOC or erosion potential based on primary data). This allows the calculation of foreground CFs specific to the actual conditions based on primary data and to consider details in land using activities such as management practices, and soil quality parameters that are used as input in LANCA®. For the data collection on level three, a template will be provided in WP4.

11.3 Cut-off rules

Data collection for LCA can be an intensive task, which in practice requires asking which data can be seen as negligible and left out of the study on the basis of so-called cut-off rules. The PEF guideline gives the possibility to apply a 1% cut-off rule to exclude processes based on their environmental significance (i.e., those processes contributing to less than 1% of impacts in each of the impact category analysed), with an overall 3% cumulative cut-off acceptable at maximum. E.g. capital goods (including infrastructure) and their end-of-life should be excluded from the LCA, unless there is evidence from previous studies that they are relevant. The PEFCR provides information of the significant data to be included in the assessment, but if a PEFCR doesn't exist, the significance can only be identified after doing a complete LCA with no cut-off. Within ORIENTING, the applicability of cut-off rules will be studied from the comprehensive LCSA point of view, considering its feasibility and operationality.

Since LCA is based on collected data and mathematical relations between them, the results are as accurate as the data used. Thus, the quality of data needs to be high to gain reliable results. In the PEF method, the data quality is rated based on technological, geographical and time-related representativeness and precision. The **data quality requirements and reporting** in ORIENTING should follow the PEF approach (European Commission, 2021a), while diverging approaches should be justified.

11.4 Principles for allocation

When a process/activity provides several functions (e.g., multiple products or services), it is 'multifunctional'. In such case, an allocation issue shall be handled to attribute environmental impacts to several functions (outputs) provided by a certain process/activity. This can also include the allocation of environmental impacts between subsequent life cycles of products/materials in a circular economy (e.g., in case of reuse of parts or recycle or materials). Allocation subdivides inputs and emissions, and thus also the related environmental impacts, between different functions.

There are several options that can be applied, and the preference of the options according to the PEF (2021) recommendations is the following.

1. Allocation should be avoided by using process subdivision or system expansion, if possible.
    a. Subdivision means that the multifunctional process is disaggregated to collect data on a more detailed level to attribute inputs and emissions to a specific function (this is often not possible in a rigorous way).
    b. System expansion broadens the system boundaries and considers several functions simultaneously, thus affecting the definition of functional unit(s) of the system.
2. The allocation should be based on relevant underlying physical relationship.
    a. This can for example be based on the mass or energy content of the products.
    b. A direct substitution of a similar function is also possible if there is a direct substitution effect and it is possible to subtract an LCI of the substituted product (e.g., by-product electricity is sold to a grid, substituting average electricity mix in the country).
3. The allocation can also be based on some other relationship, e.g., economic market value.

Allocation procedures might be flow-specific, for example, some flows might be allocated by mass and others by economic value. In this case, the used allocation should be clearly described in the documentation.

At their end of life, products, parts and materials can be reused, recycled or recovered, and used in other systems. This creates a question on how to set boundaries between the first and second product system (the system producing the raw material and the system using the recycled raw material as an input), i.e., how to allocate the burdens and benefits of producing or using recycled raw materials, and to avoid double counting or gaps between different product systems. To handle this issue, the PEF methodology has developed the circular footprint formula (CFF) (European Commission, 2018) which is also recommended to be used in the ORIENTING approach. The CFF consists of (i) production burdens within the cradle to gate system boundary, (ii) burdens and benefits related to secondary materials input, (iii) burdens and benefits related to secondary materials output, energy recovery and disposal. The formula includes allocation factors between the first and second use of materials to ensure that no double accounting occurs in the assessment. The CFF also considers the market realities related to offer and demand of materials, quality of the secondary materials compared to primary materials, and emissions related to recycling processes. To calculate the CFF, the share of secondary materials used in the manufacturing is needed. In addition, the expected end of life options shall be estimated to show the share of recycled, incinerated or landfilled products. The PEF methodology and each PEFCR gives application- and material specific default factors for allocation and quality of primary and secondary materials.

11.5 Required tools

Data collection to LCA is often done with spreadsheets. For ORIENTING, a data collection template for primary data collection is provided. In addition, a public database as a secondary data source and an LCA software (e.g. GaBi, SimaPro, OpenLCA or SULCA) can be of help when conducting the calculations.

11.6 Conclusion with provisions

Provisions 3. Environmental inventory

- A flow sheet of the studied value chain shall be presented in the documentation
- Primary data of the company specific processes shall be used, as far as possible
- All life cycle stages shall be included. If the product is an intermediate product, the distribution, use and end of life stages shall be excluded.
- Life cycle inventory (LCI) shall be compiled.

Note: for requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

12. Inventory for circularity

12.1 Introduction

Circularity is the subject of several assessment approaches. Considering an inclusivenes of the different approaches, this section will describe the inventory for circularity assessment in two quantitative and consecutive levels – intermediate and advanced (Figure 12). At the intermediate level, the circularity assessment is performed using a narrow scope that includes mainly information about the BoM. This level does not take into consideration the full life cycle of the product. At the advanced level, the assessment scope is broader and includes BoM, product use, and EoL. This level takes into consideration the full life cycle of the product, but it only regards flows of materials within the technosphere (i.e, no exchange of elementary flows with the environment). With these two levels, circularity assessment is built up sequentially and consistently between levels. One circularity indicator is proposed for each level; these indicators are based on previous studies and deliverables from ORIENTING.

This section describes the inventory as the parameters to calculate the indicators. The calculation of the indicators is described in Chapter 18 as impact assessment.

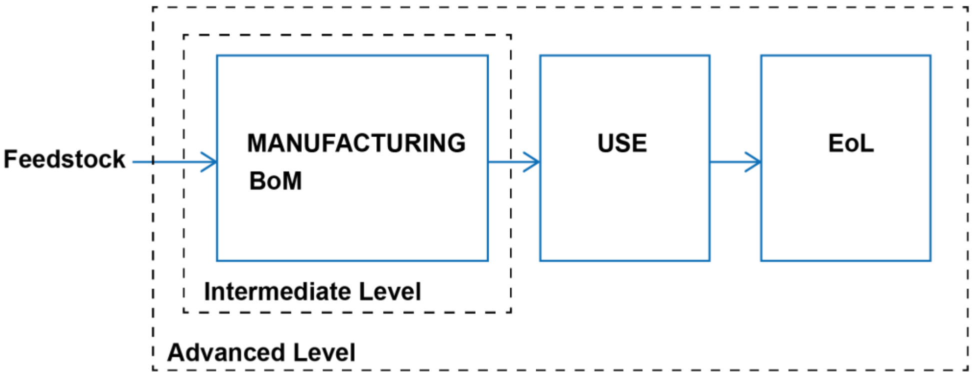


Figure 12: Intermediate and Advanced levels for circularity assessment in D2.3

12.2 Data needs

12.2.1 Assessment at intermediate level

The assessment at the intermediate level is intended as a simpler qualitative assessment of circularity that mainly includes information on the BoM. Therefore, one of the indicators described in ORIENTING D2.2 is suggested for the intermediate level – *% Circularity* from Circularity Transition Indicators v2.0 (CTI2.0) (WBCSD, 2021).

CTI2.0 was developed by the World Business Council for Sustainable Development (WBCSD). WBCSD's objective in developing CTI2.0 was to offer insights to companies about their circular economy performance. CTI2.0 includes information related to bio-based materials, water, and revenue. Their methodology claims to be of easy implementation and versatile scope, allowing businesses to measure circularity at the level of product to the entire business. CTI2.0 provides three groups of indicators called "Close the Loop, Optimize the Loop, and Value the Loop". Each group is composed of indicators aiming to measure flows of materials, emissions, water, energy, critical materials, and money. To avoid overlapping of the circularity indicators and LC(S)A in the integration, particularly with the Life Cycle Impact Assessment phase and criticality, we focus on one indicator of the first module about the flow of materials. In this case, the flow of materials is described by the indicator % Circularity.

CTI2.0's % Circularity is based on the material flows considering a company's boundary. Hence, in a general sense, this indicator is designed to calculate the circularity of companies, but it might be used also to calculate the circularity of products. Table 24 shows the parameters for calculating the indicators presented in the impact assessment part. % Circularity indicator measures the so-called inflows and outflows of materials, components, and products. Inflows are related to how circular materials and products are sourced, whereas outflows are related to the design of products and systems ensuring technical recovery of components and materials (e.g., designing for disassembly, repairability, recyclability, biodegradability). CTI 2.0 also depends on the regional/national actual recovery for a given material (e.g., recycling rate for packaging); this is the only parameter with data collection outside the company's boundary.

Table 24 Data requirements for the indicator *% Circularity* in the Circularity Transition Indicators (CTI2.0)

Parameter	Definition	Formula
% circular inflow X	% renewable or % non-virgin content. These materials have been (partially) used in a previous cycle (for example reuse, remanufacturing, recycling). For the % circular inflow it makes no difference whether a material is considered circular because it is renewable or non-virgin. Both classifications count as equally circular. In some cases, inflow can be both renewable and non virgin. In such cases, only count the inflow in one of the circular categories to prevent double counting.	Input parameter (%)
%recovery potential	% recovery potential (which is focused on design). The % recovery potential reflects the ability of the company to design its outflow to ensure it is technically recoverable through either the technical or biological cycles. For most flows, the typical categorization is: YES, this outflow is fully recoverable – resulting in 100% recovery potential. Or NO, this outflow is not recoverable – resulting in 0% recovery potential.	Input parameter (%)
% actual recovery	The % actual recovery indicator captures the amount of outflow recovered at the end of its initial life cycle. (standard recovery rates or regional/sector recovery rates or manual recovery rate + justification)	Input parameter (%)

12.2.2 Assessment at Advanced level

The assessment at the advanced level is intended as a more complex assessment of circularity and includes information on BoM, use, and EoL of materials and products. Therefore, one of the indicators described in ORIENTING D2.2 is suggested for the advanced level – Material Circularity Indicator (MCI) (EMF & Granta, 2019).

MCI is an indicator for products developed by the Ellen MacArthur Foundation (EMF) and Granta Design (EMF & Granta, 2019). The quantitative indicator considers so-called technical and biological cycles in a single score (index) that is not directly related to any other sustainability dimension. The MCI measures the extent to which linear flows have been minimised and restorative flows maximised for the component materials of a product, and for how long and intensively the materials are used compared to a similar industry-average product. The result is a value between 0.1 and 1, where higher values indicate higher circularity. The calculation of the indicator considers: the mass flows in the life cycle; the utility or function of the product via lifespan of usage (including durability of products, repair/ maintenance and shared consumption business models) and intensity of usage; rates and flows at the EoL that are going to landfill (or energy recovery), collected for recycling and collected for reuse; the rates *and* flows of recyclable materials; composting and energy recovery from biological materials. Data is mostly retrieved from companies. In addition, average data on the product analysed is needed as well.

The data needs for the indicator MCI are described in Table 25. Considering the requirements for the flow of materials, MCI shows data requirements that can be obtained from the BoM and are related to the faction of virgin, secondary and biobased materials and reuse of components (Figure 13). The data needs also include information about the use of the product (time and function) in relation to similar products in the market and to the EoL in relation to recovery possibilities. Companies can make predictions of the lifetime and number of functional units based on warranty return rates and product reliability testing or reliability models (EMF, 2015). For example, lifetime of a washing machine may be 8 years based on reliability testing. Moreover, functional unit is a dimensionless measure of a product's function. For example, a washing machine may have 3000 washing cycles.[16]

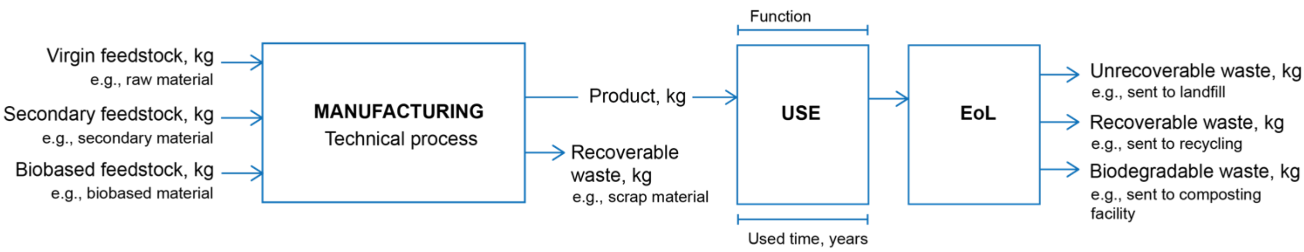


Figure 13: Example of data collection needs for a product circularity assessment at advanced level

The data from the BoM and EoL, first part of Table 25, is used to calculate the so-called Linear Flow Index (LFI). Morever, the data about use time and functionality, second part of Table 25, is used to calculate the so-called Utility Factor. Both LFI and Utility factor calculations are described in the impact assessment section.

Table 25 Data requirements for the Material Circularity Indicator (MCI)

Parameter	Definition	Formula
M	Mass of a product	input parameter (kg)
F_R	Fraction of mass of a product's feedstock from recycled sources	input parameter (%)
F_U	Fraction of mass of a product's feedstock from reused sources	input parameter (%)
C_R	Fraction of mass of a product being collected to go into a recycling process	input parameter (%)
C_U	Fraction of mass of a product going into component reuse	input parameter (%)
E_C	Efficiency of the recycling process for the portion of a product collected at the end-of-life for recycling	input parameter (%)
E_F	Efficiency of the recycling process used to produce recycled feedstock used as input material in a product	input parameter (%)
L	Actual average lifetime of a product	input parameter (unit of time)
L_{AV}	Actual average lifetime of an industry-average product of the same type. According to EMF this can be estimated from literature or expert analysis. When estimates cannot be established, L_{AV} should be equal to L.	input parameter (unit of time)
U	Actual average number of functional units achieved during the use phase of a product	input parameter (FU)
U_{AV}	Actual average number of functional units achieved during the use phase of an industry-average product of the same type. According to EMF this can be estimated from literature or expert analysis. When estimates cannot be established, U_{AV} should be equal to U.	input parameter (FU)

[16] The term *MCI's functional unit* was used to avoid confusion with the LCA standards terminology. In EMF methodology, the MCI's functional unit "is a measure of the product's use. For example, it could be one kilometer driven for a car, or one wash cycle for a washing machine."

12.3 Potential similarities and issues with the LCA framework

Generally, the data for the two indicators in intermediate and advanced level is similar to the LCA framework, particularly from the Scope definition and Life Cycle Inventory analysis phase, as described by ISO 14040 and 14044, and in Chapter 11 for the purposes of Environmental assessment.

For both circularity indicators, the information of materials flows can be treated or taken from environmental LCI considering intermediate and product flows at the foreground level (e.g., based on the Bill of Material). For example, inflows and outflows in CTI2.0's % Circularity are similar to intermediate and product flows. In this sense, elementary flows are not necessary for the calculation of the two indicators, as originally conceived by EMF and WBCSD, as they do not account for exchanges with the environment (i.e., elementary flows) through the adoption of a rigorous life cycle perspective.[17] This can potentially make circularity indicators difficult to operate with LCA datasets as the calculation of environmental impact results starts from elementary flows in the LCI.

Allocation of co-products may be needed with the use of these indicators. In this case, allocation principles should follow environmental LCA.

12.4 Required tools

The documentation of the indicators proposed at intermediate and advanced level (i.e., MCI and CTI2.0) is freely available in the methodological reports, and they can be implemented in spreadsheets (e.g., Microsoft Excel). However, tools are also available to aid calculations. In the case of MCI, there is a freely downloadable excel file programmed with macros for easy visualization where the user could test parameters and check the final MCI results; this excel file is available on EMF website under the link “dynamic modelling tool” (https://ellenmacarthurfoundation.org/material-circularity-indicator). Moreover, MCI is used by Simapro in their P-ACT tool developed in collaboration with Procter & Gamble to reduce impact and assess the circularity of packaging. On the other hand, WBCSD partnered with the company Circular IQ to develop the CTI2.0 online tool (http://www.ctitool.com/), which is a paid website said to improve the accessibility and usability of the indicators. Moreover, these indicators can also be implemented in classical LCA software, such as SimaPro, and their results can be visualized with LCIA results.

[17] Exeptions are mining and extractive industries, which extract elementary flows. However, for the proposed indicators, there is no differentiation between a flow that was extracted from the environtment (elementary) and a flow that came from another company (intermediate).

13. Inventory for criticality

13.1 Introduction

When integrated to the LCSA framework, criticality methods are suggested to be used to create characterization models and factors (CF) for impact assessment, following a similar logic as per LCA. The European Commission's Criticality Assessment (EC-CA) methodology and the geopolitical-related supply risk (GeoPolRisk) were identified as mature approaches that can provide indicators on criticality in the context of ORIENTING. The use of one or another method is advised according to the implementation options, presented in this chapter and in Chapter 19 (Impact assessment for criticality).

In both cases, the inventory data collected to perform the (environmental) LCA can be utilized. Hence, the data collection needs and guidelines and data requirements specified in Chapter 11 apply here as well. However, only the input flows of raw materials and the output flows of products (products, co-products and by-products) and waste are relevant for criticality (see Figure 14). The use of GeoPolRisk would require the collection of additional information. This chapter introduces both EC-CA and GeoPolRisk methods, the data needs for each implementation level.

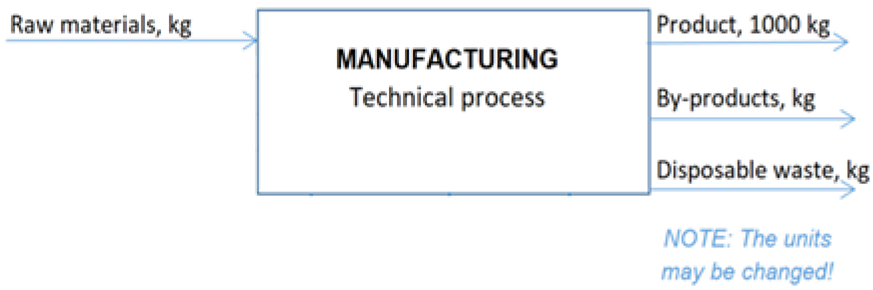


Figure 14 An example of data needs for the criticality assessment of a process in LCSA

13.2 The European Commission's Criticality Assessment (EC-CA)

The **European Commission's Criticality Assessment (EC-CA) methodology** was developed to assess the criticality of non-metallic minerals, metal ores, fossil fuels and natural biomass that are important for the EU economy and that might be subjected to supply risks. The methodology is composed of two main indicators: Supply Risk (SR) and Economic Importance (EI). Both indicators are calculated for a list of candidate materials and a threshold set by expert knowledge for each of the indicators. Only if both thresholds are surpassed, a raw material is considered critical. The outcome of the assessment is a list of Critical Raw Materials (CRM) for the EU.

The first EU CRM list and methodology description was released in 2011. The list is updated every three years to consider key trends, trade flows and barriers and to identify potential bottlenecks and supply risks throughout the value chain. The methodology is slightly improved every time. However, for the sake of comparison, it maintains its core structure as published in 2017 (European Commission, 2017b). The last list was released in 2020, with slight updates on methodology such as the inclusion of differentiation between mining and refining processes in the supply chain, data source hierarchy - EU data preferred - and better sourcing of EoL rates (European Commission, 2017b, 2020b).

The following definitions are provided for SR and EI:

- ***Economic importance (EI)*** *provides insights on the importance of a material for the EU economy in terms of end-use applications and the value added of corresponding EU manufacturing sectors, corrected by a substitution index value related to technical and cost performance of the potential raw material substitutes for individual applications.*
- ***Supply risk (SR)*** *reflects the risk of a disruption in the EU supply chain. It is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects. Depending on the EU import reliance, proportionally the two sets of the producing countries are taken into account — the global suppliers and the specific countries from which the EU is sourcing the raw materials. SR is measured at the 'bottleneck' stage of the material (extraction or processing[18]). Substitution and recycling are considered risk-reducing measures.*

13.3 GeoPolRisk

GeoPolRisk method proposes an import-based indicator for the geopolitical supply risk of resources in LCSA (Gemechu, Helbig, Sonnemann, Thorenz, & Tuma, 2016). The method includes features similar to the EC-CA, but adapted to the LC(S)A perspective. The supply risk of raw materials is primarily determined from the perspective of the resource demanding country, considering the import share of the demanding-country from the supplying country, the global share of a supplying country in the production of a certain commodity and the geopolitical stability of that country. Thus, the indicator is at a country level, employing global shares.

The method was extended by Helbig et al. (2016) to add a second stage layer to the supply-chain analysis. The proposal acknowledges that e.g. mining and processing of resources might not happen in the same country and that the relationship between the countries where these processes happen is also relevant. In 2017, (Cimprich et al., 2017) proposed an additional improvement on the methodology. The authors propose adding the vulnerability parameter based on the so-called economic importance indicator and the product-level importance factor. In this sense, the economic importance - the second indicator from the EC-CA methodology - is addressed (although not explicitly integrated in the subsequent reviews), and the mass flows are considered at the level of impact characterization. Later, in 2018, Cimprich et al. (2018) added substitutability as a vulnerability-reducing parameter, however with no specification as to which substitutability accounting approach to take. In their case study, the authors use application-specific substitutability values - ranging from 0 (highest substitutability) to 1 (lowest substitutability). Finally, Santillan-Saldivar et al. (2021) propose the use of recycling rates as a vulnerability-reducing parameter, also based on application-specific values. The latest developments on the method indicate the potential use of GeoPolRisk as and "endpoint" indicator: by means of monetization of the indicator, the GeoPolEndpoint considers the effects the increase of costs due to supply disruption to socio-economic damage (Santillán-Saldivar et al., 2021).

13.4 Data needs

The input data for the evaluation of criticality is similar to that required for accounting the life cycle inventory in (environmental) LCA. This can be the Bill of Materials (BoM) and/or the LCI, depending on the goal and scope of the assessment. As presented in Chapter 11, the LCI of all material, energy, waste flows and other outputs (such as in main products and by-products) in the foreground system need to be compiled as a basis

[18] SR is assessed for both stages of the life cycle of the raw material, while the highest value is taken further for criticality evaluation;

for life cycle modelling and interpretation. Emissions into air, water and soil can be disregarded for the analysis of criticality.

For analysis of criticality at the **entry-level,** input flows such as fuels, electricity, heat and water might be disregarded as the BoM and source/origin of materials are the only necessary information for the assessment.

For **intermediate and advanced levels**, the CF (derived either from the EC-CA methodology or from the GeoPolRisk method) can be directly associated to the input “elementary flows” of natural resources from the environmental LCI. Note that inconsistencies may arise from this characterization since criticality assessment provide values to the technological flows of raw materials according to geo-political and socio-economic characteristic of its production process and trades. The connection of CFs to intermediate flow is under study in ORIENTING. Additional information regarding the upstream supply chain of products might be relevant to understand the bottleneck of supply risks (see Box 2 for details and examples). Once these metadata are included in the inventory of the (environmental) LCA, no other data would need to be collected.

The BoM as well as material losses in processes might not be readily available in background databases. If the BoM can not be provided by the company/organisation, additional data treatment might be needed at the inventory phase to identify the mass of materials in the product. A customized solution would be necessary as LCI results do not currently show that. This solution is under study in ORIENTING.

Box 2. Scope of CRM analysis in different LC stages (e.g., electric vehicles and electric traction motors)
Both GeoPolRisk and the EC-CA acknowledge that subsequent stages of the supply chain, i.e., processed materials and manufactured components and assemblies, have different supply risks due to concentration of suppliers. In the EU’s foresight assessment (European Commission, 2020a), technologies are assessed according to a gate-to-gate approach to identify the bottleneck of the supply chain, e.g., for the electric motors. In this example, “a high risk is identified for the supply of raw materials, while a medium level of risk is estimated for the supply of processed materials and components” due to a more globally distributed production of the last two. The same gate-to-gate analysis regarding the hotspots of supply risk among the extraction and the processing stages is applied in the EU’s study on the CRMs (European Commission, 2020b). A similar approach was proposed by. Helbig et al. (2016) for GeoPolRisk.

13.4.1 Entry level

At the entry level, the data needed is limited to the quantification of the BOM of the product and the idenfication of CRM (See Chapter 8 and Table 6).

13.4.2 Intermediate and advanced levels

At the intermediate level and advanced levels, the EC-CA method and EU CRM list (2020) can be used to create CFs. Those CFs will be provided by ORIENTING and are described in a spreadsheet that is made available for the case studies.

Alternatively, GeoPolRisk is suggested at an advanced level. At this level, the practitioner performing the LCSA analysis can optionally make use of this method to produce CFs that are specifically related to the product and supply chain under study. In this case, the CFs are not provided by ORIENTING and the model to obtain the CFs is detailed in Chapter 19. To this end, the data needed is described in Table 26. Additional information on data needed to apply GeoPolRisk method can be found in (Gemechu et al., 2016; Santillán-Saldivar et al., 2021; Santillán-Saldivar, Gemechu, Muller, Villeneuve, & Young, 2022)

Table 26 Description and source of data of parameters required to apply GeoPolRisk (A= raw material/resource assessed; c= importing country; i= raw material/resource producer and exporting country (Santillán-Saldivar et al., 2022)

Parameter	Description	Source of data
HHIA	Herfindahl-Hirschman Index for raw materials A	e.g., World Governance Index (WGI)
gi	Geopolitical (in) stability of country i	e.g., Worldwide Governance Indicators (WGIs)
fAic	Imports of raw materials A from country i to country c	e.g., National databases; PRODCOM / NACE 2Rare
FAc	Total imports of raw materials A to country c	e.g., National databases; PRODCOM / NACE 2 Rare
pAc	Domestic production of raw materials A in country c (includes recycled material estimated from the EoL-RIR)	e.g., National databases; PRODCOM / NACE 2 Rare

13.5 Required tools

The criticality of materials within the product system is expected to be calculated mainly with the help of spreadsheets, containing the information from both the inventory and the characterization factors for the criticality indicator (adopted from the literature, potentially to be modified). The tools needed for the development of the inventory will be similar to those used for the (environmental) LCA, as mentioned in Chapter 11. Alternatively, specifications for the integration of a “ORIENTING-LCIA method” for criticality into software’s repositories (e.g. SimaPro) might be explored and developed during the project. The indicators shall be able to answer stakeholders question regarding criticality. Thus, the tables with criticality CFs will be provided by ORIENTING after testing in the case studies.

14. Economic inventory

14.1 Introduction

The economic inventory mainly consists of costs occurring along the life cycle of products. Positive cash flows (e.g., revenues) can also be considered and supplementary data is often needed for base year adjustments (notably currency conversion and inflation adjustment). Figure 15 shows how the costs and positive cash flows can be conceptualised, visualising flows in a similar way as done for environmental LCA (see Figure 11 in Chapter 11).

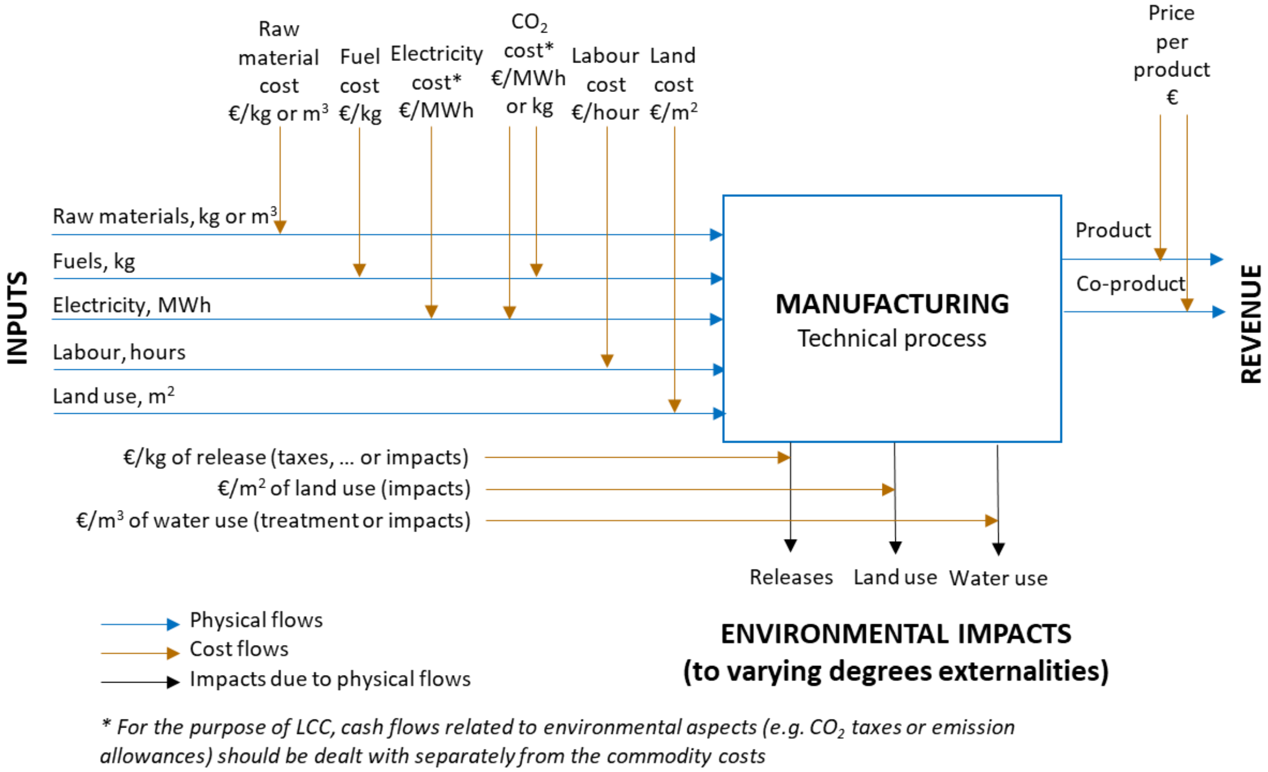


Figure 15 Flow diagram for the economic assessment

Care shall be taken to avoid double counting of costs (cf. Moreau & Weidema, 2015). For example, if (intermediate) product prices are integrated into the economic inventory as costs, the costs of raw materials, fuels, labour etc. used to produce this (intermediate) product shall not be considered, since already integrated in the price of the (intermediate) product. That could be the case for an economic assessment carried out from the perspective of manufacturers (purchasing intermediate products), or consumers (purchasing final products). Product prices might also serve as revenues to the vendor.

The availability of reliable cost data is crucial in order to quantify any of the indicators described in section 20.1 (impact assessment). The creation of an inventory represents a substantial part – often underestimated – of the overall work required. Gathering financial data can be time-consuming and will depend, to a great extent, on the resources made available by the involved companies and institutions. The types of costs included depend on the goal and scope of the study (e.g., the life cycle stages included or the stakeholder perspective adopted), and on the relevance (materiality) of each cost element for the intended analysis.[19] Conversely, the lack of data for certain aspects (e.g., specific externalities) might require to re-consider the goal and scope of the study (iterative approach).

Section 14.2 presents a Cost Breakdown Structure to support the collection of data and organise cost elements according to economic inventory categories and life cycle stages, while section 14.3 proposes an evaluation of data in terms of needs, availability and confidentiality that can be used for the collection phase. All cost data should be specific to the technical and geographical context and be given in the same reference unit (currency) and reference year ("base year" in the following). In addition to cost data contained in the Cost Breakdown Structure, therefore, further (complementary) data is needed for currency and inflation adjustments (see section 14.4). Section **Error! Reference source not found.** deals with tools with which to conduct LCC.

14.2 Data needs: Cost Breakdown Structure of ORIENTING

14.2.1 The Cost Breakdown Structure in detail

One of the main challenges in LCC is to clearly define the Cost Breakdown Structure (CBS), i.e., to identify, estimate and organise all cost elements to be considered. To this aim, Figure 16 shows the cost classification that is suggested to be used by default in the goal and scope definition phase and during data collection to

(1) help define the scope of the analyses (according to industrial partners' perspectives); and

(2) assess the data needs for LCC.

Depending on the purpose of the application, the cost elements to be collected will differ. The different cost elements can either be entered in a disaggregated way (e.g., single raw material inputs and their costs) or in a more aggregated way, if disaggregated data is not available. The CBS is said to be "extended" when it also includes non-cost elements, i.e., positive cash flows such as revenues.

The ORIENTING CBS (Figure 16) organises the economic inventory categories (rows) according to life cycle stages (columns). Letters from A to H identify different economic inventory categories, broadly distinguishing between the common categories CAPEX (capital expenditures) and OPEX (operational expenditures), but also distinguishing other types of (indirect) costs, for instance environmental externalities. Further, LCC-related studies and standards (e.g., ISO-15663, 2021) do not necessarily limit themselves to costs but also include revenues and other benefits (using metrics such as the Net Present Value, NPV). Therefore, an additional row "I" for positive cash flows is included. A full description of each economic inventory category is provided in Table 27, along with some examples for each category. In brief, the following economic inventory categories are distinguished in ORIENTING's LCSA framework: A. Capital costs (fixed, one-off expenses); B. Material/utility costs (costs directly proportional to the manufacturing or use of the product); C. Personnel cost; D. Transport cost; E. Other operational costs (annual costs required to keep running the business or use); F. Emission & discharge & waste related costs (e.g., disposal of waste, pollution taxes, emission credits); G. Soon-to-be-internalised external costs; H. Non-internalised external costs; I. Positive cash flows (e.g., revenues by sold products, residual value of waste, by-product waste…).

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[19] Note that for example when LCC is conducted for benchmarking purposes between different products, only items that change between the two products are often considered, while the other items can be excluded.

		LIFE CYCLE STAGES						
HIGHER LEVEL COST CATEGORY	ECONOMIC INVENTORY CATEGORY	1. Design - R&D	2. (Raw) material acquisition and pre-processing	3. Industrial processing	4. Distribution / retail / installation	5. Use	6. Maintenance, repair, refurbishment	7. End-of-Life (incl. recovery & recycling)
CAPEX	A. Capital costs							
OPEX	B. Material/utility costs							
	C. Personnel							
	D. Transport							
	E. Other operational costs							
	F. Emission, discharge & waste related costs							
EXTERNALITIES	G. Soon-to-be-internalised external costs							
	H. Non-internalised external costs							
POSITIVE CASH FLOWS	I. Positive cash flows (e.g. revenues by sold products, residual value of waste, by-product waste…)							

Figure 16 extended Cost Breakdown Structure of ORIENTING

Table 27 Definition of the cost elements distinguished in the extended Cost Breakdown Structure

CBS category	Description	Link with LCA inventory	Examples
A. Capital costs	Capital costs are fixed, non-recurrent expenses. These can refer to the purchase of land, buildings, or even the repair of a product if done as a one-off expense. Capital costs include expenses for tangible goods such as the purchase of industrial plants and machinery, as well as expenses for intangible assets such as trademarks and software development. Capital costs are not limited to the initial construction of a factory or other business. Namely, the purchase of	Linked in the case that capital goods are accounted for in an LCA inventory, depending on the chosen system boundaries.	Industrial plant investment, equipment costs, trademark, licenses, software etc.

CBS category	Description	Link with LCA inventory	Examples
	a new machine to increase production and last for years is a capital cost. Capital costs do not include labour costs (note that they do include construction labour though). Unlike operating costs, capital costs are one-off expenses but payments can be spread out over many years in financial reports and tax returns. Capital costs are fixed and are therefore independent of the level of output.		
B. Material/utility costs	Expenses related to the acquisition/consumption of goods. These can include: (1) raw materials like sand, iron or chemicals, (2) industrial intermediate goods such as steel, plastic, glass etc. and (3) utilities like energy, water, oil, fuel etc. These costs are, to a large extent, proportional to the output produced (once accounted for due economies of scale).	Generally linked to material and energy flows used to quantify the LCA inventory	Cost of wood, steel, iron, sand, gravel, electricity, water, glass, paper, plastic etc.
C. Personnel cost	Expenses related to wages and salaries (plus employers' social security costs) and training. A distinction is made between salaries and wages. Salaries refer to management or professional positions that are paid on a fixed amount basis and are not linked to the production. Wages refer to labour cost linked to production and are proportional to the number of hours worked.	Typically, not linked. These items require an extension of the LCA inventory.	Wages, salaries and training cost
D. Transport cost	Expenses related to the transportation of goods or to the transportation of people when delivering a service. To note that it may be the case that transportation costs are already included in the price of goods. To be checked case by case.	These costs can be calculated based on the distances used for the quantification of LCA inventory	Transportation of raw materials from the mines to the place of further processing, delivery of products to retail outlet, travel by craftsmen (e.g., for maintenance or installing)

CBS category	Description	Link with LCA inventory	Examples
E. Other operational costs	Operational expenses not included in other categories. They can refer to annual ongoing costs for using a product or running a business or system.	Not linked. These items require an extension of the LCA inventory.	Rent, insurance, marketing, maintenance of equipment etc.
F. Emission, discharge & waste related costs	Costs of business operation related for example to releases to air, soil or water, as well as waste management activities, that businesses pay for in the form of taxes, fees or permits (legislation enacted and effective)	Generally based on LCA inventory	Waste fee, CO_2 emission tax or permit
G. Externalities - Soon-to-be-internalised	Adverse consequences (e.g., due to emissions) for which legislation is already in place today such that users or manufacturers of products will have to pay for (part of) these consequences in the future (e.g., in the form of taxes). Note that it is not sufficient that a policy is already under negotiation/consideration: it must have at least been adopted (legislation not yet enacted)	Generally based on LCA inventory	Emission and discharge costs: taxes or other indstruments accounting for impacts due to water pollution, soil pollution, GHG emissions, air pollution etc.
H. Externalities – Non-internalised external costs	Adverse consequences (e.g., due to emissions) for which users or manufacturers of products do not have to pay. These could be monetised and considered in (societal) LCC. (legislation not yet enacted)	Environmental (including health) externalities are linked to environmental aspects, contained in an LCA inventory (above all regarding environmental flows). These are different from "F" and "G" in the sense that they are not yet integrated or planned to be integrated into prices through taxes or other instruments (neither today nor expected to be in the decision relevant future). If social externalities were to be included, inventory data from social LCA would be required.	Emission and discharge costs as well as societal costs: monetised impacts due to water pollution, soil pollution, GHG emissions, air pollution etc.
I. Positive cash flows	Referring to the positive inflow of money (in the present or in future years) in the form of, e.g., sales	Link with LCA in terms of functional unit(s), not necessarily when it comes	EoL residual value, revenues, waste-to-energy, waste by-product etc.

CBS category	Description	Link with LCA inventory	Examples
	income, accounting for residual values.	to accounting for product sales.	

14.2.2 Dealing with internalised externalities: the example of Greenhouse Gas Emissions

Environmental aspects, as collected in the environmental LCI, can lead to externalities. Some of these externalities can already (partly) be internalised, some will soon be internalised, or will remain non-internalised for the moment. The associated costs will, therefore, need to be classified in the CBS as "F. Emission, discharge & waste related costs", "G. Soon-to-be-internalised external costs" or "H. Non-internalised external costs", respectively. In the following, the prominent case of greenhouse gas (GHG) emissions is discussed.

In different parts of the world, Greenhouse Gas (GHG) emissions are already taxed or emission allowances need to be purchased in certain sectors. Thus, the associated environmental impacts are already internalised, at least in part. For the proper classification of the related costs, one needs to distinguish at the environmental LCI level between those GHG emissions that a) already come with a cost (CBS category "F"), or b) will soon come with a cost (CBS category "G"), and report these separately from those that c) are not yet covered by any environmental regulation (CBS category "H"). Distinguishing between these environmental flows at the environmental LCI level might turn out to be difficult to achieve and will be tested during the demonstration phase within the ORIENTING project.

14.3 Identifying data needs, availability and confidentiality to structure the collection of cost data

The data needs for LCC depend of the chosen LCC approach (cLCC, eLCC or sLCC), the perspective taken, whether or not positive cash flows are considered, and the intended application of results (internal vs. external). The cost-breakdown structure (Figure 16) provides an overview about which kind of data is needed for the assessment.

14.3.1 Approach

In order to structure the data collection, the CBS of ORIENTING is coupled with an evaluation of materiality (see also chapter 8), availability, feasibility and confidentiality. *Materiality* in accounting terms means that only those items that are expected to have a significant impact on the result should be part of the analysis. This same principle is proposed in ORIENTING for the choice of cost elements to consider in the final indicator calculation during the implementation stage. *Availability* refers to those cost elements that can be made readily available from the company (no estimation needed). *Feasibility* refers to those cost elements that cannot be made readily available from the company (estimation needed). *Confidentiality* refers to those cost elements that cannot be disclosed by the company for confidentiality reasons.

One might have to find a balance between confidentiality and availability: confidential data might be available to a company but cannot be used in the intended application (e.g., external communication purposes, also depending on the level detail of the communicated results). Data collection might need to be planned accordingly.

14.3.2 Allocating product-unspecific cost elements

In ORIENTING, cost data are linked to the functional unit of the product in question. However, there are costs that are not directly related to the analysed product. These include capital costs, which relate to the total investment needed to bring a project to a commercially operable status (e.g., purchase of land, building, equipment), and overhead costs, which are expenses incurred to support the business while not being directly related to a specific product or service (e.g., rents, administrative costs, insurance). In some cases, the consideration of these costs is essential in determining the price of a product or service in such a way that the company makes a profit. In these cases, they should also be included in the LCSA, taking into account that, due to their nature, adjustments are required to correctly refer them to the functional unit of the product in question (see following paragraphs).

In order to correctly attribute capital expenditure of an asset to the functional unit, some additional information is required, including 1) the selected allocation strategy, 2) the useful life of the asset and 3) the quantity of FUs produced over the time period. The definition of the allocation strategy refers to the way in which a share of the total capital expenses is related to the FU. Since the evaluation is of an economic nature, it seems reasonable in this case to privilege the allocation based on economic relations (e.g., turnover or profits) over allocation based on physical quantities.

Economic allocation can be explained by a simple example: an equipment has a useful life of 10 years and is used to produce two types of goods, A and B. The profit generated by production line A in 10 years is estimated to be 2 arbitrary economic units (AEU), while the profit generated by production line B is estimated to be 3 AEU. The capital expenditure of the equipment is 50 AEU. The allocation factor for production line A will be 0.4 (i.e., 2/(2+3)), while the allocation factor for production line B will be 0.6 (i.e., 3/(2+3)). The share of capital expenditures allocated to production line A and B will be 20 AEU and 30 AEU, respectively.

Once the overall share of capital expenditures relating to the FU system has been estimated, it is necessary to define the current amount of the capital expenditures attributable to a single FU. Capital expenditures generally refer to durable goods that operate for several years. Since more products (or FUs) will be produced during this time, the previously calculated share of capital expenditure cannot be directly attributed to the FU. Rather, it shall be divided among the total production during the selected time frame. Following the sample provided above, if production line A produces 10 goods over 5 years, the share of the capital expenditure to be imputed to the FU will be 0.4 AEU (i.e., 20/(10 x 5)).

It is evident that the consideration of capital expenditure introduces further difficulties in the economic analysis, especially if the uncertainty relating to the useful life of the assets and the quantity of goods produced over this period are considered. Indeed, the case can also occur where the production is not constant but increases over the years. Moreover, it could result in potential inconsistencies with the environmental LCA, which, in general, does not include capital goods. Nevertheless, in the case that capital goods are included in both assessments, it is suggested to use the same allocation approach, for example physical or economic, to ensure consistency.

14.3.3 Secondary data sources

Identifying public data sources is crucial to obtain reliable results when primary economic data cannot be accessed. A number of publicly available databases can be used to fill the economic inventory.

Eurostat (2022) offers a wide range of economic data, mainly gathered from the different Member States' national statistical institutes. Of special interest for ORIENTING are product price and employment wage statistics.

Trading databases such as the UN ComTrade (2022) can also be used to derive commodity prices. Here, aggregated values namely monetary trading volumes and material trading volumes among two countries are provided for a given timeframe. Thus, specific commodity prices per kilogram can be obtained. The main observed limitation to this kind of database occurs when material trading volumes are not reported, so that it is not possible to derive the specific commodity prices per kilogram. Also, these values can differ substantially between countries and years, potentially requiring further treatment to derive robust and broadly applicable values.

Within ORIENTING Task 2.4, these and other data sources are currently analysed with the goal to provide further background information, assess their completeness and limitations, and see how far they can be recommended for use within the ORIENTING LCSA framework.

14.4 Currency and base year definition and adjustments

For the consistent quantification of economic indicators, it is necessary to define a common currency and base year (constant prices).

Different options for currency adjustments exist. Most relevant for conventional cost data is the choice of a consistent and sufficiently complete source for market exchange rates for currency conversions (e.g., using annual average conversion factors from publicly available sources such as World Bank or Eurostat). As an optional element, used mainly in the context of converting monetisation factors for externalities (and in line with ISO 14008 (2019), a currency conversion can be done using so-called purchasing power parity[20] (PPP) factors. PPP data can be obtained from World Bank Group (2021) or Eurostat (2021).

Inflation adjustments are necessary when dealing with cost data from different base years (as a related topic, discounting of future cash flows is discussed in section 20.2). Different options for inflation adjustments exist when dealing with cost data from different historical base years. In line with ISO 14008 (2019), a distinction is made between monetary values (including costs) that concern consumers and those that concern producers. A consumer price index or the gross domestic product implicit price deflator shall be used if consumers (only) or producers (and potentially also consumers) are affected, respectively. While determining monetary values for future base years can be relevant for environmental impact modelling purposes, this case is not considered here (see ISO 14008 (2019) for respective provisions). Only in sufficiently motivated cases, alternative ways to base year adjustments are allowed. The harmonised index of consumer prices and the gross domestic product implicit price deflator data can be obtained from Eurostat (2021) and the World Bank Group (2021), respectively.

The sequence whether one first adjusts for currencies and then for the base year, or vice versa, can lead to different results. Regarding this question, the consensus found within the group having developed ISO 14008 (2019) is to distinguish mobile from immobile goods. An immobile good (including also natural assets) stays in a given location such that its value will develop in the same currency domain. As a result, adjusting for inflation should be conducted before converting the currency.

[20] Purchasing power parity compares two currencies in terms of the price to be paid for a basket of identical traded goods and services.

14.5 Required tools

Generally, LCC (indicator) computations do not require specialised software tools and can be carried out with non-specialised tools, such as spreadsheets.

This can also be observed in the scientific literature. According to a case study review of França et al. (2021), LCA software is not frequently used to carry out LCC studies, even though Umberto, SimaPro and OpenLCA for example have some related built-in functionalities. In their review, França et al. (2021) did not identify a reason why this functionality is hardly used. One possible explanation relates to the fact that many LCC studies are carried out as independent assessments that are not necessarily aligned with an environmental LCA and its inventory.

In the frame of conducting a LCSA, LCA software could therefore be helpful to keep the LCC analysis aligned with the environmental LCA, as suggested by Swarr et al. (2011). An environmental LCI built on existing LCA databases, would then serve as basis for carrying out LCC in alignment with eLCA. The main challenge lies in identifying and collecting the necessary cost data from internal or public sources.

In the same context, the ORIENTING Cost Breakdown Structure (CBS), as presented in section 14.2 and which is also available as spreadsheet for the ORIENTING case study companies, can be seen as a useful tool to support the creation of an economic inventory. It complements an environmental LCI by extending certain life cycle stages and by flexibly allowing to consider also externalities and positive cash flows. Moreover, it supports an assessment of materiality and data availability.

Some simple spreadsheet-based LCC tools are made available for procurement decisions of certain types of products, e.g., by the European Commission (2021b).

14.6 Conclusion with provisions

Provisions 4. Economic inventory

Cost Breakdown Structure (section 14.2.1)

- The Cost Breakdown Structure (CBS) as suggested in Figure 16 should be used. If a different or adapted CBS is used, this shall be stated and justified in the documentation.
- The cost elements considered in the assessment shall be stated in the documentation, preferably by economic inventory category and life cycle stage.
- If (intermediate) product prices are integrated into the economic inventory as costs, the costs of raw materials, fuels, labour etc. used to produce this (intermediate) product shall not be considered in addition. Product prices may serve as revenues to the vendor.

Dealing with (partial) internalisation of externalities (section 14.2.2)

- If emissions or discharges are covered or planned to be covered by environmental regulations (e.g., through taxes or trading schemes on CO_2 emissions), it shall be distinguished at environmental LCI level between those that a) already come with a cost (induced by regulation), b) will soon come with a cost, and c) those that are not covered by regulation (“non-internalised”) and thus emitted “for free”, the aim being to properly classify the related costs according to the Cost Breakdown Structure.

Assessment of data needs, availability and confidentiality to structure the collection of cost data (section 14.3)

- To structure the data collection, cost data should be assessed in terms of materiality, availability and confidentiality. The origin of the data (e.g., internal data, publicly available data from international statistical agencies or from commercial databases) by cost element shall be stated in the documentation. Estimation procedures, if used, shall be justified in the documentation.

Currency and base year definition and adjustments (section 14.4)

- All monetary values shall be expressed in the same currency for a given (base) year (e.g., € in 2021 prices). The currency and the base year shall be clearly stated in the documentation.
- The way in which currencies are adjusted shall be stated in the documentation. Currencies shall be converted with the help of market exchange rates from official sources and the rates used shall be documented. If a different approach to currency adjustment is followed, this shall be justified in the documentation.
- In case that historical monetary values do not have the same base year as the one stated in the goal and scope definition, those values shall be inflation adjusted. The way in which monetary values are inflation adjusted shall be stated in the documentation. Base years shall be converted with the help of a consumer price index or the gross domestic product implicit price deflator when consumers (only) or producers (and potentially consumers) are affected, respectively. If a different approach to base year adjustment is followed, this shall be justified in the documentation.
- Inflation adjustment should be carried out before currency adjustment. If the adjustments are carried out in a different sequence, this shall be stated and justified in the documentation.

Tools for assessing economic indicators (section Error! Reference source not found.**)**

- Any software tool, including ad-hoc spreadsheets, may be used to assess economic indicators. In the frame of a LCSA, use of LCA software, especially for the inventory, can facilitate the creation of an economic inventory. The tool(s) used shall be stated and justified in the documentation.

For requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

15. Social inventory

15.1 Introduction

The social inventory consists of mapping, colleting and elaborating data and information on social topics occurring along the product value chain, in relation to a set of stakeholders, defined in the goal and scope phase. The social topics are then expressed via performance or risk indicators against a reference scale, which allows comparing an activity/process with a reference point, against which the social performance can be evaluated.

Differently from the other methodologies included in the LCSA framework, in S-LCA the data and the information collected in most of the cases are not directly related to the analysed product system but refer to company behaviour in relation to a defined social topic. For example, corruption (which is one of the 27 social topics selected for S-LCA) refers to the extent to which the organization has implemented appropriate measures to prevent corruption, and if there is evidence that it has engaged or has been engaged in corruption. The product per se is not responsible for causing “corruption” but the organisation behaviour towards corruption (if considered a material topic) is then attributed to the product. The attribution shall not be meant as a form of allocation: the performance of the organisation becomes an attribute of the product. For example, let us consider the case of a company A producing a product X and one supplier B of theirs, producing a component Y used in X, as well as other products/components. The supplier might make use of child labour for manufacturing several products but not the component Y used in X, for example because different production lines are involved. In this case, the supplier does not carry responsibility only for that part of production included in the product system X, but for its overall behaviour (Zamagni, Amerighi, & Buttol, 2011)

There is another key characteristic of S-LCA to know when doing the inventory. In many cases, knowing “how much” of a certain social topic is not needed: the presence of child labour is a social issue per se, whose relevance does not change whether there are, e.g., 1, 2 or more cases in the organization. In addition (and as a consequence of the characteristics of S-LCA highlighted above) the RSA proposed by ORENTING is **qualitative and semi-quantitative**, and **will not make use of the activity variable**, i.e., social topics will not be attributed to the product in relation to variables such as work hours or value added.

The elaboration of inventory in S-LCA entails collecting information, evidence and supporting information (or data) on the social topics identified in the goal and scope of the study. The collected information shall be supported by context-related information, which might increase or not the severity of certain behaviour. Two main steps compose Life Cycle Inventory for S-LCA:

1) Prioritize data collection in accordance with Goal and Scope and LCSA level (see Chapter 9.7);
2) Collecting information and data for each social topic and stakeholder group defined in the Goal and Scope, following the structure of the product life cycle and thus considering the topics in relation to each life cycle stage and process.

Collection of data[21] along the whole life cycle is a time-consuming step, even for a small value chain. It is especially difficult to get information on remote parts of the life cycle, on which the organization does not have control, such as for example the raw materials extraction. Also in S-LCA, mirroring the approach adopted in LCA, a distinction is introduced between primary and secondary data:

- **Primary data** are those that describe the behaviour of the organization and are used then for assessing the social performance.
- **Secondary data** are related to the remote parts of the life cycle or to those on which the organization does not have the capability of collecting primary data. They then describe the likelihood that a certaint social topic might be relevant/occur. These types of data are used for assessing the social risks.

The different nature and quality of information which can be collected lead to an assessment where **performances and risks are usuallyintegrated along the product life cycle.**

The following Chapter 15.2 will provide more information about the type of data to be collected and presents potential data sources. It explains how data collection for performance and risk assessment can be carried out.

Chapter 15.3 describes the social indicators to be used for the study. For each of the social topic selected for the study, and related stakeholder group, (see Chapter 9.7) the RSA requires the collection of qualitative and semi-quantitative information according to inventory indicators. Social performance indicators shall be used to express the performance of a company or value chain actor on a social topic agains a reference scale. Social risk indicators shall be used to express the likelihood of occurrence of a social topic. Since a clear and unique list of social indicators is not available yet, within ORIENTING a list of indicators is provided, resulting from the integration of indicators from the Methodological Sheets (UNEP, 2021) and the PSIA Handbook (Goedkoop et al., 2020) .

Chapter 15.4 provides an overview about evaluating data quality in S-LCA, in accordance with the LCSA level. Finally, Chapter 15.5 describes practical tools, developed within ORIENTING, which can suppport the social inventory phase.

15.2 Data needs for qualitative social assessment

The data that ought to be collected depend on social inventory indicators and on the goal and scope of the assessment. Data can be classified according to the following parameters:

- **Nature of the data:**
  - Qualitative data: they describe the attributes or properties that an object possesses, e.g., the description of how sustainability issues are included in the purchasing policy of an organisation. The data then represent attributes of the object concerned (UNECE, 2000).
  - Semi-quantitative data: they come_from an index or similar tools, which were given a certain value/ranking based on defined characteristics/criteria (UNEP, 2020).

[21] In the context of S-LCA, data are meant to include also information.

- Data source
    - Primary data: data that are directly collected through, for example, interview, survey, or participant observation.
    - Secondary data: data from statistics, literature, database and which cane be used directly or after a manipulation to make it tighter to the product under evaluation.

In most of the cases, primary data correspond to company-specific and/or site-specific information; company-specific information regard the company as a whole but not refered to a specific production site (e.g. information about supplier relationship, policy about code of conduct), while site-specific information refers to data collected for a specific production activity/process, occurring in a specific facility and geographic location (e.g. community engagement activities, health and safety of workers).

Depending on the level of experience, but also on the goal of the study, the type of data needed could vary. Since the higher the quality of the data and the more time it takes to collect them, the type of data to use in an S-LCA study is also related to the level of LCSA (entry, intermediate, advanced). While the entry level analysis could rely mainly on generic secondary data, when moving to intermediate and advanced levels the amount of primary data will be predominant in the overall product life cycle. In addition, the type of data could vary among product life cycle stages and processes. It is important to consider that the type of collected information affects the type of results.

Primary data are mandatory for all the core activities (activities run by the company), while secondary data can be collected for upstream and downstream activities. If the level of analysis increases to intermediate and advanced, primary data shall be collected also for other activities, starting from those processes where the company has some control over, or from processes or companies, with which the company has established relationships. These aspects will be also discussed in Chapter 15.4 on data quality.

15.3 Social topic evaluation

The quantification of the social performances and risks require the definition of suitable indicators. In line with the data type described in Chapter 15.2, qualitative and semi-quantitative indicators are proposed, by integrating the approach proposed in the Handbook with a selection of indicators provided in the Methodological Sheets (UNEP, 2021). This list is suitable for primary data collection and support collection of information toward social performances assessment.

In addition, a mapping of the social topics present in the most widespread and recognized commercial databases and public sources was done in order to help and guide practitioner in the data collection of secondaty data. This type of information could support the assessment of social risks.

For these reasons, social indicators description is structured in the following sections according to the performance and risk assessment, respectively.

15.3.1 Assessment of social performances

Indicators used for the assessment of social performances (named Performance indicators) are qualitative markers of performance for each of the social topics. A performance indicator can only have the values “True/False“ and “Undetermined” since they attempt to evaluate a certain situation, or conditions, of a certain company with respect to a given social topic (Goedkoop et al., 2020)..

In ORIENTING, the list of performance indicators has been developed by integrating indicators from the Methodological Sheets (UNEP, 2021) and the Handbook (Goedkoop et al., 2020). As an example, Table 28 shows indicators suggested by Methodological Sheets and the Handbook for the social topic “Discrimination and equal opportunities”. As it can be observed, some indicators cover similar aspects/actions a company could take toward a certain social topic (both in terms of positive and negative perspective); they are grouped in the table on the basis of their similarity.

Table 28 Example of indicators suggested in the methodological Sheets (UNEP, 2021) and Handbook (Goedkoop et el, 2020) for Discrimination and equal opportunities

Inventory indicators from Methodological Sheets	Performance Indicators from Handbook
Presence of formal policies on equal opportunities	Description of the management system objectives and timeline
	Investments and participation in public private initiatives and NGOs that effectively deal with the issue.
	Statements from credible authorities’ organisations such as NGOs and unions.
	Public statements by the company, workers or unions
	Established grievance mechanisms for workers to report a complaint or raise concerns about any actions that violates non-discrimination policy.
	The company has fully committed to the United Nations Global Compact as a participant or signatory member or has policies that are equivalent to the UNGC principles
	While the company is in an area or sector where this situation often occurs according to statistics, there is evidence that the company has started to address the situation with a clearly defined timeline.
Total numbers of incidents of discrimination and actions taken	Complaints, lawsuits and other signals that may signal issues
	Absence of positive information while the company is in an area where this situation often occurs according to statistics.
	The number of complaints, lawsuits and other signals have been significantly reduced during the last 3 years.
Ratio of basic salary of men to women by employee categor	Wage slips or wage records of workers confirm equal pay for work of equal value.
Announcements of open positions happen through national/regional newspapers, public job databases on the internet, employment services, or other publicly available media ensuring a broad announcement	Not included
Composition of governance bodies and breakdown of employees per category according to gender, age group, minority, group membership, and other indicators of diversity	Not included

Depending on the social topic, collecting primary data might be complicated, especially if there is a risk the company or a supply chain actor is responsible for situations that are detrimental to human wellbeing. There is a low probability that the questionnaire will be returned or that the answers are truthful. Therefore, for some social topics, indirect indicators might work better: they can be used as default approach to collect information, and/or as complementary approach to direct questions.

To illustrate this concept, we use an example in which a company sources cotton from suppliers in India which have big plantations with their own staff (workers and not smallholder farmers). The materiality assessment, also supported by the hotspot identification analysis, reveals "occupational health and safety" as a relevant topic and potential serious risks could exist due to the use of harmful pesticides and inadequate use of personal protection, and the use of dangerous (primitive) tools and equipment.

Let us assume 4 suppliers are evaluated, and the following information about them is found

1. Supplier 1: is listed as a member of the Sustainable Apparel Coalition. This is a global coalition of companies aiming to make apparel more sustainable. Being a member does not imply the company is audited, but it has made its commitments to improve its sustainability performance: http://organiccottonfabricindia.com/index.html
2. Supplier 2: the website describes how it is working on optimising health and safety and other social impacts, and it believes it has already been very successful, although there are no audited reports. A randomly chosen example can be found here: http://www.appachicotton.com/contractfarming.html
3. Supplier 3: there is no information on any actions the company has taken
4. Supplier 4: states it is producing under a certification scheme that clearly requires high standards on health and safety. The company claims on its website they have won an award that recognises the superior performance on issues as health and safety. A randomly chosen example is found here https://pratibhasyntex.com

While hard evidence is not provided in these situations, it does help to understand the risks connected to sourcing from these suppliers.

The highest risk is typically connected to supplier 3: there are many problems in the cotton industry, and if the supplier does not show any initiative to address this, there is a very significant risk that the workers are not safe.

Supplier 1 is apparently aware of the risks and has clearly committed to improve. Being a member of the Sustainable Apparel Coalition may not provide evidence that there are no health risks, but if such risks are reported, the company can convincingly state that it is working on it.

Supplier 2: shows its proactiveness and commitment to address health and safety as well as other areas. By doing so it exposes itself to scrutiny from NGOs and others, and this will generally only be done when it can substantiate these efforts.

Supplier 4: works under a certification system, and also claims it has won several awards. While in this example it is not directly clear what the criteria for receiving the award are, this indicates a really proactively operating company.

Note that none of these suppliers actually provide data on accident rates or lows working hours. There may be a chance that suppliers 2 and 4 will be willing to provide this, as they could be proud of their achievements, but it is highly unlikely that supplier 3 would be willing to do so.

The full list of performance indicators will be provided by means of excel workfile (see Chapter 15.5).

Note	The full list of indicators for social performances is not available yet for consultation. Because they are strictly linked to the definition of the reference scale, they wil be made available during the following months, when the impact assessment step will be finalised.

15.3.2 Qualitative assessment of social risk

The assessment of social risks mainly relies on the use of secondary data and generic information (at sector and country levels) which can be retrieved either from international statistics, or from databases.

Within ORIENTING, indicators for social risks have been mapped through existing social databases and other data sources from NGOs and international organisations, and in relation to the social topic list described in the goal and scope. An extract is included in this document, the full mapping is made available in a spreadsheet workfile (see section 15.5).

PSILCA (Product Social Impact Life Cycle Assessment) and SHDB (Social Hotspot Database) are the databases considered for the social topic mapping. The main difference between the two databases is the use of different Multi-Regional Input-Output (MRIO) databases (and related models), and the risk-based model: PSILCA uses Eora and SHDB uses the Global Trend Analysis Project (GTAP) model (GTAP, 2021). Both databases cover the same stakeholder groups: workers, local community, value chain actors, and society. PSILCA covers 25 social impact categories and SHDB covers 26 categories. A detailed description of them, together with a comparison, is provided in the ORIENTING deliverable 1.2.

The following table shows an extract of social topics mapped in PSILCA and SHDB. As it can be seen, some social topics are present in both database while others not; moreover, different social indicators are used for the same social topic, as in the case of "Contribution to economic development". In PSILCA, more that one indicator is generally used to assed a social topic; they are not reported in detail in Table 29.

Table 29 Mapping of social topics in social DB (extract)

Social topic	Database	
	SHDB	PSILCA
Access to material, immaterial resources and cultural heritage		Access to material resources
Accessibility		
Affordability		
Child labour	Child labour	Child labour
Community engagement		
Contribution to economic development (including local employment)	Unemployment	Local employment

In addition to commercial social LCA databases, there are other data sources that are provided by various Non-Governmental Organizations (NGOs) and international associations. Much of this data is primarily open source and available on the NGOs websites. The information provided is presented as statistics obtained at the country or region level. A description of the characteristics of these data sources can be found in D1.2 of the ORIENTING project[22].

Table 30 shows an extract of the type of information that can be found on each of the NGOs. Overall, the mapping included the 14 most relevant sources that covers the majority of social topics identified by the UNEP guidelines (UNEP, 2020) and the product social impact assessment handbook (Schenker et al., 2020). Similarly,

[22] The document can be downloaded at https://orienting.eu/publications/

the information available can be obtain in two main formats: i) dataset (downloadable as xlsx or csv file) and ii) annual reports (downloadable as PDF). OECD, ILO, UN, The World Bank, WIPO, UNESCO and Living Wage Database have interactive platforms from which the datasets can be gathered (information can be filtered to select the specific figures of interest); the other NGOs included in the mapping (i.e., World Economic Forum, ITUC, Amnesty Internationl, Transparency international statistic, IOM, PETA, WAP) publish their statistic results via PDF reports. The direct link to the data sources is reported as hyperlink in the table.

More details on the NGOs description, as well as the data collection level (i.e. regional or country), the data collection methodology, and data transparency can be found in ORIENTING Deliverable 1.2 (Section 4.3).

Table 30 Mapping of social topics in open sources (extract)

	Name of source							
Social topic	Organization for Economic Co-operation and Development (OECD)	International Labour Organization (ILO)	United Nations (UN)	The World Bank (WBG)	World Economic Forum	International Trade Union Confederation (ITUC)	World Intellectual Property Organization (WIPO)	Amnesty international
Website	https://data.oecd.org/	https://www.ilo.org/global/statistics-and-databases/lang--en/index.htm	http://data.un.org/	https://data.worldbank.org/	https://www.weforum.org/reports	https://www.ituc-csi.org/ituc-global-rights-index-2020?lang=en	https://www3.wipo.int/ipstats/keyindex.htm	https://www.amnesty.org/en/countries/
Access to material, immaterial resources and cultural heritage								
Accessibility								
Affordability								
Child labour	Information on ending child labour	Information on children's rights, child labour						Information on child labour and child soldiers
Community engagement								

Contribution to economic development (including local employment)		Information on employment, unemployment, educational attainment, labour cost, and economic performance						

In Annex B the detailed mapping of the social topics in the different commercial and freely available sources is reported, as support to the conduction of S-LCA studies.

15.4 Data quality

The quality of data and information used in S-LCA studies affects the reliability and validity of the findings, and it is then important to support the interpretation of results. For the time being, there is still no comprehensive guidance document addressing general data quality requirements and management for social and socio-economic data in S-LCA, with the exception of the pedigree data quality matrix included in the PSILCA database (Maister, Di Noi, Ciroth, & Srocka, 2020) , which is also recalled in the Social LCA Guidelines. The Pedigree evaluates quality in terms of reliability of sources, completeness, temporal, geographical and technical conformances.

ORIENTING proposes to evaluate the data quality according to the Pedigree Matrix, integrated with the following principles:

- ***Relevance*** – importance of the information related to the topic,
- ***Accuracy*** – how truthful, correct and descriptive the information is,
- ***Purpose*** – reason the information exists and intent/motive of the content.

These criteria and principles can be applied to evaluate the following types of sources:

- Generic sources (i.e. NGOs, certifications, newspapers, statements from representatives of the stakeholder group).
- Scientific evidence (i.e. scientific evidence about health claims for users).
- Public authorities (i.e. statements showing (non)compliance, watchdog reports, legal proceedings).
- Self-declarations (i.e. declaration by the supply chain actors).

As already described in section 15.3, especially when primary data are collected it is not always easy to collect evidence on a certain declaration about a social topic (both in negative and positive sense) and this also affects the quality of information. It could happen that a company is effectively proactive and committed to address a certain social topic, but it is not able to provide concrete evidence since it is still working on it. When this situation occurs, the general approach of ORIENTING is to encourage the company in performing the social assessment anyhow and to clarify how S-LCA results could be used. Overall, three situations can occur in terms of existence of evidence supporting declaration:

1. No evidence but internal experts' judgment (in line with materiality assessment outcomes) (no evidence)
2. Partial evidence (i.e. self-declaration) + experts' judgment (partial evidence)
3. Complete evidence (self-declaration, social audit/certification/ethic code etc.) (complete evidence)

These three situations correspond to different levels of S-LCA as shown in the following table Table 31.

Table 31 Presence of evidence supporting S-LCA information according to different levels of LCSA

	Upstream activities	Core activities (run by the company)	Downstream activities
Entry level (Chapter 8)	Secondary data (risk per sector and country)	Primary data (company-specific data and/or site specific) (no evidence)	Secondary data (risk per sector and country)
Intermediate level	Secondary data + Primary data (processes controlled by the company and/or related to orgnisations with which the company has established relationships) (partial evidence)	Primary data (company-specific data and/or site specific) (partial evidence)	Secondary data + Primary data (processes controlled by the company and/or related to organisations with which the company has established relationships) (partial evidence)
Advanced level	Secondary data + Primary data (processes controlled by the company) (complete evidence)	Company-specific data (complete evidence)	Secondary data + Primary data (processes controlled by the company) (complete evidence)

15.5 Required tools

Within ORIENTING, three tools are under development to guide data collection in S-LCA[23].

- "Materiality assessment_S-LCA" (excel file): this file guides practitioner through materiality assessment by means of four main steps. The first to identify material social topics for the specific sectors and product groups; the second to define the level of materiality for each social topic; the third to define the capability of collecting information/data on the identified social topics, along the value chain; the fourth to structure available information/documents/evidence for each social topic.
- "Perfomance indicators_S-LCA" (excel file): description of all social performance indicators for the social topics identified in ORIENTING.
- "Mapping social topics" (excel file): full mapping of social topics identified in ORIENTING in the open sources and social DB, to support the risk assessment. List of social topics is available in Annex B of this document.

As for the use of social DB, they are currently available in some the LCA software, as shown in the following Table 32.

[23] Stakeholders interested in reviewing the files can contact info@orienting.eu for gaining access to these files.

Table 32 Overview of software tools that have integrated S-LCA databases

Software tool	S-LCA Database	
	PSILCA	SHDB
GaBi	no	no
openLCA	yes	yes
SimaPro	yes	yes
Umberto	no	no

16. Impact assessment

16.1 Introduction

The impact assessment (IA) is meant to characterize the magnitude and significance of impacts caused by the exchanges happening in the product system. In other words, it is the modelling of the impact pathway from the flows in the inventory to the cause-and-effect chain at an early level and/or a final level through midpoint and endpoint impact models, respectively (Valdivia et al., 2021b). While midpoint indicators are normally preferred for communication of products' impacts due to availability and acceptability of models, the endpoint impact categories are a way of communicating damage to the areas of protection (AoPs) (Schaubroeck & Rugani, 2017). In fact, AoPs are the definition of the subject of sustainability, i.e. what is there to be sustained or protected (Dewulf, Benini, et al., 2015), while the LC(S)A is an assessment, monitoring and management tool to achieve that goal. In this sense, AoPs could serve as a basis for developing impact assessment for the three domains, and potentially to understand how materials' circularity and criticality fit ORIENTING LCSA framework.

In (environment) LCA, there is general consensus that the AoPs are "Human Health", "Natural Environment" and "Natural Resources" (EC-JRC, 2011; UNEP/SETAC, 2019). "Man-made environment" may also be considered (De Udo Haes et al., 1999). However, the AoPs established for the environmental domain such as Human Health are also considered multidisciplinary. For example, "Human Health and safety" appear in sLCA frameworks alongside with "Happiness" as the AoPs, that could also be aggregated into a broader AoP called "Human-well Being" (Goedkoop et al., 2020; UNEP, 2020). In LCC, the AoPs are not as clear, since LCC cost values alone do not represent causal chains of impact. However, a recent framework from Neugebauer et al., (2016) suggests that LCC indicators could be connected to macroeconomic indicators of impact and build up to AoPs of "Economic stability" and "Wealth generation".Neugebauer et al., (2016) suggests that LCC indicators could be connected to macroeconomic indicators of impact and build up to AoPs of "Economic stability" and "Wealth generation".

16.2 Assessment approach

Defining the AoPs is key for understanding the overlaps between the domains and to avoid double-counting of impacts and benefits of the product system. However, the definition of AoPs in LCSA is not consensual. While this aspect is under study in ORIENTING, the operational approach followed is to quantify and aggregate indicators within and across the pillars of sustainability (LCA, S-LCA, LCC). Considering the circular economy a means to achieve sustainability, LCSA indicators are compared with CE indicators. (See Chapters 18, 19 and 22 for more information).

The steps included in the IA phase are slightly different for the different sustainability domains, and include both quantitative and qualitative methods and indicators. The selection of impact categories (and related characterization factors where relevant) should be consistent with the overall goal and scope of the LCSA study, and provide a comprehensive picture of potential sustainability impacts related to the studied product system. Together, results of the impact indicators represent the life cycle sustainability impact assessment (LCSIA) profile for the product system (ISO-14044, 2006):

- In the environmental IA phase, the life cycle inventory results are assigned to selected impact categories, and numerical indicator results are calculated using specific characterization factors (in the so-called "characterization step"). Within ORIENTING, the environmental impact assessment will apply the impact assessment methods recommended in the PEF method (2021), which will be complemented with new impact indicators and characterization factors as explained in Chapter 17.

- Indicators quantified in the circularity assessment are treated in this report as impact assessment results (although they are not precisely impacts). In Chapter 18, the calculation of the indicators proposed at the intermediate level (i.e., CTI 2.0) and advanced level (i.e., MCI) are described building on the data used for the life cycle inventory.
- The impact assessment phase for criticality is similar to the one used for environmental LCIA. Depending of the selected level of assessment (intermediate or advanced), the characterization factors for criticality assessment can be acquired from EU's list of Critical Raw Materials (European Commission, 2020b), or from the GeoPolRisk method, as described in Chapter 19.
- For the economic assessment (focusing on LCC), the impact assessment phase sums up costs and, potentially, economic benefits (occurring in the life cycle of a product), leading to different aggregate indicators (all related to the Net Present Value (NPV) formula). It builds on the economic inventory combined with other methodological choices (related for example to discounting and the potential monetisation of externalities). The impact assessment phase for the economic assessment is explained in detail in Chapter 20.
- For the social assessment (implementing the Reference Scale Approach, data on social performances collected in the inventory step are assessed against a reference scale, to assess social performances and risks associated along the product life cycle. The Reference Scale to be applied in ORIENTING case studies is still under development, and not included in this report. However, the idea of the social performance assessment is described in Chapter 21.

Further methodological refinements will be carried out in ORIENTING, also on the basis of knowledge gained in demonstration phase and through the public consultation process.

17. Environmental impact assessment

The environmental impact assessment classifies, characterises and aggregates the released emissions and resource consumptions to environmental impacts on natural environment, human health and natural resources. Furthermore, results are normalized to reference impacts and weighted according to their overall significance, which is necessary to aggregate all environmental impacts to a single score.

17.1 Classification and Characterisation

The PEF guideline presents characterization factors for 16 environmental impact categories with respective indicators, units, characterisation models and evaluated robustness levels. In ORIENTING, the assessment of environmental impacts shall follow the PEF recommendations except for the land use impacts, where an updated version of the SQI (based on the LANCA® indicators on erosion, soil organic carbon, physichochemical filtration and groundwater regeneration) and two additional indicators provided by the LANCA® model on biotic production and biodiversity applies (See Anned D). Descriptions of the environmental impact categories applied in the ORIENTING methodology are presented in Table 8, as part of Chapter 9.2.

In addition to the indicators described in the table, the indicator "Climate Change, total" is constituted by three sub-indicators: "Climate Change, fossil"; "Climate Change, biogenic"; and "Climate Change, land use and land use change", which shall be reported separately if they show a contribution of more than 5% each to the total score of climate change (European Commission, 2021a). Characterization models and factors used to quantify the cause-effect environmental mechanism between the LCI and the indicators of each EF impact category are provided in the PEF method and will be applied in the case studies by the LCA practitioners.

In general, it is necessary to assign elementary flows from the environmental life cycle inventory to their respective impact assessment categories through specific methods and models. In practice, each elementary flow per defined functional unit is multiplied with appropriate characterization factors, e.g. each greenhouse gas emission is converted into carbon dioxide equivalents and summed together to form one value describing the global warming potential of the studied system. To facilitate this, ORIENTING studies shall comply with the elementary flow list provided in the EF package. The results can be reported transparently, e.g., by referring to key LCI contributions or life cycle stages (see the example in Figure 17). This shows the hot-spots in the life cycle that can be tackled to minimize environmental impacts in each impact category.

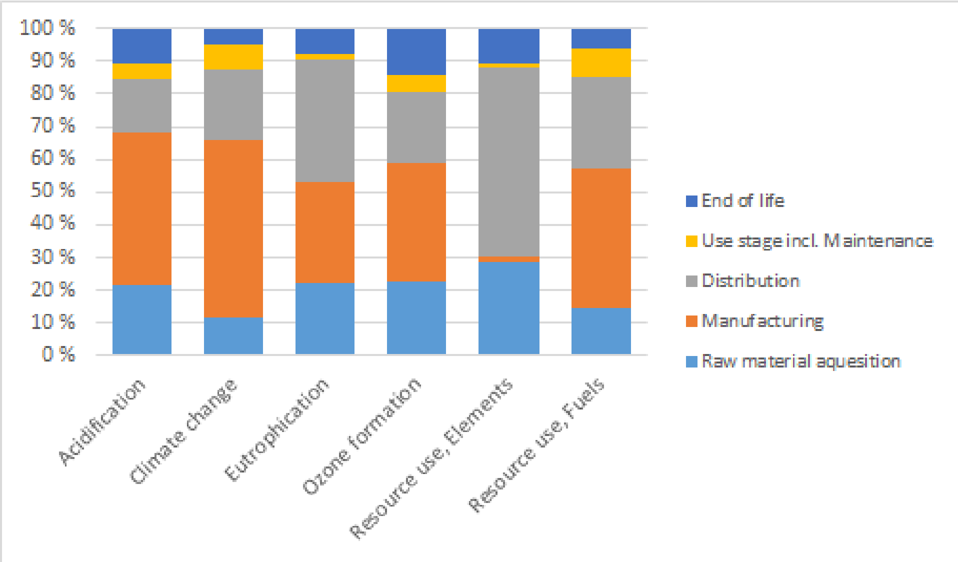


Figure 17 An illustrative example of fictional results from LCIA stage reported by life cycle stages

The PEF guideline states that "the most relevant processes are those that collectively contribute at least with 80% to any of the most relevant impact categories identified". Similarly, the most relevant impact categories contribute cumulatively at least 80% of the total environmental impact (excluding the toxicity related impacts), calculated through normalisation and weighting, according to the PEF method. Within ORIENTING, the applicability of cut-off rules will be studied from the comprehensive LCSA point of view as they are applied in the inventory but refer to impact assessment significance, considering its feasibility and operationality Deviations deviations from the PEF recommendations shall be explained and justified.

17.2 Normalisation and weighting

The midpoint results from the life cycle impact assessment can be normalized, weighted, and aggregated as endpoints (addressing areas of protection) and/or single scores. The PEF method provides normalization and weighting factors for producing a single-score, which will be applied in ORIENTING as well. The PEF normalisation method creates dimensionless values per capita referring to a global value, and the weighting builds on the work done by the EC's Joint Research Centre (Sala, Cerutti, & Pant, 2018). Their applicability in the light of approaches available for other sustainability domains will need to be considered as discussed in Chapter 22, and may require other normalisation methods to be applied as well. This single score approach may ease the comparison of different products/calculations but, at the same time, it can come with drawbacks associated with potential compensation of tradeoffs and double counting issues, as well as a loss in transparency. Thus, this needs to be handled with care, ensuring that also non-aggregated results are made available.

While the normalisation and weighting for most impact categories can directly be applied using the EF values, specific normalisation and weighting factors for land use are provided in ORIENTING. Within the PEF method the normalisation factors are expressed per capita based on a global value, and provided in the EF 3.0 reference package. For land use impact normalisation, the characterisation factors for the impact categories soil quality, biotic resources and biodiversity will be developed in ORIENTING Task 2.2 including the provision of normalization factors using the approach developed by Farago et al (2019) that is also applied for the normalisation of the SQI values in EF 3.0.

The weighting factors for land use are derived from the available EF weighting factors, assuming the same significance for the already addressed land use impacts, but providing the impacts on soil quality and biotic resources separately (see Table 33). As biodiversity is not covered in the weighting factors provided, a proxy factor for biodiversity is assigned, assuming the same weighting and robustness as for the overall land use. Due to the addition of this new category, all weighting factors are rescaled from to again sum up to 100.

Table 33 Weighting factors for ORIENTING building on the EF 3.0 weighting factors

Impact category	Aggregated weighting set (A)	Robustness factors (B)	Intermediate Coefficients (C=A*B)	EF weighting factors (incl, robustness) scaled to 100	ORIENTING weighting factors (scaled to 100 including biodiversity)
Climate change	12.90	0.87	11.18	21.06	19.49
Ozone depletion	5.58	0.60	3.35	6.31	5.84
Human toxicity, cancer effects	6.80	0.17	1.13	2.13	1.97
Human toxicity, non-cancer effects	5.88	0.17	0.98	1.84	1.71
Particulate matter	5.49	0.87	4.76	8.96	8.30
Ionising radiation, HH	5.70	0.47	2.66	5.01	4.64
Photochemical ozone formation, HH	4.76	0.53	2.54	4.78	4.43
Acidification	4.94	0.67	3.29	6.20	5.74
Eutrophication, terrestrial	2.95	0.67	1.97	3.71	3.43
Eutrophication, freshwater	3.19	0.47	1.49	2.80	2.60
Eutrophication, marine	2.94	0.53	1.57	2.96	2.74
Ecotoxicity freshwater	6.12	0.17	1.02	1.92	1.78
Land use, total	9.04	0.47	4.22	7.94	N/A
Land use, Soil Quality	6.78	0.47	3.19	N/A	5.56
Land use, Biotic resources	2.26	0.47	1.06	N/A	1.85
Land use Biodiversity	9.04	0.47	4.22	N/A	7.36
Water use	9.69	0.47	4.52	8.51	7.88
Resource use, mineral and metals	6.68	0.60	4.01	7.55	6.99
Resource use, fossils	7.37	0.60	4.42	8.32	7.71

17.3 Conclusion with provisions

Provisions 5. Environmental impact assessment

Classification and Characterisation

- The classification shall fully comply with the EF recommendations, and assign all elementary flows to the EF impact categories to which they contribute using the EF classification data (EF developer node)
- For the characterisation of environmental impacts, the most recent EF recommendations except for land use shall be applied (see Table 8)
- Land use impacts on soil quality, biodiversity and biotic resources shall be characterised using the level 1 land use framework developed in ORIENTING (see Annex E) and provided by Task 2.2.
- If land use impacts are identified as significant, an additional land use impact assessment using level 2 or level 3 of the framework may be performed.
- For comparison, the EF 3.0 SQI on land use may be reported as additional environmental information
- Furthermore, other biodiversity assessments may be applied and provided as additional environmental information as described in the EF recommendations (European Commission, 2021a)
- All characterised impact assessment results shall be reported separately without normalisation or weighting applied

Normalisation

- Normalisation shall be performed using the EF normalisation values as described in Sala et al (2018)
- Normalisation factors for land use impact assessment shall be used according to the land use framework developed in Task 2.2.
- Other normalisation approaches may be applied in addition for sensitivity analysis or to allow for specific interpretation and integration options.

Weighting

- Weighting shall be applied using the modified EF weighting factors provided in Table , splitting land use (7.94% for Land use, of which 25% is allocated to biotic resources), adding biodiversity using the same weight (7.94%) and rescaling the final 18 categories to an overall weighting score of 100.

For requirements on the use and meaning of “shall”, “should”, “may” and “can”, see section 0.

18. Impact assessment for circularity

The result of the circularity indicators is here treated as an impact result. The circularity indicators, however, do not present an impact pathway as an environmental life cycle assessment. The assessment at entry, intermediate, and advanced levels happens with exchanges in the technosphere (and not in the ecosphere). In this section, the calculation of the indicators proposed at the intermediate level (i.e., CTI 2.0) and advanced level (i.e., MCI) are described taking as inputs the data needs presented in the inventory.

18.1 Assessment at Intermediate level

The calculation for the indicator % Circularity from CTI2.0 is presented in Table 34. The parameters presented in the inventory section are shown to clarify the calculation.

The indicator % Circularity is the average between the parameters % circular inflows total and % circular outflows total. These two parameters describe, respectively, the input share of circular material resources (materials, products, components) and the share of the material resources that are designed to be recovered with functional equivalence (that is, according to WBCSD, designing for disassembly, reparability, and recyclability) or that are designed to be readily biodegradable and non-toxic to the environment. The parameter % circular outflow X is needed for each material to calculate % circular outflows total. It represents the multiplication of the recovery potential of a material (e.g., the PVC in a PCV bottle is 100% recyclable) and the actual recovery based on regional or national data (e.g., maybe only 50% of PVC bottles may be collected for recycling in a specific region).

Table 34 Overview of parameters and equations for the indicator *% Circularity* in the Circularity Transition Indicators (CTI2.0)

Parameter	Definition	Formula
% circular inflow X	% renewable or % non-virgin content. These materials have been (partially) used in a previous cycle (for example reuse, remanufacturing, recycling). For the % circular inflow it makes no difference whether a material is considered circular because it is renewable or non-virgin. Both classifications count as equally circular. In some cases, inflow can be both renewable and non virgin. In such cases, only count the inflow in one of the circular categories to prevent double counting.	Input parameter (%)
%recovery potential	% recovery potential (which is focused on design). The % recovery potential reflects the ability of the company to design its outflow to ensure it is technically recoverable through either the technical or biological cycles. For most flows, the typical categorization is: YES, this outflow is fully recoverable – resulting in 100% recovery potential. Or NO, this outflow is not recoverable – resulting in 0% recovery potential.	Input parameter (%)
% actual recovery	The % actual recovery indicator captures the amount of outflow recovered at the end of its initial life cycle. (standard recovery rates or regional/sector recovery rates or manual recovery rate + justification)	Input parameter (%)
% circular outflow X	If the materials are neither treated in such a way that they have any technical recovery potential, nor able to be reintroduced into the value chain or biological cycle, consider the outflow as linear.	%recovery potential * % actual recovery
% circular inflow total	This indicator assesses the total circularity of inflowing materials. In the equation, the parameters A, B, and C represent the different inflowing materials in a hypothetical product made of these three materials.	[(% circular inflow A * mass A) + (% circular inflow B * mass B) + (% circular inflow C * mass C)]/ total mass A + B + C
% circular outflow total	Like total % circular inflow, this formula assesses the total circularity of outflowing products, by-products and waste streams. In the equation, the parameters D, E, and F represent the different outflowing materials in a hypothetical product made of three materials.	[(% circular outflow D * mass D) + (% circular outflow E * mass E) + (% circular outflow F * mass F)]/ total mass D + E + F
% Circularity	The % circularity is based on the average of the total mass of circular inflow and circular outflow divided by the total inflow and outflow. In most cases, this will be around 50%/50% but in specific cases (e.g., high stock) it is necessary to correct that difference by taking the weighted average.	[(% circular inflow total * total mass A + B + C) + % circular outflow total * total mass D + E + F)]/ total mass A + B + C + D + E + F

18.2 Assessment at Advanced level

The calculation for the indicator MCI is presented in Table 35. The parameters presented in the inventory section are shown again to clarify the calculation.

The final equation of MCI can be described as the product of two parameters – complement percentage of the Linear Flow Index (1-LFI) and Utility Factor. On the one hand, the parameter LFI gives a score based on the materials' linearity; hence, its complement percentage (*1-LFI*) gives a score of materials' circularity. LFI shows the proportion of materials that are considered linear, which computes materials by summing up linear inputs (virgin feedstock) and linear outputs (unrecoverable waste). Linear input material flows are those from virgin sources, while linear output materials are those not designed for the material recovery (preventing reusability and recyclability). On the other hand, the parameter Utility Factor is a measure of time and/or a measure of product's function. The Utility factor is calculated as the multiplication of the product's lifetime in relation to the average lifetime of similar products and the product's functional units in relation to the average functional unit of similar products. It is important to mention that in products where lifetime and functional units overlap, only one parameter should be used in the calculation of the Utility Factor. For example, a washing machine may deliver 5000 washing cycles over its lifetime. The number of washing cycles is the product's functional unit, but this number is also linked to the product's lifetime (the product may not work over a certain number of washing cycles). Hence, only one parameter may be used to calculate Utility Factor in the case of washing machines and other products with similar overlap.

When there is insufficient data to estimate the Utility Factor, with either lifetime (L/L_{av}) or functional units (U/U_{av}), the value should be equal to 1. In this case, the assessment at the intermediate level shall be preferable to at the advanced level.

Table 35 Overview of parameters and equations for the Material Circularity Indicator (MCI)

Parameter	Definition	Formula
M	Mass of a product	input parameter (kg)
F_R	Fraction of mass of a product's feedstock from recycled sources	input parameter (%)
F_U	Fraction of mass of a product's feedstock from reused sources	input parameter (%)
C_R	Fraction of mass of a product being collected to go into a recycling process	input parameter (%)
C_U	Fraction of mass of a product going into component reuse	input parameter (%)
E_C	Efficiency of the recycling process for the portion of a product collected at the end-of-life for recycling	input parameter (%)
E_F	Efficiency of the recycling process used to produce recycled feedstock used as input material in a product	input parameter (%)
L	Actual average lifetime of a product	input parameter (unit of time)
L_{AV}	Actual average lifetime of an industry-average product of the same type. According to EMF this can be estimated from literature or expert analysis. When estimates cannot be established, L_{AV} should be equal to L.	input parameter (unit of time)
U	Actual average number of functional units achieved during the use phase of a product	input parameter (FU)
U_{AV}	Actual average number of functional units achieved during the use phase of an industry-average product of the same type. According to EMF this can be estimated from literature or expert analysis. When estimates cannot be established, U_{AV} should be equal to U.	input parameter (FU)
V	Mass of virgin feedstock used in a product	M*(1-FR-FU)
W	Mass of waste that cannot be recovered by reusing or recycling	W0+(WF+WC)/2
W_0	Mass of waste generated from a product that is not reused nor recycled (e.g., because going into landfill, waste to energy, or other type of processes)	M*(1-CR-CU)
W_C	Mass of unrecoverable waste generated in the process of recycling parts of a product	M*(1-EC)*CR
W_F	Mass of unrecoverable waste generated when producing recycled feedstock for a product	M*[(1-EF)*FR/EF]
LFI	Linear Flow Index	(V+W)/(2M+(WF-WC)/2)
F(X)	Utility factor built as a function of the utility X of a product. The constant 0.9 was defined to penalize products whose LFI is fully linear (LFI=1).	0.9/X
X	Utility of a product. According to EMF, this parameter should be calculated with either lifetime or MCI's functional unit, but not both. This is to avoid double counting the effects that lifetime can have on the use phase and vice versa.	(L/L_{AV})*(U/U_{AV})
MCI	**Material Circularity Indicator of a product**	**MAX(1-LFI*F(X),0)**

18.3 Intrepretation of circularity indicators

In ORIENTING, circularity is understood as a means that can promote sustainability. Hence, although improving the circularity of products is desirable, an improvement of the overall sustainability performance is sought in the end. In the proposal of ORIENTING, circularity is presented as a topic alongside other LCSA pillars, but its results shall not prevail over other sustainability domains. In the case of ORIENTING, results from circularity (and criticality) assessments shall be interpreted together with results from LCA, LCC and S-LCA.

The circularity assessment results in an aggregated circularity indicator, and specific parameters contributing to its calculation (e.g., use of virgin materials, production of waste). The interpretation phase may be done qualitatively or quantitatively. Qualitative analysis (e.g. via visualisation techniques) can allow observing how circularity aspects vary between alternatives, and if an improvement of circularity is coordinated or not with an improvement in other LCSA topics.

Quantitative analysis may further inform and facilitate decision making (e.g. in sensitivity analyses to understand how much LCSA impact results change through the variation of circularity parameters, such as recycling content, material recyclability, or product longevity). Further studies on this topic will be conducted during ORIENTING, and more guidelines will be provided as part of final methodology version. Interpretation and integration of circularity indicators in an LCSA study is discussed more thoroughly in chapter 22.

19.Impact assessment for criticality

Following the questions at the definition of Goal and Scope, at an entry level, one can make use of the EU CRM list to addresses which raw materials contained in a product are critical. This is made by making reference to the BoM of the product, as described in Chapters 8 and 13 concering criticality. The raw materials in the BoM can be screened against the EC's last updated list of CRM, i.e., the 2020 list of CRM, as provided in the Table 6 (as part of Chapter 8). Raw materials not included in that list can be considered as non-critical (see Annex A for the full list of materials assessed).

19.1 Characterization at intermediate and advanced level

At the intermediate and advanced level, raw materials' criticality is assessed following similar approach to the assessment of environment impacts. The criticality indicator of a material "A" is the product of the multiplication of the total mass of the material "m" (used to deliver the defined functional unit) and the criticality characterization factor (CF) associated to that material "m" (Equation 1). Hence, the total criticality of a product is the sum of the criticality indicators of all the materials characterized.

Equation 1 $$\boldsymbol{Criticality\ indicator_m = \ total\ mass\ of\ material}\ \mathrm{m} \times \boldsymbol{CF_m}$$

As introduced in Chapter 13, the total mass of materials can be calculated through different approaches, depending on the Goal and Scope. It might account for the total mass of materials in the BoM or for the total mass of materials in the LCI, considering or not the material losses throughout the supply chain. Besides, the analysis at an LCI level might include only materials that are present in the final product (based on their direct and indirect uses in the supply chain) or all material flows in the supply chain. Due to complexity of application, the assessment at a BoM level is considered as an intermediate level of assessment. The assessment at a LCI level is considered as an advanced level of assessment.

Different criticality indicators might be communicated using different characterization factors. The choice of indicators shall be in line with on the Goal and Scope. The indicators fall within three categories:

1. supply risk (SR) indicators;
2. economic importance (EI) indicators; and
3. criticality indicators *per se,* which represent the interpretation of the previous two indicators in an integrated form.

The CF might be based on EU CRM list and related EC-CA method, or on the GeoPolRisk method. CF based on the EC-CA method can provide indicators within the three categories mentioned above. CF based on the GeoPolRisk method fall under the category of supply risk indicators. While the difference between the methods was introduced in Chapter 13, the following sections explain the criticality CF and indicators based on EC-CA and GeoPolRisk.

Both methods are considered consistent, robust and relevant for criticality assessment. The choice between the methods depend on the scope of the study. The latest study on the EU's list of Critical Raw Materials provides SR and EI values for 80 critical material candidates which can be used as a basis for the creation of CFs (see Chapter 19.1.1).

In GeoPolRisk, CF are available for 14 materials for 13 countries/regions (for further details, see Gemechu et al. (2016)). Note that the available GeoPolRisk CF in Gemechu et al. (Gemechu et al., 2016) are not updated according to the latest version of the method (Cimprich et al., 2018; Santillán-Saldivar et al., 2021, 2022). The most recent publication of an adaption of GeoPolRisk also provide the Supply Risk Potential indicator for aluminum, nickel, cobalt and copper according to the materials' price in 2015, 2016 and 2017 (Saldivar et al., 2022). In this sense, the extensive use of existing GeoPolRisk indicators is yet limited. The use of this method would be needed on a case-specific demand. Due to complexity of application, CF based in GeoPolRisk method are considered at an advanced level of assessment.

GeoPolRisk covers similar yet fewer supply risk and mitigating parameters when compared to EC-CA method - depending on the version of the method utilized. This means that EC-CA method is broader, yet more complex. For example, it depends on expert knowledge to delegate substitutes for specific technologies. In this sense, considering that GeoPolRisk is an equally robust method and the easiness of application, its use is suggested:

(a) if there are no CFs or indicators for the raw material(s) under study;

(b) if the latest version of EC-CA based CFs is not considered sufficiently representative of present contexts[24];

(c) when the ORIENTING LCSA methodology is applied in extra-EU contexts;

(d) when there are country-specific data available regarding imports, domestic production and/or secondary raw materials from recycling that are representative to the raw material under study; and/or

(e) when communicating criticality as endpoint indicator through the consideration of price elasticity and potential economic loss for the country/region (Santillán-Saldivar et al., 2022).

19.1.1 Characterization factors based on EC-CA method

Based on EC-CA method, the SR and EI values for 80 critical material candidates (European Commission, 2020b) were used to create a first set of three indicator within ORIENTING: (a) EUCRM SR; (b) EUCRM EI; and (c) EUCRM. Indicators (a) and (b) correspond to the values obtained from the EU's list of CRM. Indicator (c) is a binary indicator that correspond to value "1" to critical and "0" to non-critical raw materials. The CFs are available in an excel-file that can be applied during the demonstrations.

The values of SR and EI (ranging from zero up to eight in the CRM list) have been previously applied as CF in LCA studies by Mancini et al. (2016) and Tran et al. (2018). The studies highlight two issues related to the use of such indicators to assess life cycle impacts of products:

(i) the scale of results when related to the inventory materials evaluated, and
(ii) the inconsistency regarding characterization of criticality when using LCI databases.

Regarding issue (i), Mancini et al. (2016) highlight that the SR values/scores utilized as CF have low variability, which might hide relative difference between materials in terms of supply security. The authors suggest few solutions (e.g., the use of exponentials to spread the resulting values in a wider range, or dividing indicators

[24] Note that the EU CRM list is updated every three years.

by values of market size or the geological reserve data to express the differences due to small market and resource availability, respectively), and conclude that relating the values of SR to the annual mine productions (i.e., to the market size) could better express the importance of specialty metals. Alternative indicators and CFs based on EC-CA method and EU CRM list might be considered. Recommendations such as those from Mancini et al. (2016) are under study in ORIENTING.

Following the principles of LCSA, CFs are intended to allow the computation of indicators that are comprehensive, relevant, interdisciplinary, consistent, transparent and operational. Thus, the two main concerns regarding the use of different CFs are: (1) the comprehensiveness, relevancy and consistency of CFs in responding stakeholders' questions regarding the supply risk and vulnerability to supply disruption, and raw materials' criticality; and (2) the interdisciplinary nature of ORIENTING LCSA. Thus, the use of alternative formulae to the CFs will be tested in ORIENTING case studies to confirm their usability. In the case of (2), special attention will be given to the use of parameters such as resource availability, to avoid double counting regarding indicators from environmental, social and economic assessments.

Meanwhile, criticality and supply risk indicators characterise raw materials as products of human/industrial processes, not as natural resources in the environment, such as represented in LCI (topic ii). Tran et al. (2018) suggest the use of correction factors to adjust CF to correspond to datasets of minerals and metals that are often aggregated in ores or groups and have different levels of purity or composition in nature. For example, e.g., the case among other differences in equivalence between CA studies and LCIs that can be found in literature, the EU's CRM study analyses the criticality of "iron ore". The correspondent elementary flow in the Ecoinvent v3.1 database for LCA would be "Iron, 46% in ore, 25% in crude ore, in ground". In this case, Tran et al. (2018) proposed an adjustment factor of 2.17 (=1/0.46), considering that 2.17 kg of iron ore (EU's CRM study) is needed to produce 1 kg of iron (Ecoinvent v.3.1). Basically, the elementary flow of Ecoinvent should be multiplied by 2.17 to obtain the equivalent amount of ore considered in the EU's CRM study, and vice versa. The corrections proposed by Tran et al. (2018) are incorporated to the CFs (see the Excel template for criticality CF's).

The potential connection of CFs to intermediate flows is under study in ORIENTING.

19.1.2 Characterization factors based on GeoPolRisk method

The formula (Equation 2) is used to obtain the GeoPolRisk indicator of a raw material "A" in use in a country "c" in a given year (Helbig et al., 2016; Santillán-Saldivar et al., 2022). The potential source of data for the calculation of GeoPolRisk are indicated in chapter 13.4.2. GeoPolRisk values should be calculated for the materials under study, according to the Goal and Scope. Additional information and details about the method can be found on the literature (Cimprich et al., 2018, 2017; Gemechu et al., 2016; Gemechu, Sonnemann, & Young, 2015; Helbig et al., 2016; Santillán-Saldivar et al., 2021, 2022).

Equation 2 $$GeoPolRisk_{Ac} = HHI_A \times \sum_i \frac{g_i \times f_{Aic}}{p_{Ac} + F_{Ac}}$$

Where:

HHIA=	Herfindahl-Hirschman Index for raw material A
Gi=	Geopolitical (in) stability of country i
fAic =	Imports of raw material A from country i to country c
FAc =	Total imports of raw material A to country c
pAc =	Domestic production of raw material A in country c (including recycled materials estimated from the EoL-RIR)

19.2 Intrepration of criticality indicators

The existing indicators from EC-CA are used as basis to create characterization factors. In this sense, demand-side stakeholders and suppliers of materials refer to the EU market, which might not necessarily match the stakeholders of the overall LC(S)A study (see further rational at the goal definition, section 9 & 9.5). The criticality indicator as proposed in this document characterizes the criticality of raw materials in a product based on the importance of that material in EU economy, as well as the risks of supply disruption according to suppliers in the EU market or in the global market (depending on data availability). The consideration of specific suppliers at a company level is out of the scope of the LCSA framework proposed by ORIENTING. Yet, the use of other CA methods (e.g. adapting the GeoPolRisk) that can provide a look into an organisation's supply risk is recommended for in-depth analysis of potential criticality-mitigating actions such as the diversification of suppliers.

From the perspective of the applied CA methods, the criticality of a material disregards the amount of raw material needed, since the absence of that material would still create a gap for the production and proper function of a component or product. However, when applied to LCSA from a product-level perspective, CA is also subjected to the analysis of functions of the product and the product system. Thus, the results of criticality indicators within the LCSA express criticality of different materials not only in terms of the difference in supply risk and vulnerability (i.e. economic importance), but also in terms of quantities needed for the provision of a functional unit of the product under study. The definition of the function unit is done according to the (environmental) LCA.

Another potential issue regarding CFs based on the EC-CA method is the use of thresholds. A raw material is classified as "critical" when the indicator exceeds a threshold (European Commission, 2020a). The "criticality area" (or range) represents the opinion of experts on the comparison among materials analyzed. Thus, "critical" is a relative concept subjected to the questions: "To whom?", "Where?", and "When?" (Mancini et al., 2013). The use of CFs from results of CA indicators before applying thresholds, i.e. SR- or EI-based, could be a potential solution to avoid thresholds. Thus, it is advised that indicators without thresholds are used by default, while the use of thresholds/weighting factors or the use of aggregated indicators with thresholds is suggested as an optional element. The choices of indicators should be consistent with the established goal and scope of the criticality study, as well as the LCSA study (see chapter 9 and 9.5) for guidelines on goal and scope definition) and consistency should be checked and documented. Besides, different criticality indicators should be analysed and interpreted together to draw more solid conclusions.

Interpretation of the results from the criticality indicators in the context of an LCSA study is further discussed in Chapter 22.

20. Economic impact assessment

The economic (impact) indicators are mainly assessed by means of the Net Present Value formula (see section 20.1). For this, discounting might be needed (20.2). Potential double-counting aspects within the economic pillar and between other pillars of LCSA are addressed (20.3). For the special case of conducting societal life cycle costing (sLCC) that also aims at monetising externalities to a large extent and potentially assigning different importance to impacts affecting different groups of people ("equity weighting"), guidance is provided in the annex of this document (Annex C).

20.1 Impact assessment using the Net Present Value formula

The Net Present Value (NPV) formula can be used as an overarching framework for considering all relevant input data and for calculating aggregated decision indicators in any type of LCC. The NPV is computed as follows:

	$$NPV = \sum_t \frac{\sum_i B_{i,t}}{(1+DR\ \ )^t} - \sum_t \frac{\sum_j C_{j,t}}{(1+DR\ \ )^t}$$	Eq. 1
where	$B_{i,t}$:	Benefit i occurring along the life cycle in year t, expressed in the same currency and valid for the same base year as C
	$C_{j,t}$:	Cost j occurring along the life cycle in year t, expressed in the same currency and valid for the same base year as B
	DR :	The discount rate; for more details on discounting, see section 20.2
	NPV:	Net Present Value (or discounted cash flow), representing the sum of all discounted costs and benefits over a given period ($t = 0, \ldots, T$)

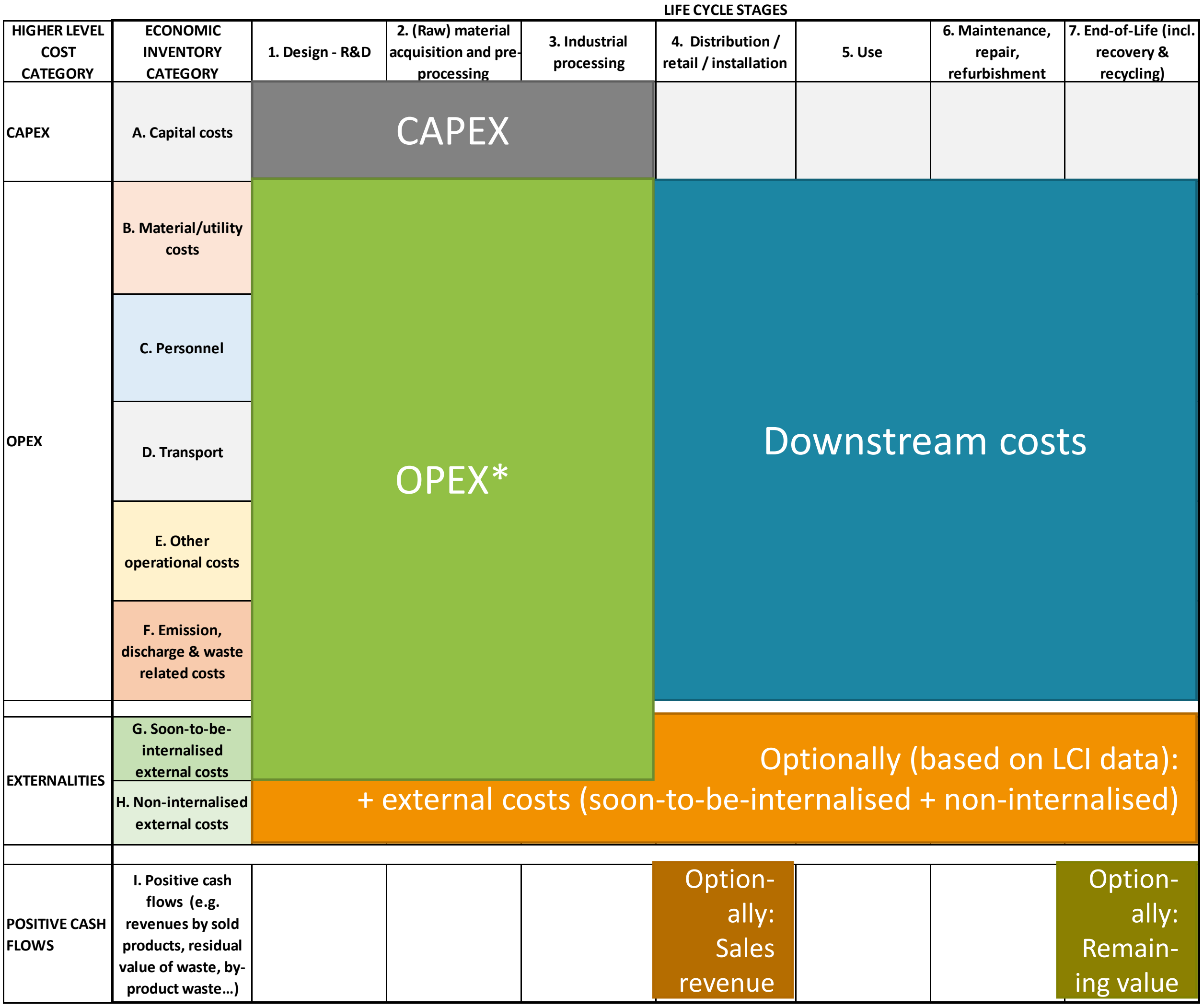
Note that benefits and costs can occur at different life cycle stages and that different kinds of costs can be included (internal and external costs). Depending on the goal and scope of the study, different choices can be made concerning the inclusion of benefits and use of discounting. These choices result in variations of the above formula and, accordingly, four (aggregated) main decision indicators are proposed for the ORIENTING LCSA methodology (see also Table 13 in section 9.6):

- Net present value (or total discounted value): the sum of all discounted costs and benefits over a given time period.
- Total undiscounted value: the sum of all (undiscounted) costs and benefits over a given time period.
- Present costs (or total discounted costs): the sum of all discounted costs over a given time period.
- Total undiscounted costs: the sum of all (undiscounted) costs over a given time period.

Note that this framework allows for the inclusion of private as well as external costs and would also allow to limit the time dimension of the assessment only to a present year or to also include future years. In the context of perspective assessments, discounting refers to the so-called "time value of money". In simple words, a unit of money received today is valued by most people higher than a unit of money received in some future year, which is why these future values get "discounted" to be expressed in present terms (see section 20.2 for further details).

Most existing (conventional) LCC studies concentrate on different cost indicators, including both aggregated and disaggregated ones (Alejandrino, Mercante, & Bovea, 2021). In many practical settings (again depending on the defined goal and scope), costs are complemented by further information. A typical case is the combined consideration of negative (costs) and positive (revenues) cash flows, allowing to perform financial assessments using NPV or similar related indicators (e.g., Internal Rate of Return (IRR), or payback period). Another case is the combination of economic with environmental indicators, e.g., calculating the eco-efficiency of products or processes.

In addition to the four aggregated economic indicators above, more granular results can be of interest in line with the defined goal and scope. For example, three sets of less aggregated indicators could be defined for a company-internal application (e.g., by a manufacturer or EoL actor) and for a consumer-focused application, as shown in Figure 18, Figure 19 and Figure 20, respectively. Note that the boxes with different colours serve simply to distinguish between the different less aggregated indicators suggested. The use and usefulness of such less aggregated indicators are intended to be tested throughout the ongoing ORIENTING case studies and results of this testing will feed into the final LCSA methodology recommendations. Complicating aspects include that manufacturing companies could also cover distribution costs or offer downstream services such as during the use phase of their products (maintenance, repair, etc.) or at the End-of-Life (e.g., in the context of the European Waste from Electric and Electronic Equipment Directive, Directive 2012/19/EU); these are not considered in these figures.



* For the purpose of ORIENTING, OPEX related to materials might be shown separately

Figure 18: Less aggregated cost and benefit indicators from a manufacturing company internal perspective

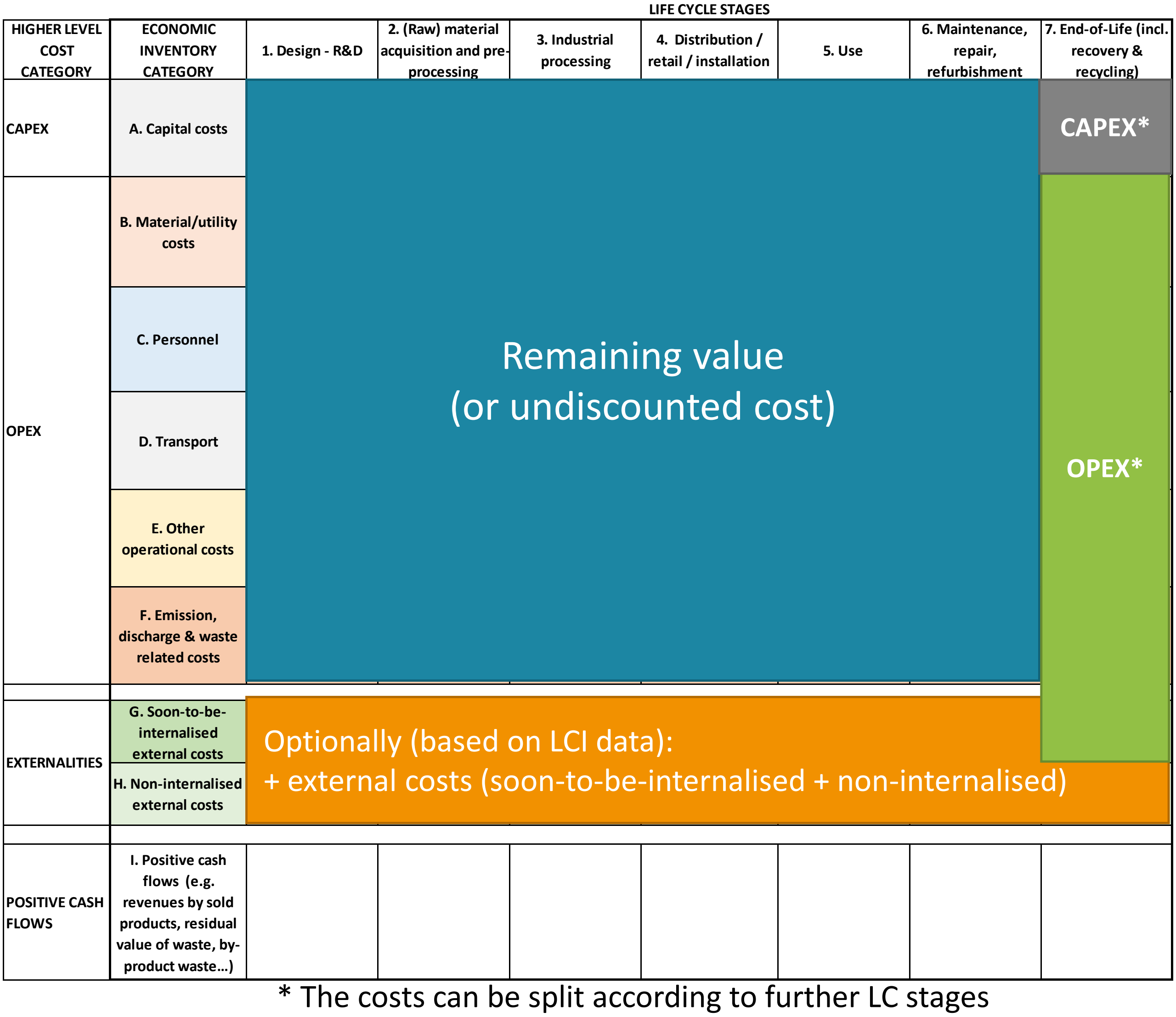


Figure 19: Less aggregated cost and benefit indicators from an EoL service provider internal perspective

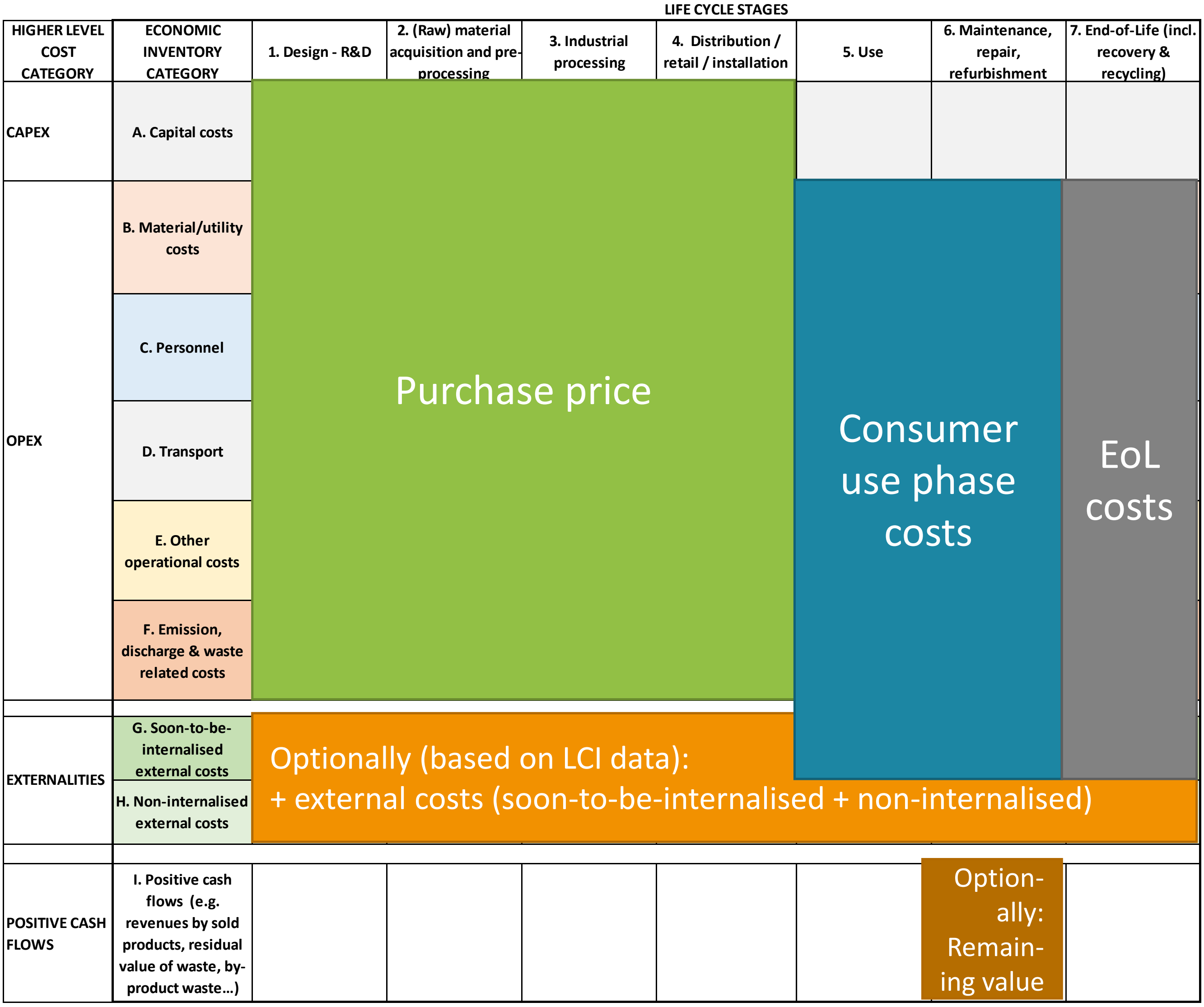


Figure 20: Less aggregated cost and benefit indicators from a consumer perspective

20.2 Discounting

Discounting is used to express future monetary flows in today's terms. With a positive discount rate, it also means assigning a lower value (or weight) to future costs and benefits (or impacts in general) than to those occurring today. The rate at which these weights decline from year to year is known as the discount rate, the weight is referred to as discount factor[25]. Discounting at a rate of 0% is a special case (so-called "no discounting") in which no difference is made in terms of importance between now and the future, noting that negative discount rates are also used sometimes[26].

Discounting can be done with a constant discount rate that does not change over the time horizon considered, which is the most common use. An alternative is to use variable discount rates that change from year to year or after certain time periods (ISO-14008, 2019; ISO-15686-5, 2017). Note that the NPV equation (section 20.1) is given for the case of a constant discount rate; when using variable discount rates, "DR" would be written as "DR_t". The overall procedure to discounting at constant or variable rates is referred to as discounting scheme.

Discount rates from a private perspective are usually higher (ranging typically between 5% and 20%, see Hunkeler et al. (2008)) than those from a societal perspective. For companies, the private discount rate is usually given as the Weighted Average Cost of Capital (WACC). It represents the costs of a business to finance its activities, calculated as the the weighted average of the interest on debt paid to creditors and the return on equity expected by equity providers. Regarding the choice of a social discount rate, in its latest guidance, the European Commission (European Commission, 2017a) recommends a real[27] (i.e., inflation-adjusted) discount rate of 3%). For long time frames, declining discount rates are sometimes suggested to be used (HM Treasury, 2020; Zheng, Easa, Yang, Ji, & Jiang, 2019), even if only for sensitivity reasons (European Commission, 2017a). Being funded by the European Commission, it is considered appropriate that the LCSA framework of the ORIENTING project follows respective EU guidance as provided in the latest impact assessment toolbox (European Commission, 2017a).

Discounting shall be applied consistently, choosing a fixed base year (preferably consistently with the base year defined in the inventory, cf. section 14.4) and reflecting the decision-making time period relevant of the selected actor. In this sense, it may be the case that specific time frames will apply depending on the actor perspective, i.e., manufacturer, user or EoL actor (see Figure). As an example, for the user perspective all cost elements borne during the use of the product will be discounted, and its base year is normally the day when the good was purchased. From an EoL actor's point of view, a likely base year for discounting (and inflation adjustment) is when products to be handled are received. Also, it is important to note that when considering both, costs and benefits, the use of discounting represents the most conservative choice (from a project appraisal perspective) when considering NPV metrics. This is because benefits typically occur later than costs and are thus discounted more. The situation, on the other hand, is the reverse when considering only costs, i.e., no discounting is the most conservative approach. As a result, it is recommended as a good practice to provide both discounted and undiscounted results.

[25] The discount factor is generally calculated as $DF = \prod_t \frac{1}{1+DR_t}$.

[26] When relying on the Ramsey formula to compute discount rates, a negative discount rate can result when there is negative economic growth.

[27] A real discount rate applies for inflation-adjusted monetary values, meaning they refer to the monetary value valid in the specified base year, whereas a nominal discount rate, as the name suggests, is not adjusted for inflation and refers, for example, to the nominal interest rate / the nominal costs of capital. Inflation adjustment is dealt with in section 14.4.

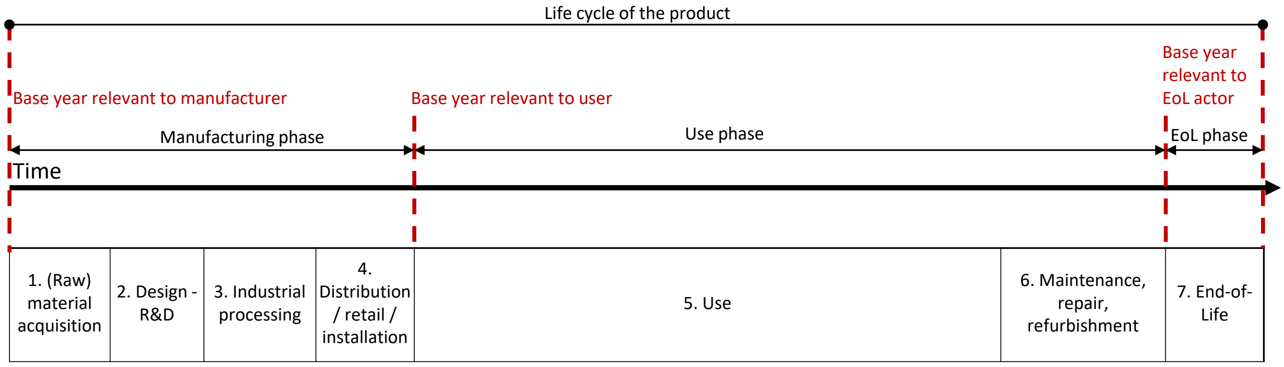


Figure 21: Use of discounting according to the actor's decision-making time period relevance

In the special case of using data that has already been discounted in a different context (e.g., monetary values of future environmental damage such as from climate change), the underlying "base year" could be different from the base year in which prices are expressed (see section 14.4 on inflation adjustment) and to which other future costs are discounted.

Behavioural aspects can play a role when determining private discount rates, such as split incentives (e.g., landlord/tenant), short time horizons, risk averseness, information asymmetries or other obstacles or barriers. The choice of inclusion or exclusion of the mentioned behavioural aspects may depend on the objective pursued. In applications of discounting outside LCSA, with a normative objective in mind, such as valuation or least-cost planning for rational decision makers[28], a consistent choice of the discount rate would reflect the cost of capital only. For end users, this corresponds to the medium-term market price of capital. With a descriptive objective in mind, however, for example in simulating consumer choices (with limited rationality), it can be suitable to reflect behavioural aspects by choosing a higher discount rate, all other things being equal[29].

20.3 Double counting

Double counting, in the sense of presenting/considering the same information more than once, has been identified to potentially occur in two cases:

a) **Within the economic domain**, when different economic costs and indicators referring to the same issue are presented side-by-side. One example is when presenting aggregated indicators (such as NPV) and constituents thereof (such as costs during the use phase) side-by-side. Another example is when

[28] In the sense of classical economic theory, a rational decision maker is a theoretic concept of a decision maker purely pursuing his or her own self-interest, optimising his or her own level of utility. Such a person sometimes is thought of to have complete knowledge about the consequences of his/her choice.

[29] This means that the observed discount rate implicit in the decisions of real decision makers can diverge from their cost of capital, for non-rational reasons (in the ideal sense of classical economic theory), that are referred to as "behavioural", such as for example risk aversion or limited information.

presenting results from the user perspective (e.g., Total Cost of Ownership, TCO), and from the producer perspective (e.g., CAPEX and OPEX), the latter being included in the former.

b) **Across different LCSA topics**, when environmental/social aspects or impacts that are already included as indicators in a separate environmental/social LCA (in physical units or qualitatively) are monetised and double counted in the further integration/aggregation of the three pillars. This particularly concerns resource use (e.g., minerals, water and energy)[30] and releases (e.g., greenhouse gas emissions) that are simultaneously captured in the Life Cycle Impact Assessment (e.g., in terms of abiotic resource depletion or CO_2-equivalents) and within Life Cycle Costing indicators (e.g., costs for acquiring metals, water, fuels, or CO_2 taxes). An even higher risk exists when conducting societal LCC, where environmental/social aspects or impacts are monetised to a larger extent. As stated in section 9.6, however, societal LCC could be perceived to constitute an LCSA framework in which social and environmental impacts are weighted in monetary terms. In that case, environmental and social LCA would be merged into LCC, which at least for now is not suggested by ORIENTING.

Against this background, at least two positions and respective actions can be distinguished:

(i) "own realities": the risk of double counting is acknowledged and described, but not seen as an issue because each individual assessment (environmental, social or economic) reflects its own reality. This notably concerns the consideration of environmental aspects both in physical terms in the environmental LCA and in monetary terms (internalised externalities) in LCC (see the example of greenhouse gas emissions in section 14.2.2). Such an overlap should be transparently documented and reported;

(ii) "LCA/S-LCA/LCC overlap issue": the risk of double counting is acknowledged, described and seen as an issue for which corrective actions could be taken. For example, a remedy could be to disregard resource depletion of mineral, metals, sand, gravel and fossil fuels as an environmental LCA's impact category altogether and only consider their costs in the LCC. The true environmental consequences of their extraction will be captured in other environmental LCA impact categories (e.g., related land use changes and releases). The issue with releases (e.g., CO_2 emissions) is not as straightforward given that taxes or permit prices do not necessarily reflect their true damage costs (or true shadow prices). Nevertheless, releases coming with a cost could be reported separately (from those without a cost) in the environmental LCA results. Further corrective actions may be conceivable.

The preferred position of ORIENTING is the "own realities" perspective, as it avoids to retroactively manipulate results obtained within the separate sustainability dimensions (e.g., PEF recommendastions for environmental LCA or an environmental LCC including (soon-to-be) internalised externalities).

[30] There has been a scientific debate for many years about whether to include the use of resources other than water and land in an environmental LCA.

20.4 Conclusion with provisions

Provisions 6. Economic impact assessment

Aggregation indicator used in LCC

- It shall be stated and justified in the documentation which aggregation indicator is computed, i.e., total undiscounted cost, total discounted cost, total undiscounted value or total discounted value (Net Present Value, NPV) (see Table 13 in section 9.6).
- If benefits (i.e., positive cash flows such as revenues) are considered, the considered benefits shall be stated and justified in the documentation.
- The actor-perspective, time frame, life cycle stages and types of costs considered shall be stated and justified in the documentation.
- Components of aggregated indicators may be used as separate indicators that shall be stated and justified in the documentation. Double-counting of aggregated indicators and components thereof in decision-making shall be avoided.

Discounting

- The discounting scheme shall be chosen according to the perspective for which the economic indicators are assessed. For private sector assessments (household/users and business/producers), private discount rates shall be used. For companies, the private discount rate is often given as the Weighted Average Cost of Capital (WACC). For users of products, finance costs shall be considered, potentially complemented by behavioural aspects, depending on the study objective pursued. All choices shall be stated and justified in the documentation.
- For policy decision makers, a real (i.e., inflation-adjusted) discount rate of 3% shall be used, in line with recommendations by the European Commission (European Commission, 2017a). A sensitivity analysis with a discount rate of 0% shall be conducted ("no discounting"). If discounting schemes other than no discounting are used, their results shall be compared to those obtained with no discounting and the findings discussed in the documentation.
- A sensitivity analysis addressing different discount rates should be conducted, especially when longer time horizons are involved (e.g., several decades).
- It shall be ensured that all data involved in the assessment is discounted consistently to the same year. If this is not possible, this shall be highlighted and explained in the documentation.
- The discount rate(s) used and the way in which they have been obtained as well as to which year discounting is performed shall be stated and justified in the documentation.

Dealing with double counting for the economic indicators

- In case that more than one economic indicator is communicated or reported, it shall be clearly stated in the communication or reporting if the economic indicators contain the same information. In any case, these indicators shall not be aggregated.
- If double counting occurs across different LCSA topics in the sense of presenting the same information more than once, the "own realities" position shall be adopted. When environmental and social externalities are monetised more broadly (taking a sLCC approach), the risk of double counting shall be clearly stated in the communication or reporting.

For requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

21. Social performance assessment

This phase consists of assessing the social performances and risks along the whole life cycle, with reference to the social topics identified in the goal and scope. The assessment is carried out according to the Reference scale approach (RSA) which assesses the social performance of activities of organizations in the product system based on specific reference points of expected activities. Social risks, when used to describe those parts of the whole life cycle on which it is not possible/feasible to collect primary information and data, are also evaluated according to the RSA approach.

These reference points are context-dependent and based on international standards, local legislation, or industry best practices (UNEP 2020). The scales can be qualitative or semi-quantitative, organized usually into five levels or even less, like in the examples of Figure and Figure 23

+2	best in class, continuous improvement
+1	beyond generally acceptable situation, continuous improvement
0	generally acceptable situation,
-1	unacceptable situation but improving
-2	unacceptable situation, no improvement

Figure 22 Example of quantitative Reference Scale according to five levels (Goedkoop et al., 2020)

Figure 23 Example of qualitative Reference Scale (UNEP, 2020)

Note	The definition of the reference scale is still under development within ORIENTING, and it is not included in this document. The scale will be made available in the coming months so that it can be applied during the case studies. Interested stakeholders will be invited to provide feedback on it. The developments pursued in ORIENTING are set on harmonising the current approaches, considering different ways for setting the referencing system, as pointed out by Russo Garrido et al. (2018). • Norms and best practices • Norms and socio-economic context • Stakeholders' judgment of companies' compliance to norms • Researchers' experts' judgment of companies' activities • Distribution of performance • Comparison between alternatives. In addition, the extent to which the choice of the referencing system affects the final outcomes of S-LCA studies is considered.

22.Interpretation and Integration

22.1 Introduction

Interpretation is a procedure focused on the analysis of the results from the inventory and impact assessment phases, in relation to the goal and scope of the study, as well as data gathering and processing (ISO-14044, 2006). The aim of the interpretation phase is to analyse the results of the LCSA (including both, the results from individual assessments and the integrated LCSA results as a whole), and identify significant issues (e.g., hotspots in terms of life cycle stages, processes, stakeholders, inventory items; trade-offs between indicators, life cycle stages and stakeholders). Additionally, the interpretation phase includes a critical evaluation of completeness, sensitivity, uncertainty and consistency of the study, based on which to yield overall conclusions and recommendations, and highlight limitations (ISO-14044, 2006).

Within the ISO14044 (2006), normalisation, weighting and aggregation of the impact indicator results is an additional and optional step of the impact assessment phase. In PEF (2021), normalisation and weighing are described as steps that shall be conducted as part of the environmental footprint impact assessment phase for informative purposes. Within ORIENTING, these steps are discussed under the heading of integration. Within ORIENTING, the integration step is a fundamental element to support the interpretation and communication of results (while ensuring transparency), and further inform decision-making processes.

Previous chapters allow for addressing the individual assessment of different dimensions of sustainability, as well as material criticality and circularity. During the ORIENTING project, specific guidelines for interpreting results from different sustainability dimensions will be further developed, building upon existing guidelines for LCA, LCC and S-LCA, and taking into account the experiences gained during the case studies. However, a comprehensive and consistent LCSA entails the integrated assessment of relevant sustainability aspects over the life cycle of products. This is done in the integration phase, which is a mandatory step of the LCSA methodology of ORIENTING.

Addressing the relevant aspects of sustainability over the entire life cycle of products and presenting the results in a comprehensive, clear and transparent manner is a challenging task for which no widely recognized approach exists (at least to date). ORIENTING aims to fill this gap by providing an approach and methods that allow for the integration, interpretation and communication of multidimensional LCSA information, whilst managing in an operational manner its inherent complexities such as potential shifts of burdens across impact categories, sustainability topics, life cycle stages, and stakeholders.

22.2 ORIENTING approach for integration

In ORIENTING, **integration** is defined as the analysis of the outcomes of LCSA across different sustainability domains (environmental, social, economic), including the consideration of circularity and criticality aspects **Figure 24**. In this context, it is important to introduce the concepts of normalisation, weighting and aggregation:

- **Normalisation** divides results by reference values, converting the units of different indicator results into a dimensionless (or comparable) format. According to ISO/DTS 14074:2021, and in specific reference to LCA, normalisation can be used as an intermediate step before weighting to provide an assessment of the relative magnitude of indicator results, to check the plausibility of indicator results, and to assist in the interpretation and communication of results.

- **Weighting** uses numerical factors to convert different indicator results into unit formats addressing specific issues (e.g., monetary value), and reflecting the significance of impacts (UNEP/SETAC Life Cycle Initiative, 2011b). Different weighting methods can produce results with varying degree of objectivity.
- **Aggregation** refers to the process of combining indicators presenting compatible units into single scores, composite indices and indicators (Gan et al., 2017a). Aggregation, as shown in **Figure 24** can be performed at different levels (e.g., individual sustainability domains and sub-domains, areas of protection, overall LCSA). Additionally, integration (and aggregation) can also involve the use of visualisation techniques.

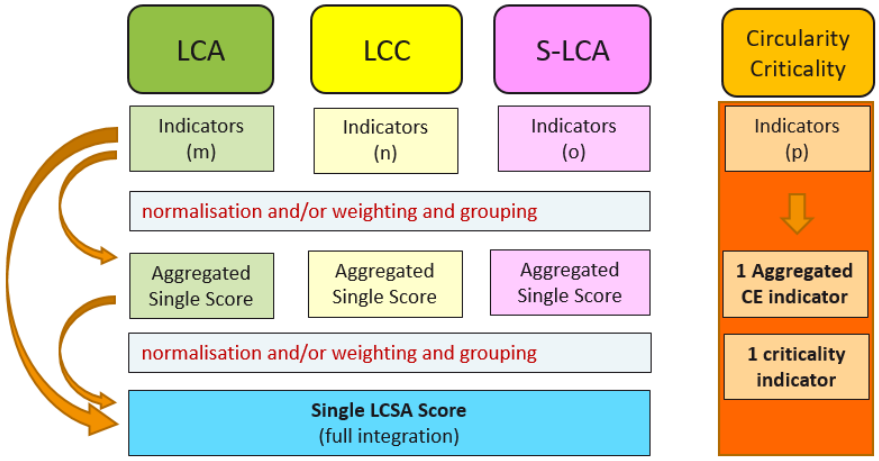


Figure 24 Illustration of the potential integration within/across domains in ORIENTING

The Table 36 shows how the integration within the ORIENTING LCSA framework can be performed as a series of consecutive steps. Following the 1-to-3 steps provided in Table 36:

1- Firstly, individual indicator results are obtained and reported for each domain/topic after the application of the impact assessment methods, as explained in chapters 16-21.

2- Secondly, the aggregation of the indicators is carried out within each domain following normalisation and/or weighting, as explained in the impact assessment sections 16 to 21 where relevant. This step could result in the obtention of one or more aggregated scores per LCSA domain.

3- Lastly, the aggregated indicators for environmental, economic and social domains can be further aggregated into a single LCSA indicator using the guiding steps provided in this section for the selection of an appropriate method for this purpose.

As for the consideration and integration of circular economy aspects within LCSA, for ORIENTING, circular economy is not an end but a means towards sustainability. This means that the information generated applying the ORIENTING LCSA methodology shall be split into two groups:

(1) Results obtained from LCA, LCC and S-LCA, as explained above in points 1) to 3); and

(2) Results of circularity and criticality assessment, which will form a parallel set of indicators to analyse how far a variation towards more circular and resilient production and consumption systems can translate in terms of sustainability (LCA + LCC + S-LCA). The separate results obtained for the circularity and criticality

assessments shall be compared with LCSA single score and relative contributions. It could be also conceivable to aggregate the results of the circularity and criticality assessments into a Circular Economy score through a scoring system, if needed. However, this system should be subordinate to LCSA results.

Table 36 : Integration of the LCSA results after the impact assessment per domain

	ENVIRONMENTAL	ECONOMIC	SOCIAL	CIRCULARITY	CRITICALITY
1) Impact Assessment results per domain					
Indicators (number of indicators obtainable; quantitative or qualitative; units)	**18 indicators** **Quantitative** (midpoint) **Unit**: Diferent units per indicator	**1 to 4 aggregated indicators** (**NPV**, Total undiscounted value; Total discounted costs, & Total undiscounted costs) + other indicators, if deemed useful (e.g. disaggregated components) **Quantitative** **Unit**: € for a given base year	**X** performance indicators per **Y** stakeholder (up to 7) and **Z** material topics (up to a maximum of 27) **Qualitative** information, transformable into semi-**quantitative** information through the reference scale impact assessment method **Unit**: dimensionless value (e.g. -2 to 2)	**1 to 2 aggregated indicators** (CTI2.0, MCI) **Quantitative** **Unit**: dimensionless value (0 to 1)	**1 to 2 indicators (SR, EI)** **Quantitative** **Unit**: dimensionless value (for SR between 0 and 7; for EI between 0 and 9)
2) Aggregation of indicators within each domain following normalisation and weighting					
Normalisation	External for all indicators, adapted from PEF. *Other normalisation methods could be tested.*	Not envisaged for the moment.	Not needed with reference scale.	Not envisaged for the moment.	Not envisaged for the moment.
Weighting	Weighting scores from PEF (weighted single score environmental indicator). *Other weighting methods could be tested (e.g. monetary weighting).*	The aggregated indicators (e.g., NPV) add and weigh specific costs and benefits.	*Weighting methods to be tested (e.g., grouping social topics per SDG).*	Specific mass flows must be added and used for the calculation of the aggregated indicators.	Not envisaged for the moment.

Aggregated results at the domain level	1 aggregated environmental single score	1 aggregated economic single score (e.g., NPV) (monetary unit).	Options: i) 1 aggregated social result per stakeholder (up to 7), material topic (up to 27) and single S-LCA indicator (dimensionless unit); ii) reduction of the number of social topics and indicators to work with, based on the outcomes of the materiality assessment	1 aggregated circularity indicator (0 to 1).	1 criticality indicator (dimensionless unit).
3) Integration across domains (many methods potentially applicable)					
Normalisation options	Internal or External			Not envisaged for the moment.	Not envisaged for the moment.
Weighting options	Equal weighting Own-criteria weighting Panel weighting Weights obtained through AHP			Not envisaged for the moment.	Not envisaged for the moment.
Result	**Single LCSA result + sub-indicators** **+ visualisation aid**			**Set of Circular Economy indicators (both aggregrated and separated into constitutive elements such as use of virgin materials and production of non-recyclable waste)** **+ visualisation aid.**	

22.3 Methods and approaches available for integration and aggregation

Building on findings from ORIENTING D1.5 'Critical evaluation of sustainability integration approaches', this section aims to guide the user of this document into different types of integration and aggregation approaches and how they can be appropriate for specific applications taking intended purpose and level of expertise into consideration, as shown in Table 5.

Integration and aggregation within the environmental domain

Various methods have been developed and applied to normalise, weight and aggregate LCA results into a single-score or index. A common practice for aggregating the LCA results has been the combination of weighted sum of results after external normalisation (Prado et al., 2020). In such an approach, the characterised impact assessment results are first divided by the external normalisation values, and then multiplied by weighting factors reflecting the relative importance of environmental issues.

The weighting methods most commonly applied in the context of LCA are panel-based weighting, monetary weighting and distance-to-target (DtT) weighting. Commonly applied weighting methods have been integrated in LCA software and impact assessment methods. Additionally, MCDA methods are also used often for aggregating LCA results through internal normalisation and weighting.

The normalisation and weighting factors included in the PEF method (2021) have been explained as part of environmental impact assessment in Chapter 17.2. Their use as part of the LCSA integration will be studied during the project.

Integration and aggregation within the social domain

Aggregation in S-LCA can occur at several steps of the assessment and serve different purposes:

- Condensing the outcomes of a social topic, expressed with several indicators.
- Consolidating outcomes of different social topics at stakeholder level.
- Consolidating the outcomes of a study for the whole life cycle or per life cycle stage.

The development of aggregation approaches requires the definition of weights, to be established in function of the goal and scope of the study and in conjunction with the other LCSA domains for ensuring consistency. So far there is relatively little experience with aggregation in the social domain. Considering that aggregation is a process driven by values, which might not be agreed upon by all stakeholders, options shall be explored for the integration and visualisation of results without aggregation.

Integration and aggregation within the economic domain

Aggregation within the economic domain is relatively straightforward as long as all impacts and indicators are expressed in monetary terms. This is the case for the currently proposed indicators in the economic domain (see section 20.1), although other economically relevant indicators may present different units (e.g., payback time or internal rate of return; see a related question for the public consultation in a separate document). Currently, the economic assessment within ORIENTING's LCSA framework follows the eLCC approach, refraining from the use of sLCC. sLCC is regarded as an LCSA framework of its own in which monetary valuation methods are used to weigh social and environmental impacts, thus allowing to aggregate results from all domains. More guidance on the monetisation of environmental (including human health) impacts is provided in section 0 in the Annex.

Integration and aggregation for Criticality and Circular Economy aspects

In relation to circularity aspects:

- In ORIENTING, addressing circularity means (i) providing operative indications of value retentation (of the product, its parts or materials) in the goal and scope phase (e.g., in the definition of the functional unit and of the granularity of product's life cycle stages), (ii) referring to dedicated circularity indicators, which complement other indicators in the LCSA framework and do not directly contribute to endpoint indicators, areas of protection and/or single LCSA scores.
- Integration of circular economy aspects could see the use of one single circularity indicator, aggregated single score index, or the analysis of several indicators (that provide specific quantitative and qualitative information and/or feed the single index).

In relation to criticality aspects:

- Criticality indicators are considered as 'early midpoint' indicators, which could be potentially integrated or linked with other domains and endpoints (with the consequent management of double counting issues), in particular the economically-related ones.

Criticality is typically expressed either in terms of "supply risk", or in terms of "supply risk and economic importance". In the last case, indicators might be considered as separate or aggregated in a single "criticality" score, such as expressed in the EC-CA method. The use of separate or aggregated indicators depends of the goal of the study (see chapter 9.5).

Integration and aggregation across domains

In ORIENTING D1.5, the following methods for the integration and aggregation of results across sustainability domains were identified based on a literature review.

1. Analytical integration methods:
    - Multi Criteria Decision Analysis (MCDA) methods or Multi Criteria Decision Making (MCDM) or Multi- Attribute Decision Making (MADM) methods, applied to evaluate a finite set of alternatives based on multiple criteria (attributes);
    - Multi Objective Decision Making (MODM) methods (evaluated as a group of methods) applied to decision making problems where multiple conflicting objectives have to be considered simultaneously and the set of alternatives is very large and implicitly defined by constraints; and
    - Data Envelopment Analysis (DEA) methods (evaluated as a group of methods), applied to analyse the relative efficiency of sample of alternatives if the efficient frontier is unknown;
2. Visual integration methods for LCSA (e.g., Life Cycle Sustainability Dashboard; SEEBalance©).
3. Other aggregation methods (e.g., monetary weighting).

Only the MCDA methods within the analytical integration methods listed above have been further analysed and included as a non exhaustive list of examples in this document, in the following section. As per the integration of criticality and circular economy aspects in the LCSA framework, options to consider could include for example:

- Integrate such considerations in relevant domains of environmental, economic and social sustainability, without aggregation (e.g., for the quantification of "Relative Benefit Indices") (Cordella, Sanfelix, & Alfieri, 2018).

22.4 Classification of approaches for integration

Different approaches for normalisation and weighting and their combinations can result in different approaches/methods for the integration of LCSA results. Table 37 presents a classification of different approaches available for the integration of LCSA results. Table 37 has been produced to guide LCSA practitioners and users into different integration approaches, their characteristics and possible uses. A non exhaustive list of examples of methods fitting under each group of approaches are also provided. The table builds also on the following sources of information:

1. ISO/DTS 14074:2021 Environmental management- Life Cycle Assessment- Principles, requirements and guidelines for normalization, weighting and interpretation.
2. Development of a weighting approach for the Environmental Footprint (Sala et al., 2018).
3. D1.5. Critical evaluation of sustainability integration approaches (ORIENTING, 2021) .

Table 37 Technical classification of approaches towards integration in ORIENTING

Type of approach	Description & possible use(s) in LCSA	Examples (non exhaustive list)
A. INTERNAL NORMALISATION + WEIGHTING	**Indicator results divided by an internal benchmark (e.g., a reference design option), then weighted and aggregated based on the relative importance of topics.** **Possible uses:** - **Relative performance of different options (same or different products) within/across sustainability dimensions/AoP for internal uses.** - **Materiality.**	
A1. Internal normalisation + Panel-based or own-criteria weighting	Weights assigned by a panel of experts, stakeholders, or analysts. AHP could be used as a weighting method to obtain weighting factors.	SAW AHP MAUT/MAVT
A2. Outranking methods Internal normalisation + Panel-based weighting; or own-criteria weighting	Differently from A1, the output of its application is an outranking relation on the set of alternatives analysed. Weights assigned by a panel of experts, stakeholders, or analysts. AHP could be used as a weighting method to obtain weighting factors.	ELECTRE PROMETHEE VIKOR
A3. Internal normalisation + Distance to Target (DtT)	Weights calculated that reflect the distance between impacts/pressures and targets (e.g., policy goals or regulatory limits, science-based targets, societal boundaries). DtT ranks impacts as being more important the further they are from the achievement of desired targets or an ideal solution.	TOPSIS
B. EXTERNAL NORMALISATION +WEIGHTING	**Indicator results divided by an external benchmark (e.g., an impact at global level), then weighted and aggregated based on the relative importance of topics** **Possible uses:** - **Relative contribution of different options to overall reference impacts within one sustainability dimension (e.g., as done in PEF), AoP, or even across them.** - **Materiality.**	PROSUITE project (Laurent, Hauschild, & Wood, 2013)
B1. External normalisation + Panel-based weighting or own-criteria	Weights assigned by a panel of experts, stakeholders, or analysts. AHP could be used as a weighting method to obtain weighting factors	SAW

Type of approach	Description & possible use(s) in LCSA	Examples (non exhaustive list)
B2. External normalisation + Distance to Target (**DtT**)	See above (A3)	A distance-to-target weighting method for Europe 2020 (Castellani, Benini, Sala, & Pant, 2016)
C. OTHER WEIGHTING AND AGGREGATION FACTORS	**Conversion and aggregation of different indicators using equivalency factors (without normalization)**	AHP Equal weighting Budget Allocation (BAL) (Gan et al., 2017a)
C1. Endpoint modelling for AoP	**Possible uses:** Equivalency factors used to convert inventory results into endpoint impacts for AoPs (e.g., human health, ecosystem quality, resources).	ReCiPe (Huijbregts et al., 2016)
C2. Monetisation	**Possible uses:** Monetary values used as equivalence factor. Aggregation of results at the inventory, midpoint and endpoint level into single scores, within/across pillars or AoPs.	**ISO/DTS 14074** **ISO 14008** (ISO-14008, 2019) (Amadei, De Laurentiis, & Sala, 2021)
D. SCORING SYSTEMS	**Definition of evaluation criteria and assignment of semi quantitative scores depending on the characteristics of the analysed system.** **Possible uses:** - **Ranking different product options within/across dimensions/AoP (e.g. as entry level for CE aspects)**	**Repair score systems** (Bracquené et al., 2021)
E. VISUALISATION APPROACHES	**Visualization techniques used to integrate LCSA results.** **Possible uses:** - **Visual integration/ranking/interpretation**	**LCSD (Life Cycle Sustainability Dashboard)** (Traverso, Finkbeiner, Jørgensen, & Schneider, 2012) **Eco-efficiency portfolio** (BASF, 2021)
F. COMBINATIONS OF APPROACHES	**Combinations of the above leading to different outcomes.**	**Examples of outcomes: 1 single score for LCA based on PEF, 1 single score for LCC, 1 single score for SLCA based on MCDA, and 1 single LCSA score based on MCDA**

Group A (**internal normalisation + weighting**) refers to the integration of LCSA results through internal normalisation approaches, which can be followed by a weighting procedure before aggregating results. According to ISO/DTS 14074:2021, internal normalisation describes the situation in which one of the analysed options is taken as reference (e.g., base case or best-case scenario). **Group B (external normalisation + weighting)** differs from Group A by referring to external normalisations. External normalisation describes the situation in which the reference is external to the system studied (e.g., the level of impact of a territory, an average citizen, or the average product on the market in a specified time and geographical context).

Normalisation can support the comparison of different product options, or also the comparison of different design options and value chain configurations for the same product. However, when internal normalisation is adopted, it can only be possible to identify the option(s) which could provide a better sustainability performance (and for which indicators), but it is not possible to directly inform about the level of sustainability of an option.To better understand the level of sustainability of an option, indicator results shall be compared to an external reference, although this adds a further level of complexity and uncertainty compared to internal normalisation.

Independently from the approach followed (i.e., internal vs. external), normalisation can facilitate the comparison between different indicators, which are converted into dimensionless units, and the interpretation of LCSA results. A weighting step can be added to reflect the relative importance of topics, before proceeding with the aggregation of LCSA results. Different weighting procedures can be applied, weights can be assigned through:

(i) "expert" judgments or own-criteria made by panels of experts, stakeholders, analysts, which may yield more or less representative and objective results depending on composition, knowledge of topics, and value choices. Whilst it could be simpler to develop own criteria for weighting, the risk of insufficient representativeness and overlooking important aspects or broadly agreed priorities increases, when compared to a panel-based weighting system.

(ii) distance to targets (DtT) procedures, where weights reflect the distance between impacts/pressures and targets (e.g., policy goals or regulatory limits, science-based targets, societal boundaries).

A non exhaustive list of examples of applicable Multi Criteria Decision Analysis (MCDA) methods that could be linked to Group A and B integration approaches are provided in Table 37 and explained further in Annex D. These include:

- Value-based or value- measurement MCDA methods (A1) such as Simple Additive Weighting (SAW), Analytical Hierarchy Process (AHP) and Multi Attribute Utility Theory (MAUT);
- Outranking models (A2) such as Elimination of Choice Translating Reality (ELECTRE), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) and Multi-Criteria Optimization and Compromise solution (VIKOR); and
- Distance to Target methods (A3 and B2) such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

As a summary, value-based or value-measurement MCDM (A1) provide as an output an aggregated numerical score using internal normalisation and weighting. Outranking models (A2), differ from those in A1, in that the output of the analysis is an outranking relation on a set of alternatives. Whereas, Distance to Target methods (A3 and B2), however, measure how well the assessed alternatives fulfil a set of specific targets.

Note that it is not always straightforward which MCDM method to choose to perform integration across pillars and that these can sometimes be combined, potentially fitting in one or more of the classification Groups presented in Table 37 and including also other methods not mentioned here. This is explained where relevant in Annex 26.1. Also, the following sections, aim to guide the user in the selection of and appropriate method to perform the integration of the results in a given context.

Differently from Group A and Group B, no normalisation is carried out in **Group C (other weighting and aggregation factors)**, where different indicators are directly converted and aggregated using equivalency factors. A typical case is monetisation, where different results at the inventory, midpoint and endpoint level are converted into monetary value and can be aggregated into single scores within/across pillars or Areas of Protection (AoPs), as introduced in section 16 relating to impact assessment. However, also other types of equivalency factors can be found for different (AoPs), in the so-called "endpoint impacts modelling", for example. Such type of integration can be very communicative but is affected by a higher grade of complexity and uncertainty, compared to groups A and B.

Group D (scoring systems) addresses the possibility of defining evaluation criteria and assigning semi quantitative scores depending on the characteristics and LCSA results of the analysed system. This can be an easy solution to integrate results, although it is affected by a higher grade of subjectivity.

Group E (visualisation approaches) covers the integration of LCSA results through the application of visualisation techniques. This group can enhance the interpretation of results and identifying the possible occurrence of trade-offs, but it does not allow alone for handling such trade-offs. In fact, for aggregating results, visualisation techniques must be coupled with previous approaches. Examples of LCSA methods including visualisation techniques is the Life Cycle Sustainability Dashboard by (Traverso et al., 2012).

Group F (combinations of approaches) aims to indicate that hybrid approaches could also be envisaged, combining elements of other groups and leading to LCSA outcomes. This offers some flexibility, provided that the risk of incurring inconsistencies is mitigated.

22.5 Linking the intended application of the LCSA to the integration approach

This section explains which of the integration approaches described are most appropriate considering the purpose of LCSA integration and desired outcomes. Table 38 provides criteria for filtering compatible and incompatible integration methods. Criteria marked in red are exclusive (i.e., the approach cannot be used) and those marked in green are inclusive (i.e., the approach can be used). For example, if the application of criterion 1 results in adopting a strong (instead of weak) sustainability perspective, no aggregation into single scores may be possible. Therefore, the groups of approaches leading to aggregation into single scores would be ruled out from their application in this given context.

Table 38 Key features for the integration of LCSA results and link to applicable Groups of integration methods (criteria in red are exclusive, i.e., the approach cannot be used and those marked in green are inclusive, i.e., the approach can be used)

Criteria	
1. Weak/strong sustainability perspective	**a) if a strong sustainability perspective is considered within/across domains, no aggregation into single scores may be possible (Groups A, B, C and D are ruled out).**

Criteria	
1. Does the integration method require/aim to adhere to a weak or strong sustainability perspective within domains? And across domains?	b) if a weak sustainability perspective is considered, compensation is allowed amongst LCSA indicators and aggregation can be carried out.
2. Purpose of the integration 2. Does the integration method require/aim to: (2.1) obtain a score? (2.2) rank options? (2.3) include the perspective of different stakeholders in the weighting of results?	**Scores/ranks:** **a) If absolute values are to be obtained all groups except E (visualization approaches) could be applied.** **b) Groups A and group B methods are the only ones applicable for the obtention of benchmarks (whilst also potentially providing concrete values).** **Perspective of stakeholders:** a) if not, all methods work. **b) if yes, group A and group B methods should be used, where weights are defined based on a panel of stakeholders. Group C and group D methods could also work.**
3. Integration of qualitative and/or quantitative information Does the integration method require/aim to integrate qualitative data?	a) In case only quantitative information is used, aggregation can be carried out using any of the methods. b) In case qualitative information is used, this can be converted into numerical parameters (semi-quantification) through evaluation criteria (e.g., for the social impact assessment, a five point reference scale shall be tested transforming qualitative values into quantitative ones (see section 21). **Group C methods (e.g., monetization) are incompatible in case of qualitative information.**
4. Complexity 4.1. Does the integration method require a high level of experience for its application? 4.2. Does the integration method require a high level of data?	In increasing order of complexity: **Group E is the simplest, followed by Group D and Group A.** **Group B and Group C are the most complex ones, for which data may not be available for all pillars.**
5. Consideration of absolute sustainability Does the integration method require/aim to the consideration of an **absolute sustainability assessment?**	a) In terms of single LCSA score, only a relative sustainability perspective can be adopted (every method would apply). **b) An absolute sustainability assessment requires referring to planetary boundaries and minimum**

Criteria	
	social safeguard requirements (also linking to SDGs), which implies referring to Group B or Group C methods.
6.Integration of burdens and/or benefits Does the integration method require/aim to aggregrate burdens and benefits?	a) If not, only footprints are considered for the calculation of aggregrated LCSA results (every method can be used). b) If yes, footprints and handprints are considered (and aggregated) seprately.

An example on how to apply these criteria, used as filtering questions for the selection of an appropriate integration method is provided in Table 39, based on a fictional context. A table format is provided to show which groups of methods would apply after the filtering with the selection criteria.

Table 39 Selection criteria (6) and associated questions for the selection of the integration method

Criterion	(1) Adherence to weak/strong sustainability	(2) Purpose of the integration					(3) Integration of qualitative and/or quantitative info?	(4) Complexity		(5) Relative/absolute sustainability assessment	(6) Burdens and Benefits
Does the integration method require/aim to	1: Adhere to a weak sustainability perspective?	2.1: Obtain scores?	2.2: Rank options?	2.3: Include stakeholders' perspecives in weighting of results?	2.4: Fit with all LCSA domains?	2.5: Fit with CE topics?	3: Integrate qualitative data?	4.1: A higher level of experience (method)	4.2: A high level of data	5: The consideration of absolute sustainability?	6: The integration of burden & benefit
Group A1: Int. norm + weight	Y	Y	Y	**Y**	Y	Y	Y	N	N	N	Y
Group A2: Outrank. + weight	Y	Y	Y	**Y**	Y	Y	Y	N	N	N	Y
Group A3: Int. norm + DtT	Y	Y	Y	**Y**	Y	Y	Y	N	N	N	Y
Group B1: Ext. norm + weight	Y	Y	Y	**Y**	N	Y	Y	Y	Y	Y	Y
Group B2: Ext. norm + DtT	Y	Y	Y	**Y**	N	Y	Y	Y	Y	Y	Y
Group C1: Endpoint for AoP	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Group C2: Monetisation	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Group D: Scoring systems	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y
Group E: Visualisation	N	N	Y	Y	Y	Y	Y	N	N	N	Y
Group F: Combination A1-E	Y/N	Y/N	Y	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Illustrative answers	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*	*N*	*N*	*Y*

Legend: For Group F, answers depends on those for the groups used.

Different groups of integration approaches are presented in the rows of Table 39**.** The filtering questions to aid in the selection of the integration method are presented in columns, each of which relates to the specific criterion provided in the row above. Note that the consideration, or not, of the perspective of stakeholders in the weighting of results is included under criterion number 2 "Purpose of the integration". "Y" stands for "yes" and "N" for "no" in the Table, referring to the applicability of the specific methods when answering the respective questions. The answers to the questions for the illustrative case described in this section are provided in green in the row labelled "Illustrative Answers".

For **criterion #1**, adherence to weak or strong sustainability, the specific question relates to the requirement to adhere to a **weak sustainability perspective** in which aggregation is possible.

Example: if the answer is Y, the integration context means to follow a weak sustainability perspective, therefore **any of the Groups of approaches marked with "Y" would be applicable**.

Note: only Group E methods (visualization) could be applied for a strong sustainability perspective.

In relation to **criterion #2**, five specific questions are proposed to define the purpose of the integration. With the exception of group E, all group of methods would be applicable to obtain a score value (2.1) or relative results and rankings (2.2). Similarly, all groups of methods could incorporate the perspective of the stakeholders in weighting (2.3), with groups A and B being especially suited for this purpose (marked in bold in the Table). Groups C1, C2 and E allow integrating showing results of different stakeholders and perspectives, hence their inclusion under this category. In terms of the coverage of all LCSA domains (2.4), Group B, referring to external normalization, could not be suitable since this may be more difficult for the social domain compared to the economic and environmental domain (e.g., see PEF). Lastly, for the inclusion of Circular Economy (2.5), all methods except for those within Group C could be applicable in this context.

Example: **only Group A and B methods would be applicable** if the purpose is to obtain concrete numerical values (2.1), which could serve for undertaking comparisons (2.2) and which would allow for the inclusion of the stakeholder´s perspectives in the development of the weighting factors (2.3), and for the integration of the results of all LCSA domains (2.4).

The potential integration of qualitative and quantitative information is covered under **criterion #3**. The related question implies that qualitative information is being handled which need to be integrated with quantitative one. Group C methods are not suitable for this operation.

Example: if the integration of qualitative information (e.g., coming from the social assessment) is required, **groups of methods A and B would be applicable**.

Criterion #4 relates to the complexity of the application of the integration with respect to both methodological aspects (4.1) and data demand requirements (4.2). The most complex groups of methods to be applied are B and C both in terms of the application of the concept and/or the access to the required data.

Example: if a simpler integration methods is desired, Group B is ruled out from the selection **leaving only group A as the potential option for undertaking the LCSA integration in this context**. This of course comes with limitations in terms of applicability of the LCSA results.

Criteria #5 and #6 are marked in grey as these imply a more advanced level of experience in LCSA. **Criterion #5** refers to the consideration or relative vs absolute sustainability, question 5.1 assumes that a relative sustainability perspective is applied by default and asks if an absolute perspective is instead sought. Only Groups B and C would be suitable in this case. For **criteria #6**, it is assumed that LCSA is by default considering only burdens. The related question asks about whether or not benefits are also considered. In this regard, all methods would fit this purpose.

Example: **Group A continues being an appropriate method for undertaking the LCSA integration of burdens and benefits, if no absolute sustainability perspective is sought.**

After the application of the selection criteria, a Group of methods to be applied for the integration is selected. In the example provided, **Group A** has been chosen as the preferred method.

An example on how to apply group A methods in ORIENTING is provided.

To summarise, Table 36 introduced at the beginning of this section showed how the integration within the ORIENTING LCSA framework can be performed as a series of consecutive steps. This combined with the selection criteria from Table 38, can guide the selection of the integration approach, as shown before with the selection of "Group A" methods for a fictional context. The 4 consecutive steps for the integration on ORIENTING include:

1- Individual indicator results are obtained for each domain/topic after the application of the impact assessment methods as explained in sections 16 to 21.

2- The integration and aggregation of the indicators is carried out within each domain following normalisation and weighting. In the example provided in Table 36, external normalisation and weighting factors adapted from PEF are used for the environmental domain. As per the economic and social domains, the use of additional normalisation and/or weighting factors are not envisaged at this point since the indicator results would be either already expressed in the same units (economic domain) or in dimensionless units (social domain). However, the application of other normalisation and weighting factors can also be tested in ORIENTING. The result of this step would be aggregated per LCSA domain separately.

3- The 3 aggregated indicators for environmental, economic and social domains can be further aggregated into a single indicator. According to the chosen Group A of integration methods, internal normalisation factors would need to be developed by using one of the analysed options as a reference. Different options for obtaining the weighting factors could also be applied such as equal weighting, panel-based weighting or obtaining these through the application of AHP method, for example.

4- LCSA single score and relative contributions shall be compared with the separate results obtained for the circularity and criticality assessments (both aggregrated and disaggregrated results).

22.6 Open issues and further developments

The integration methodology is under development and open for consultation. A technical classification of aggregation and integration methods has been proposed together with a method for the selection of an applicable integration method. Next steps are intended to focus on the application of the suggested methods to the different case studies of ORIENTING to test its applicability.

The methodology development will be complemented by the development of a user- friendly tool to integrate, visualize and communicate LCSA results (the so called "Integration Tool"). The Integration Tool will be developed in Task 3.3 to link and integrate consistently sustainability information relating to results for the different LCSA topics of ORIENTING. The goal of the Integration Tool is not to replicate complex analyses that need the use of specific software tools to produce results (e.g., for LCA or S-LCA). Instead, its goal is to allow users go one step further, by integrating and analysing results obtained for each topic into one single tool. In simple words, the output of computational IT tools will be the input for the Integration Tool of ORIENTING.

Since the calculations of the results of the different topics of sustainability (LCA, S-LCA, LCC, criticality and circularity) are likely to be performed with different tools, a common data format is needed to ensure that such results can be transferred in a machine-readable way to the Integration Tool. A common data format exists today only for environmental LCA: the extended-ILCD format (eILCD). Such format however is not yet designed to integrate information relating to the other topics. Within ORIENTING, an operational solution is needed that is practically applicable already in the short-term. An (Excel) ORIENTING Output Format (OOF) has been developed for this purpose. The main goal of this format is to enable a well-structured and easy compilation of data by companies to enable correct export from and import in software environments.

23. Next steps in ORIENTING

The methodology presented in this report will be tested in five case studies (demonstrations) starting from May 2022. The aim of the demonstration phase is to test the practical applicability of the methodology in different contexts and to utilise the learnings gained for developing a methodology that is robust, comprehensive, and operational. In addition to the case studies, feedback for the currently proposed methodology is collected during a stakeholder consultation that takes place in May 2022. Feedback received during the consultation will be summarised and discussed in a stakeholder workshop that will be held on June 30th, 2022.

Based on the feedback received and experiences collected during the consultation and implementation phases, a final version of the LCSA methodology will be published in August 2023. The final methodology will be presented in an LCSA Handbook that will be complemented with a proposal for developing future product sustainability footprint category rules (PSFCR), training materials, data specifications and a dedicated tool for integrating LCSA results from different domains and topics.

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25. Annexes

25.1 Annex A: Materials' criticality according to EU CRM list 2020

Table 40 presents are materials that are include in the EU's CRM list for 2020. A dedicated spreadsheet with related characterisation factors is provided for the ORIENTING case studies. If you are interested in reviewing the CF's for criticality assessment, please contact info@orienting.eu.

Table 40. Full list of materials for criticality assessment according to EU CRM (2020)

Materials' criticality according to EU CRM list 2020

Raw Material	Criticality
Aggregates	Not critical
Aluminium	Not critical
Antimony	Critical
Arsenic	Not critical
Barytes	Critical
Bauxite	Critical
Bentonite	Not critical
Beryllium	Critical
Bismuth	Critical
Boron/Borate	Critical
Cadmium	Not critical
Cerium	Critical
Chromium	Not critical
Cobalt	Critical
Cooking Coal	Critical
Copper	Not critical
Diatomite	Not critical
Dysprosium	Critical
Erbium	Critical
Europium	Critical
Feldspar	Not critical
Fluorspar	Critical
Gadolinium	Critical
Gallium	Critical
Germanium	Critical
Gold	Not critical
Gypsum	Not critical
Hafnium	Critical

Helium	Not critical
Ho, Tm, Lu, Yb	Critical
Hydrogen	Not critical
Indium	Critical
Iridium	Critical
Iron ore	Not critical
Kaolin clay	Not critical
Lanthanum	Not critical
Lead	Not critical
Limestone	Not critical
Lithium	Critical
Magnesite	Not critical
Magnesium	Critical
manganese	Not critical
molybdenum	Not critical
Natural cork	Not critical
Natural graphite	Critical
Natural rubber	Critical
Natural teak wood	Not critical
Neodymium	Critical
nickel	Not critical
Niobium	Critical
Palladium	Critical
Perlite	Not critical
Phosphate rock	Critical
Phosphorus	Critical
Platinum	Critical
Potash	Not critical
Praseodymium	Critical
Rhemium	Not critical
Rhodium	Critical
Ruthenium	Critical
Samarium	Critical
Sapele wood	Not critical
Scandium	Critical
Selenium	Not critical
silica sand	Not critical
Silicon metal	Critical
Silver	Not critical
Strontium	Critical

Sulphur	Not critical
Talc	Not critical
Tantalum	Critical
Tellurium	Not critical
Terbium	Critical
Tin	Not critical
Titanium	Critical
Tungsten	Critical
Vanadium	Critical
Yttrium	Critical
Zinc	Not critical
Zirconium	Not critical

Legend:

LREEs	Critical
HREEs	Critical
PGMs	Critical

25.2 Annex B: Description of social topics

If you are interested in reviewing the excel-files prepared for supporting S-LCA, please contact info@orienting.eu

Table 41 Harmonised list of social topics for the purposes of S-LCA

Social topic	Definition
Access to material, immaterial resources and cultural heritage	WHAT THE SOCIAL TOPIC IS ABOUT: **Access to material resources**: the ability (of local communities) to use resources, such as land, (clean) water, clean soil, electricity, internet or mobile phones, transport, medical treatment etc. These are basic resources everyone, and especially vulnerable groups, need to have access to, in order to live in a healthy community. **Access to immaterial resources and cultural heritage** include the preservation of language, social and religious practices, knowledge and traditional craftsmanship, as well as cultural spaces and objects. WHAT WE WANT TO MEASURE: The extent to which the company or facility works to prevent and mitigate adverse impacts on local communities and/or to restore and improve community access to material and immaterial resources, and cultural heritage. EXAMPLE/s: 1) implementation of high-speed internet network in an area can improve access to communication services; 2) organizations can more actively promote the preservation of cultural heritage by encouraging the sustainable use of traditional products and craftsmanship in their product design and production methods (e.g. agricultural production methods and clothing/craft design).
Accessibility	WHAT THE SOCIAL TOPIC IS ABOUT: Accessibility mainly relates to people with a handicap or disability, and the fact of being able to reach or obtain a product or a service easily. Persons with disabilities include those who have long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others' (e.g. disabled persons, the elderly, persons with low income, etc.). WHAT WE WANT TO MEASURE: The extent to which a product design, marketing and company business models affect accessibility of products or services to people with some sort of disability. EXAMPLE/s: 1) implementation of a faster and simpler procedure for wheelchair access on the bus; 2) implementation of packaging size for cosmetic good, and related price that is targeted at low income groups.

Affordability	WHAT THE SOCIAL TOPIC IS ABOUT: Affordability relates to the state of being low-priced enough for people in vulnerable situations to be able to afford it. This principle is frequently used, or only applies, to products such as medicines, food, housing, transport, education, seeds and tools for smallholders, microfinancing and other banking services, etc. Luxury goods and services, targeted at users who are not vulnerable, poor, disabled or ill, are not included under this social topic. WHAT WE WANT TO MEASURE: The extent to which a product design, marketing and company business models affect affordability of products or services to poor or otherwise under-privileged groups. EXAMPLE/s: implementation of a way to preserve food to avoid food loss and help to make food more available to vulnerable groups, if it does not significantly increase the price of food.
Child labour	WHAT THE SOCIAL TOPIC IS ABOUT: Child labour is work that deprives children of their childhood, their potential and/or their dignity, and that is harmful to their physical and/or mental development. In its most extreme forms, child labour involves children being enslaved, separated from their families, exposed to serious hazards and illnesses and/or left to fend for themselves on the streets. WHAT WE WANT TO MEASURE: The extent to which a company works towards eradicating child labour and pro-actively raises awareness of issues associated with child labour. The assessment aims to verify if the organization might or is employing children (as defined in the ILO conventions), if the conditions are favourable for the occurrence and/or eradiation of child labour, and the existence and quality of the prevention and mitigating measures taken by the organization. EXAMPLE/s: 1) The company has eliminated the use of child labour in its own organisation and its entire value chain and can demonstrate the success of its approach (e.g. records proof of age upon recruitment, including copies of documents such as birth certificates and passports; 2) The company engages and invests in public private partnerships that have a proven track record in addressing the root causes of child labour in its relevant parts value chain; 3) the company reaches recognition by independent NGOs and credible news reports.
Community engagement	WHAT THE SOCIAL TOPIC IS ABOUT: Community engagement concerns any form of relationship between the company and community stakeholders (individuals or community groups) that may be affected by the implementation of business policies and actions of an organisation that affect local environment, health and well-being.

	Different ways of engagement could exist such as the inclusion of community members' representatives in decision-making processes, or direct involvement in community initiatives, or financial support of community projects (e.g. Earth Day activities, recycling initiatives and visits to local schools). Particular attention needs to be paid to engaging representatives of vulnerable groups such as indigenous peoples, youth and women. WHAT WE WANT TO MEASURE: Whether, and to which extend, the company or facility includes community stakeholders in relevant decision-making processes through ongoing open dialogue and responds to their concerns and inquiries fairly and promptly, to continuously foster greater trust and relationship with the local community. EXAMPLE/s: 1) The company owns documents and statements that reveal the efforts and results of formal communication channels between the company or facility and the community to inform them and to hear the opinions and views. 2) The company finances scholarships for students from low-income families.
Contribution to economic development (including local employment)	WHAT THE SOCIAL TOPIC IS ABOUT: There are several definitions of **economic development**, in this context it is defined as "the cultivation of activities that create a net gain of money into the community". Organizations can foster economic development in many ways, directly or through supply chain actors. They can generate revenue, create jobs, provide education and training, make investments, or forward research. Many social topics defined in this list are addressing parts of the puzzle, needed to bring economic development; this social topic is particularly focused on the creation of jobs and generating income for local communities. In adition to that, **poverty alleviation** and **wealth distribution** targets can be included in this topic. Poverty alleviation is in line with the first Sustainable Development Goal and aims to "End poverty in all its forms everywhere". Priority actions on poverty eradication include: improving access to sustainable livelihoods, entrepreneurial opportunities and productive resources; providing universal access to basic social services; progressively developing social protection systems to support those who cannot support themselves; empowering people living in poverty and their organizations; addressing the disproportionate impact of poverty on women; working with interested donors and recipients to allocate increased shares of ODA to poverty eradication; and intensifying international cooperation for poverty eradication (https://sdgs.un.org/goals/goal1). Wealth distribution is in line with the Sustainable Development Goal 10 aiming to "Reduce

	inequalities”. WHAT WE WANT TO MEASURE: Whether and the extent to which the company or facility contributes to the economic development of the local community; to the poverty alleviation and toward wealth distribution in the local community and society in general. EXAMPLE/s: 1) The company could contribute to the economic development by paying local companies for construction and infrastructure (contributing to better infrastructure as benefit for the local community is already covered under "Access to material, immaterial and cultural heritage"), by hiring staff or sourcing from local suppliers and so producing or enforcing local employment, or by paying taxes and dues. 2) The company could contribute to the poverty alleviation by means of philanthropy.
Corruption	WHAT THE SOCIAL TOPIC IS ABOUT: Corruption is the misuse of power for personal advantages. There are different types of corruption, including bribery, embezzlement, theft and fraud, extortion, abuse of discretion, favoritism, nepotism and clientelism, conduct creating or exploiting interests, and improper political contributions. WHAT WE WANT TO MEASURE: Whether, and to which extend, the organization has implemented appropriate measures to prevent corruption, and if there is evidence that it has engaged or has been engaged in corruption. EXAMPLE/s: There are incidents of complaints, lawsuits and other signals; there are signals of little transparency and lack of willingness to provide information; there is absence of positive information while the company is in an area where this situation often occurs according to statistics.
Delocalization and migration	WHAT THE SOCIAL TOPIC IS ABOUT: Economic development (or the lack thereof) sometimes leads to the large-scale migration and delocalization of individuals seeking employment. If operations require human relocation, organizations should engage in due diligence and procedural safeguards. If this does not happen, "involuntary resettlement" may occur, which means that groups are not offered the right to refuse acquisition that leads to displacement. Next to that, when migrant workers enter a community it is important to consider how well workers will integrate with more permanent residents. WHAT WE WANT TO MEASURE: Whether, and to which extend, the organization contribute to delocalization, migration or involuntary resettlement within communities; whether migrant workers are treated adequately and whether opportunities for communication and education between migrant workers and permanent residents

	are created. EXAMPLE/s: implementation of construction sites for infrastructure in rural areas or developing country by large companies from industrialized countries.
Discrimination and equal opportunities	WHAT THE SOCIAL TOPIC IS ABOUT: Everybody has the right to be treated fairly and access to equal opportunities, it doesn't matter what sex, race or age you are, if you have a disability, your marital status, whether you are pregnant, your family status or your family responsibilities, the religious or political beliefs you might hold and your sexual orientation. Equal opportunity, or the principle of non-discrimination, emphasizes that opportunities in education, employment, advancement, benefits and resource distribution, and other areas should be freely available to all. In this social topic the focus is on the worker discrimination and so the freedom to choose their employment, to develop their potential and to gain economic rewards on the basis of merit. In order to prevent discrimination, a company should not engage in or support distinction in hiring, remuneration, access to training, promotion, termination, or retirement which is based on race, national or social origin, caste, birth, religion, disability, gender, sexual orientation, family responsibilities, marital status, union membership, political opinions, state of health (including HIV/AIDS status), age, or any other circumstance that could give rise to discrimination. WHAT WE WANT TO MEASURE: The extent to which a company is engaged in preventing discrimination and actively promoting non-discrimination at the workplace by means of equal opportunity management practices. EXAMPLE/s: 1) Wage slips or wage records of workers confirm equal pay for work of equal value. 2) Established grievance mechanisms for workers to report a complaint or raise concerns about any actions that violates non-discrimination policy. 3) Investments and support of public private initiatives that effectively inform and raise awareness on the issue.
Effectiveness and comfort	WHAT THE SOCIAL TOPIC IS ABOUT: **Effectiveness** is the degree to which something is effective in terms of successful on achieving the results that you want. Effectiveness compares the effort required to achieve the same result as with an alternative solution: the less effort required, the more effective the product/solution. **Comfort** is related to something that makes your life easy and pleasant, according to the sensory indicators of taste, touch, sound, smell and vision. In both cases, the evidence required is mostly based on external judgments of the products, in comparison to other solutions in the same product or service category.

	Overall, this topic is primarily intended to be applied to products used in a professional setting, where their comfort and efficiency affects workers and small-scale entrepreneurs. However, also the effects on consumers/users can be considered, but only when the offered products or services provide a social value and aims to solve real societal sustainability problems and not the luxury problems of affluent consumers. WHAT WE WANT TO MEASURE: The extent to which the offered products or services affect the efficiency and comfort of users. EXAMPLE/s: Design of a faster means of transport could be a sustainability-related feature depending on the use for which the means of transport has been designed. A big SUV is designed to be comfortable and effective (or at least fast). However, this is not a sustainability-related feature: it does not make the world more sustainable, but affluent owners will be more satisfied. However, if such a car is used by the police or first aid, one may think that comfort and speed are useful.
End-of-life responsibility	WHAT THE SOCIAL TOPIC IS ABOUT: Product end-of-life, including disposal, reuse or recycling, can lead to significant environmental and social concerns, such as environmental and public health impacts that stem from the accumulation of hazardous material in electronic waste. Transport of waste to less developed countries can be a breeding ground for important public health and safety impacts on the poor people who sift through landfills in search of waste with economic value. WHAT WE WANT TO MEASURE: Even if the organization is not directly responsible for the way waste are managed, this topic examines management efforts to address the social impacts of product or service end-of-life. Organizations should provide accurate, complete and clear information to consumers regarding appropriate end-of-life options. In some cases, producers should buy back and recycle or safely dispose of waste. EXAMPLE/s: implementation and support of schemes to encourage the recycling of electronic products. reduction of a certain raw material which is responsible for social impacts in the extraction and end-of-life stages (e.g. experience from https://www.fairphone.com/en/).
Ethical treatment of animals	WHAT THE SOCIAL TOPIC IS ABOUT: Ethical treatment of animals, corresponding to the principle of animal welfare, refers to farm animals but also animals used for scientific purposes as well as in other areas such as animals kept in zoos and aquaria, or regarding the use of leg hold traps or the trade of certain products (e.g. seal products or animal fur) (See https://www.fondation-droit-

	animal.org/proceedings-aw/the-european-union-legislation-on-animal-welfare/). The European Union has developed animal welfare legislation quite extensively for farmed and laboratory animals (e.g. animal testing for cosmetic products prohibited in the EU since 2009). WHAT WE WANT TO MEASURE: The extent to which the organization efforts to address the ethical treatment of animals, in all its forms. Whether the organization refers to existing standards of animal protection and welfare, and if it provides clear information to consumers. Whether the organization promotes policy-orientated research on animal protection and welfare, and/or educate the general public and raise awareness of animal welfare issues (https://ec.europa.eu/food/system/files/2016-10/aw_efsa_opinions_factsheet_farmed03-2007_en.pdf) . EXAMPLE/s: a proven track-record of choosing more ethical options with regards to animals. Documentation of communication towards consumers about the treatment of animals in the supply chain.
Fair competition	WHAT THE SOCIAL TOPIC IS ABOUT: Fair competition concerns competitive activities that are conducted in a fair way and in compliance with legislations preventing anti-competitive behaviour, anti-trust, or monopoly practices. Fair trading mainly applies in the condition of commercial relationship between companies differing in terms of size, and economic and commercial development capacity and opportunities (e.g. small-scale entrepreneurs). WHAT WE WANT TO MEASURE: Whether the organization's competitive activities are conducted in a fair way and the extent to which a company considers the potential impacts or unintended consequences of its procurement and purchasing decisions on other organizations, and take due care to avoid or minimize any negative impact. EXAMPLE/s: the company has invested in a partnership to improve the fair competition in the region it sources from. There are incidents or complaints regarding unfair competition.
Forced labour	WHAT THE SOCIAL TOPIC IS ABOUT: Forced (or compulsory) labour is any work or service that is exacted from any person under the menace of any penalty, and for which that person has not offered its services voluntarily. Providing wages or other compensation to a worker does not necessarily indicate that the labour is not forced or compulsory. By right, labour should be offered voluntary and workers should be free to leave the employment at any time in accordance with established rules. WHAT WE WANT TO MEASURE: The extent to which a company works towards eradicating forced labour and pro-actively raising

	awareness of issues associated with forced labour. The assessment aims to verify if there is no use of forced or compulsory labour in the organization. EXAMPLE/s: Documentation of the terms and mechanisms to monitor and improve the position of the worker are in place, such as "speak up" line, training, and awareness sessions, while there are no indications that the company or facility uses forced labour.
Freedom of association and collective bargaining	WHAT THE SOCIAL TOPIC IS ABOUT: Freedom of association is a fundamental human right and, together with collective bargaining, a core dimension of the International Labor Organization's work. It applies both to becoming part of organisations inside (worker committees) or outside the organisation, such as unions. All workers and employers have the right to establish and to join organizations to promote and defend their respective interests, and to negotiate collectively with other parties. They should be able to do this freely, without interference by other parties or the state, and should not be discriminated as a result of union membership. WHAT WE WANT TO MEASURE: The extent to which workers have the right to establish and to join organisations of their choice without prior authorisation, to promote and defend their interests, to strike and to negotiate collectively with other parties. EXAMPLE/s: Public statements by the company and publicly available description describing the management system on this topic; companies accept and execute the result of collective bargaining in a sector and other agreements made with unions.
Health and safety	WHAT THE SOCIAL TOPIC IS ABOUT: This topic includes all the management practices and strategies the organization should guarantee in terms of health and safety of workers, consumer, local community and small-scale entrepreneurs. The main focus in occupational health&safety for workers and small-scale entrepreneurs is on three different objectives: (i) the maintenance and promotion of workers' health and working capacity; (ii) the improvement of working environment and work to become conducive to safety and health and (iii) development of work organizations and working cultures in a direction which supports health and safety at work and, in doing so, also promotes a positive social climate and smooth operation and may enhance productivity of the undertakings. We interpret this also to include protection against all forms of harassment including sexual harassment. Consumer health and safety refers to the consumers' rights to be protected against products and services that may be hazardous to health or life (ISO 26000, 2008). Customers (end users) expect products and services to perform their intended functions

	satisfactorily and not pose a risk to their health and safety. Health and safety for local communities includes any actions, related to the work activities, that could produce positive or negative impacts for the surrounding (e.g. accidents related to unsafe equipment or structural failures of buildings; project-related land use changes can also lead to natural disasters such as landslides). In the case of local community, also the concept of secure living conditions needs to be considered. Organizations with weak security oversight may contribute to insecure living conditions, community tensions and regional conflicts. At the same time, organizations that enter relatively insecure regions may improve living conditions through responsible actions of private security personnel. Organizations may employ security forces to protect their employees and assets. This security should extend to the protection of human rights in surrounding communities. WHAT WE WANT TO MEASURE: The extent to which the management maintains or improves the safety and overall health status of the workers, local communities, and small-scale entrepreneurs; The extent to which the product, under defined conditions maintains or improves the health status and safety of the users in the target market. EXAMPLE/s: investments in partnerships that improve the health and safety in the region the company purchases from. Evidence that the company has assessed how the product can optimize the health and safety for the user.
Prevention and mitigation of armed conflicts	WHAT THE SOCIAL TOPIC IS ABOUT: Prevention and mitigation of armed conflicts is one of the target of the Sustainable Development Goal 16 "Peace, justice and strong institutions". Conflicts can be defined as a tense situation between different parties caused by different interests, aims or value systems. There are special regions in the world that are known for enduring disturbances – so-called conflict zones. This subcategory shall also consider if the organization acts in conflict zones. WHAT WE WANT TO MEASURE: This topic assesses the organization´s role in conflicts or situations that might in the future develop into conflicts. Thereby both, positive and negative impacts on conflict developments are taken into account. EXAMPLES: Is the organization doing business in a sector that features linkages to conflicts, e.g. where the depletion of resources allows significant profits (e.g. extractive industries, forestry, fishery)?
Privacy	WHAT THE SOCIAL TOPIC IS ABOUT: Organizations may provide products or services that -- through their use -- aid invasions of

	consumer privacy (e.g. computing and communication technologies). Consumer privacy concerns protecting the confidentiality of consumer sensitive data (e.g. name, location data or online identifier, racial or ethnic origin, trade-union membership, etc.), limiting personal information gathered, restricting use of data to its original or agreed-upon purpose and protecting data from external theft and/or misuse. In cases where organisations collect or process personal information, procedures should exist for individuals to dispute, remove or correct inaccurate information. This topic may become more and more relevant with the emergence of the Internet of Things and CE-related services that are provided around a product. The 2013 OECD Privacy Guidelines provide a generic set of guidelines, relating to policies to be set up by authorities. WHAT WE WANT TO MEASURE: The extent to which a company respects and protects users` privacy; whether organizational management systems work to respect and protect consumer privacy. In cases where organizations share personal information, procedures should exist for individuals to dispute, remove or correct inaccurate information. EXAMPLE/s: The software used in the product or service is recognized by consumer or privacy organizations to provide significant extra privacy performance on top of the GDPR Regulation (EU) 2016/679 requirements.
Promoting social responsibility and public commitments to sustainability issues	WHAT THE SOCIAL TOPIC IS ABOUT: Social Responsibility (SR) is an organization's obligation to consider the interests of their stakeholders as customers, employees, shareholders or communities. By integrating SR into core business processes and stakeholder management, organizations can achieve the ultimate goal of creating both social value and corporate value (shared value). This measure considers whether the enterprise manages its suppliers in a socially responsible way, including monitoring, auditing and training efforts. This subcategory also examines whether enterprises take corrective action towards suppliers when warranted. With existing suppliers, an enterprise may develop a supplier code of conduct or a contractual agreement that covers social and environmental responsibilities. Other actions towards suppliers, such as tight purchasing deadlines and low pricing policies, may discourage opportunities for social responsibility. Enterprises also can promote social responsibility by encouraging suppliers to join foundations and initiatives with a related focus. Promoting the use of social responsibility certifications and/or product labels is another positive indicator. WHAT WE WANT TO MEASURE: Whether and to which extend the organization promotes social responsibility among its suppliers and

	through its own actions. EXAMPLE/s: Implementation of selection procedures for suppliers on the basis of sustainability criteria as well as in economic and quality terms.
Remuneration and social benefits	WHAT THE SOCIAL TOPIC IS ABOUT: **Remuneration** means compensation for workers in terms of salary and social benefits. Salary should be fair, that is a wage fairly and reasonably commensurate with the value of a particular service or class of service rendered, and, in establishing a minimum fair wage for such service or class of service. Codes of conduct which deal with wages and benefits rely on the following concepts: National Poverty Line (minimum income level on which an individual is supposed to be able to survive); Minimum wage (wage established by law, collective bargaining agreement or industry standard); Living wage (can be calculated according to different methods). Social benefits refer to non-monetary employment compensation as far as offered by the employer (while in many countries such services are also offered by the government). Four basic categories of s**ocial Security benefits** can be included in workers earnings: retirement, disability coverage, healthcare and, in case of termination of employment, severance pay. Other social benefits that may be provided include medical insurance, dental insurance, paramedical insurance including preventive medicine, medicine insurance, wage insurance, paid sick leave, paid maternity and paternity leave (parental leave is covered in work-life balance). Also **employment relationship**, intended as the legal link between employers and employees that should enable the application of laws related to social security and other labor laws, could be considered within this topic. WHAT WE WANT TO MEASURE: The extent to which the management sufficiently compensates the workers in terms of salary and social benefits, and in compliance with established standards and if the wage provided is meeting legal requirements, whether it is above, meeting or below industry average and whether it can be considered as a living wage. EXAMPLE/s: Next to paying all workers a living wage, the company provides medical insurance for their employees.
Respect of indigenous rights and land rights	WHAT THE SOCIAL TOPIC IS ABOUT: Indigenous peoples have "a historical continuity with pre-invasion and pre-colonial societies that developed on their territories and consider themselves distinct from other sectors of the societies now prevailing in those territories, or parts of them" (UN Global Compact, Indigenous Peoples). **Respect of indigenous rights** includes the right to lands, resources, cultural integrity, self-determination, and self-government. In a different

	context, this social topic can be transposed to small-scale entrepreneurs' legal **rights to land** and tenure security. Smallholder farmers and, small and family fisheries activities rely on land access to lakes and rivers for their livelihoods. WHAT WE WANT TO MEASURE: This subcategory assesses organizational respect for the rights of indigenous peoples; whether the organization engages indigenous peoples to obtain consent for actions that may affect their rights; if the organization takes care not to restrict the movement of indigenous peoples when operating on or around their land, and if the organization safeguard indigenous lands by minimizing pollution and environmental degradation. Moreover, this topic assesses the extent to which the company sourcing from the community contributes to ensuring that the rights to the land and waterbodies are clearly defined, long term, enforceable, appropriately transferable, and socially and legally legitimate. EXAMPLE/s: Lack of reports that there is land grabbing or people do not have documented land-rights
Respect of intellectual property rights	WHAT THE SOCIAL TOPIC IS ABOUT: Intellectual property rights refer to the general term for the assignment of property rights through patents, copyrights and trademarks. These property rights allow the holder to exercise a monopoly on the use of the item for a specified period. WHAT WE WANT TO MEASURE: This subcategory assesses whether organization's actions safeguard and value the creators and other producers of intellectual goods and services. The legal rights dealing with the intellectual property entail intellectual activities in the industrial, scientific, literary, and artistic fields. EXAMPLE/s: Evidence on organization's policy and practice about respect of intellectual property rights.
Responsible communication and feedback mechanisms	WHAT THE SOCIAL TOPIC IS ABOUT: **Responsible communication** regards any information and claim a company makes about a product or service that enables users to make informed choices with clear and reliable information (e.g., technical characteristics, sustainability performance, etc.). Transparency is one of the main issues in the responsible communication. This can be applied both in a business to consumer context and in a business-to-business context. **Feedback mechanisms** are paths by which consumers communicate with organizations, such as surveys, return policies, quality assurances, guarantees, warranties, etc. These mechanisms help reveal consumer satisfaction related to the consumption and use of the product or service. WHAT WE WANT TO MEASURE: The extent to which communication

	between organization and consumer is supported by transparency and feedback mechanism. Whether and the extent the organization communicates on all issues regarding its product and social responsibility in a transparent way, enabling users to make informed choices, to trust and feel happy about the product they are using. This topic also assesses the effectiveness of management measures to support consumer feedback and related management practices to provide responses, regardless of the level of consumer satisfaction. EXAMPLE/s: Implementation of an information campaign, provided via websites, brochures, labels, etc. that are developed according to specific standards and recognized by consumer organisations, NGOs etc. that confirm the credibility of claims.
Skill development and technology development	WHAT THE SOCIAL TOPIC IS ABOUT: **Skill development** concerns 4 categories: 1. Skills gap, the distance between the skill level in society and the skills required to do a job in the company; 2. Skill obsolescence, the loss of skills due to the lack of use, or the risk the skills become irrelevant; 3. Skill shortages, when there are jobs, but no qualified staff in the community; 4. Over and under skilling, when people have skills above or below the job requirements. Skill development affects the community at large to creates a more resilient and healthy community, and potentially creates a resource for companies that look for new staff when needed. **Technology transfer and development** is the process for converting research into economic development, or for using technology, expertise or know-how for a purpose not originally intended by the developing organization. It is fundamental between more advanced economies and developing economies for the improvement of social conditions and to prevent further environmental damage related to old technology use. WHAT WE WANT TO MEASURE: The extent to which the company contributes to skill development for the community at large, not only in connection to the potential future staff need but in general to produce benefits for all members of the community. Moreover, this social topic assesses whether the organization participates in joint research and development for efficient and environmental sound technologies. EXAMPLE/s: 1) implementation of schools, or training and specialisation programs for the entire community around the factory to facilitate skill development of people leaving in remote areas (The Jagdish Chandra Mahindra Memorial School established on the factory site of Sanyo Mahindra in India); 2) involvement in technology transfer program or projects.

Supplier relationships and fair trading	WHAT THE SOCIAL TOPIC IS ABOUT: The **supplier relationships** terms include all mutual activities, co-operations, agreements that regulate the exchanges, trade and relation among organizations, bearing in mind that every organization in the value chain is responsible for complying with applicable laws and regulations. **Fair trading**, as defined by the International Fair Trade Centre, corresponds to enable producers and workers to maintain a sustainable livelihood; that meets day-to-day needs for economic, social and environmental well-being and that allows to improve conditions over time. There is a commitment to a long-term trading partnership that enables both sides to co-operate and grow through information sharing and joint planning. When the organization supply chain includes small-scale entrepreneurs, concepts like **meeting basic needs** and **access to service and input** become relevant. Meeting basic needs means having sufficient access to revenues to purchase basic, essential goods and services to support their family; access to services and inputs includes financial services, information and opportunities for skill development, fertilizer seeds, water and farming tools, and infrastructure. It is conceptually similar to "Access to material, immaterial and cultural heritage" but target to small-scale entrepreneurs. WHAT WE WANT TO MEASURE: Whether the organization's competitive activities are conducted in a fair way and the extent to which a company considers the potential impacts or unintended consequences of its procurement and purchasing decisions on other organizations and take due care to avoid or minimize any negative impact. In the case of sourcing from small-scale entrepreneurs, whether the organization contributes to fair trading terms, where small-scale entrepreneurs have access to basic needs, service and input as a consequence to be part of the value chain. EXAMPLE/s: From the small-scale entrepreneur perspective, one way to achieve a fair-trade relationship is to organize themselves in cooperatives so they can create a better negotiation position, share information on pricing, quality standards etc. From the perspective of companies who are sourcing from such small-scale entrepreneurs, a way to create fair trading relations is to source from communities that are certified under a credible fair-trade label, or to support the cooperatives in development of better (agricultural) practices.
Women's empowerment	WHAT THE SOCIAL TOPIC IS ABOUT: The position of women is rated according to 4 dimensions: discrimination in the family; restricted physical integrity; restricted access to productive and financial resources; restricted civil liberties. We recognize that companies sourcing from small-scale entrepreneurs could influence only the

	third dimension "restricted access to productive and financial resources". WHAT WE WANT TO MEASURE: The extent to which a company sourcing from a community of small-scale entrepreneurs is contributing to the empowerment of female small-scale entrepreneurs and the woman (spouses, daughters etc.) related to male small-scale entrepreneurs. EXAMPLE/s: The company has invested in and engages in a public private partnership to empower women in the supplier's community.
Work life balance and working hours	WHAT THE SOCIAL TOPIC IS ABOUT: Work-life balance is central to people's/workers' well-being and relies on the right balance between the commitments of work and those of private life. Employers' demands on workers' time should take this principle into account. Too little work can prevent people from earning enough to attain desired standards of living. But too much work can also have a negative impact on well-being, if people's health or personal lives suffer as a consequence, or if they cannot perform other important activities such as looking after their children and other relatives, having time for themselves, etc. Hours of work is one of the aspect influencing work-life balance, together with the possibility to choice where and how they work. Working hours comply with applicable laws and industry standards. Workers are not on a regular basis required to work in excess of 48 hours per week and have at least one day off for every 7-day period. Overtime is voluntary, does not exceed 12 hours per week, is not demanded on a regular basis and is compensated at a premium rate. The needs and expectations of the workers are taken into account in the organisation of working hours. There are also higher restrictions if the hours of work are made during the night. Hours of work are considered in function of different time arrangement (from part time to full time) and work places (e.g. from home workers to field workers and manufacture). WHAT WE WANT TO MEASURE: The extent to which a company enables workers to have choices over when, where and how they work and encourages a healthy work-life balance; whether the number of hours really worked is in accordance with the ILO standards and when overtime occurs, compensation in terms of money or free time is planned and provided to workers EXAMPLE/s: Documents and reports that explain the rules and enforcement of the rules that provide a basic work-life balance, and describe the way this is monitored, for instance with a speak-up line to report managers that allow excessive overtime to happen.

25.3 Annex C: Guidance on the monetary valuation of externalities

For the special case of conducting societal life cycle costing (sLCC), this Annex describes concepts relevant for monetising externalities to a large extent (section 25.3.1) and potentially assigning different importance to impacts affecting different groups of people ("equity weighting", section 25.3.2). Section 25.3.3summarises the provisions.

Note that sLCC is regarded as an LCSA framework of its own in which monetary valuation methods are used to weigh social and environmental impacts. For the purpose of ORIENTING's LCSA, weighting and potential aggregation are dealt with in the interpretation and integration chapter **Error! Reference source not found.**.

25.3.1 Approaches and data sources for monetary valuation of externalities

Different terms related to monetised environmental impacts (and related aspects) exist. Regarding **externalities (or external effects)**, a recent report by the SEEA Experimental Ecosystem Accounting Technical Committee (Committee of Experts on Environmental-Economic Accounting, 2021) relies on a definition by Markandya et al. (2001) that is rather similar to the one coined in the EU project series "External Costs of Energy (ExternE)[31]": "*Externalities are impacts that 'arise when the actions of an individual, firm or community affects the welfare of other individuals, firms or communities [and the] agent responsible for the action does not take full account of the effect'*" (Committee of Experts on Environmental-Economic Accounting, 2021, paragraph 12.13).[32] For the purpose of the ORIENTING LCSA framework, the following definition is adopted: "consequence of an activity that affects interested parties other than the organization undertaking the activity, for which the organization is neither compensated nor penalized through markets or regulatory mechanisms" (ISO-14007, 2019). When expressing negative or positive externalities in monetary units, these are termed **external costs or benefits**, respectively.

A main point to note here is that externalities do not occur in the books of the entity causing them. If they did, they would cease to be externalities but be (at least partly) internalised (regardless of whether or not the people affected by the damage would be compensated). Determining the degree of their internalisation poses problems because it requires a) to have a precise estimate of the "true" externality, and b) to identify and quantify the fraction of this externality addressed by a given (environmental or social) policy. For example,

[31] "*An external cost, or an externality (they are treated as equivalent terms in this study), arises when the social or economic activities of one group of persons have an impact on another group and that impact is not fully accounted for by the first group*"(European Commission, 1999, p. 3).

[32] Further examples of definitions include one in a report by the International Monetary Fund: "*An adverse externality occurs when the actions (e.g., fuel combustion) of individuals or firms impose costs on others that the actors do not take into account*"(Parry, Heine, Lis, & Li, 2014, p. 14). David Pearce described them as follows (Pearce, 2001 p. 2): "*An externality exists if two conditions are met. First, some negative (or positive) impact is generated by an economic activity and imposed on third parties. Second, that impact must not be priced in the market place, i.e., if the effect is negative, no compensation is paid by the generator of the externality to the sufferer. If the effect is positive, the generator of the externality must not appropriate the gains to the third party, e.g. via some price that is charged*". Finally with a view more on organisations, ISO 14007:2019 defines an externality as "*consequence of an activity that affects interested parties other than the organization undertaking the activity, for which the organization is neither compensated nor penalized through markets or regulatory mechanisms*"(ISO-14007, 2019, sub-clause 3.2.4).

Rabl and Spadaro (2016) prefer the term **damage costs** in order not to run into the difficulty to determine the already internalised part of the externalities.

ISO 14007 uses the terms **environmental costs and benefits** in a larger sense, i.e., comprising internal and external costs and benefits (ISO-14007, 2019). Therefore, care needs to be taken in order not to set environmental costs equal to external costs for instance given that private emission abatement costs would also be referred to as environmental costs according to ISO 14007 (2019).

In order to monetise externalities, ISO 14008 (2019) lists **monetary valuation techniques** to be used(Table 42). Values derived with any of these methods in one context may also be used (after some adaptations) in another context. This procedure is referred to as "value transfer" or "benefit transfer". ISO 14008 (2019) furthermore provides requirements and guidance concerning their use as well as associated documentation and reporting.

Table 42: Monetary valuation approaches and techniques permitted according to ISO 14008 (2019)

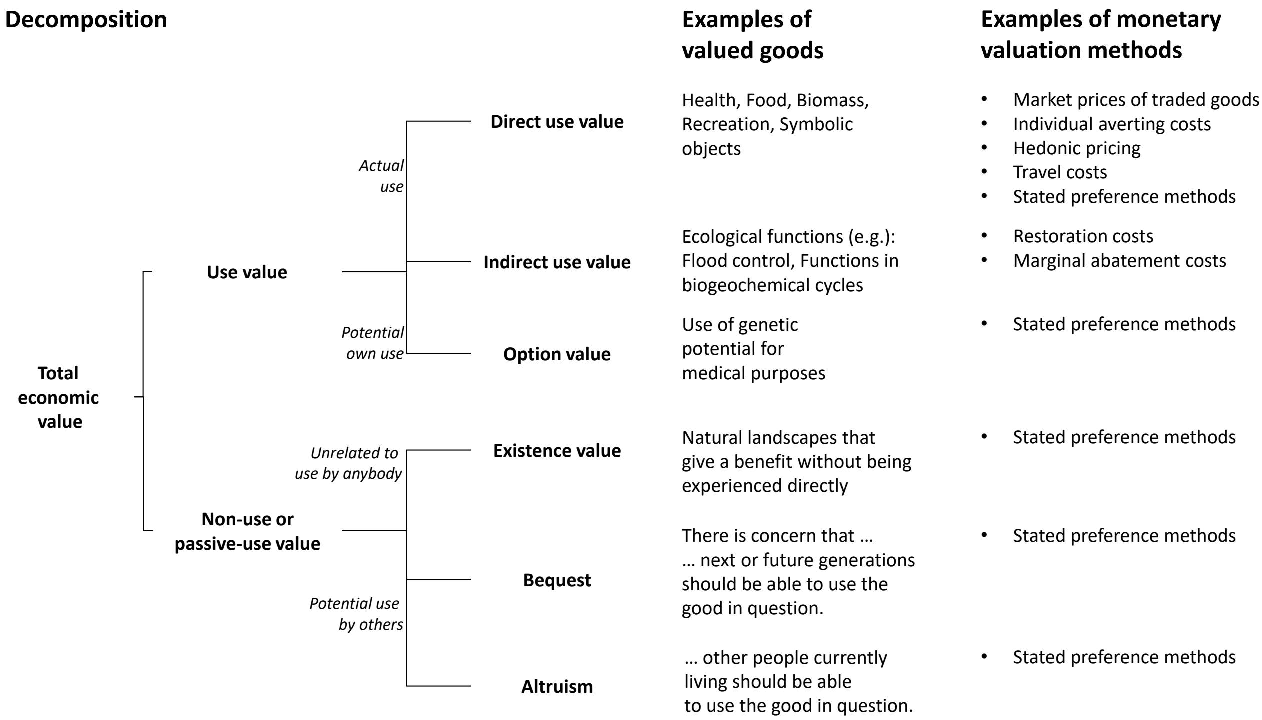
Monetisation approach	Method
Market price proxies	Market prices of traded goods and labour
	Cost-of-illness method
Revealed preference methods	Individual averting cost method
	Public averting cost method — Targets for specific sites
	Public averting cost method — Targets at administrative levels
	Hedonic pricing method – Property
	Hedonic pricing method – Labour
	Travel cost method
	Data derived from public referendums
Stated preference methods	Contingent valuation
	Choice experiment

A given monetary valuation method does not necessarily capture all elements of the so-called **Total Economic Value** (TEV) concept (Freeman, III, Herriges, & Kling, 2014; OECD, 2018). TEV conceptualises all constituents of value that are related to human well-being. At the highest level, use and non-use values are distinguished that can be further subdivided (see Figure 25). ISO 14008 (2019) defines use value as "monetary value of a good in relation to its actual, planned or possible use" and non-use value as "monetary value of a good independent of its actual, planned or possible use". While non-use values come into play when valuing impacts notably on biodiversity, ecosystems or landscapes, use values also concern human health, crops and the built-environment. Human health related direct use values are distinguished into three (additive) cost components (e.g. Markandya et al. (2019)):

- Resource costs: direct medical costs (e.g. treatments) and non-medical costs (e.g., childcare or housekeeping) that come with an adverse health impact; costs associated with litigation or processing claims also fall into this category;
- Opportunity costs associated with the productivity loss or lost leisure time;
- Disutility costs: the value of suffering from an adverse health impact (i.e., pain, anxiety or discomfort).

The TEV is an anthropocentric concept. While the (non-anthropocentric) intrinsic value of other species is excluded, the existence value component can include the concern for the survival and well-being of other species.

Figure 25: Decomposition of the total economic value and examples in terms of environmental goods and monetary valuation methods



Source: own elaboration based on Bachmann (2019), Pearce, Atkinson, and Mourato (2006), German Advisory Council on Global Change (WBGU) (2001) and ISO-14008 (2019)

Within the group of externalities, Hunkeler et al. (2008) separate out what can be called "soon-to-be-internalised external costs". While not providing a proper definition, Hunkeler et al. (2008) characterise them as "externalities anticipated to be internalized in the decision-relevant future" (p. 70) or "internalized in the near future" (p. 61). The decision-relevant future is defined in "the goal and scope of the study" (p. 54, ibid.). Typically, these costs are related to a new piece of regulation already enacted that will become effective in the future by imposing a new or higher tax (e.g., on emissions) or setting more restrictive threshold values (e.g., on emissions into air or discharges into water). According to Swarr et al. (2011), LCC shall only consider real money flows "directly covered by actors within the considered life cycle" (e.g., internal costs). For this reason, the "soon-to-be-internalized external costs" represent an exception and are defined as "costs that are not presently part of a given product system" but are "expected to be internalized in the decision relevant future" (p. 15).

For practitioners aiming to monetise environmental impacts or aspects, several approaches can be followed:

- Combining environmental LCA midpoint or endpoint indicators with monetary valuation approaches for different areas of protection, e.g., human health, ecosystems or natural resources; this can be seen as an optional LCA weighting step. This is embedded in available methods such as Environmental Priority Strategies (EPS), LIME, Stepwise or Ecotax, which makes the amount of additional data needed (beyond the LCI) fairly limited, provided that the corresponding environmental and social impact categories are used. Note that such an approach will lead to the monetisation of relevant environmental flows from the LCI and may therefore include internalised as well as non-internalised externalities.
- Combining life cycle inventory data directly with unit damage cost factors per substance, e.g. by using the social cost of carbon or monetary damage estimates of air pollution emissions (partly relying on the same data sources as the above-mentioned LCA-related approaches) in the European context. Such damage cost factors are available at national or European level and have been derived in the context of the Externalities of Energy (ExternE) project series, as well as from national or European research undertakings (CE Delft, 2018; DEFRA, 2021; Preiss, Friedrich, & Klotz, 2008; Simone Schucht, Elsa Real, Laurent Létinois, Augustin Colette (Ineris), Mike Holland (EMRC), Joseph V. Spadaro (SERC), Laurence Opie, Rosie Brook, Lucy Garland, 2021; Umweltbundesamt, 2020).

To be as specific as possible, the environmental aspects and impacts should be provided in a spatially (e.g. nationally) and temporally (e.g. annually) resolved way.

25.3.2 Equity weighting

While efficiency considerations are at the heart of Cost-Benefit Analyses in whose tradition societal LCC can be seen, concerns about the distribution of costs and benefits among different population or stakeholder groups can also be taken into account (Boardman, Greenberg, Vining, & Weimer, 2011; OECD, 2018). This can go as far as to quantitatively assigning lower or higher values to the same cost or (environmental or social) impact when borne/endured by people of higher or lower wealth, respectively. This process is known as equity weighting. For example, the economic loss of 1€ to an average person living in sub-Saharan Africa (e.g., due to climate change) is relatively more important than to an average person living in any of the OECD countries. If this was considered a concern, one could multiply the loss to the less-well off person with a value larger than one and/or the loss to the better off person with a value lower than one.

In the ORIENTING's LCSA framework, equity weighting mainly concerns the monetisation of environmental impacts, where it can be seen as an optional choice when conducting sLCC. Therefore, the interested reader can refer to the relevant literature (Boardman et al., 2011; ISO-14008, 2019; OECD, 2018) if there was an interest in applying it.

25.3.3 Conclusion with provisions

Provisions 7. Guidance on the monetary valuation of externalities

Monetising not yet internalised externalities

- If applied, the way in which externalities are monetised shall be stated and justified in the documentation. Only monetary valuation methods permitted by ISO 14008 (2019) may be used (see Table). It shall be stated to which extent all elements of the total economic value concept are covered by a given monetary value.

Equity weighting

- If equity weighting is performed, this shall be stated, explained and justified in the documentation. This includes cases when an equity weighted monetary value is used for valuing environmental (or social) impacts.

For requirements on the use and meaning of "shall", "should", "may" and "can", see section 0.

25.4 Annex D: Multi Criteria Decision Analysis (MCDA) methods that could be applied for integration

A1: INTERNAL NORMALISATION + WEIGHTING. Internal Normalisation + Panel based or own-criteria weighting.

This section describes some MCDA methods that fit under the classification of Group A integration approaches. All **value-based or value-measurement MCDM** provide an aggregated numerical score using internal normalisation and weighting. Examples of value based MCDM include: SAW, AHP and MAVT/MAUT. As follows, an explanation of their concept, integration procedure and other related features are included for each method.

SAW (Simple Additive Weighting) is the oldest, most widely known and used MCDA method. When applying SAW, recommendation is to undertake internal normalization by considering the optimal value among the alternatives for each criterion (e.g., impact category in LCSA). However, different (external) values could also be used for undertaking the normalisation, and normalised values are then available per criterion, for each alternative. Normalisation is then followed by weighting of the different criteria. Therefore, this MCDA method is overarching for both Group A and B methods, as expressed in Table 37. The weighting specific procedure is not defined by SAW, weights defined by a panel of experts or AHP could be used, for example. The single score obtained is the result of a linear weighted sum, I.e. the summation of the weighted-normalized criteria values per alternative. As an output, the method provides a ranking based on single scores for each alternative.

The SAW method consists of the following steps:

a. Calculation on N indicators "i" (criteria) for M product alternatives "j";
b. Normalization of all indicators with respect to specific criteria: indicators can be for example normalized based on the minimum or maximum value in the series (i/i_{max});
c. Normalised values are multiplied to the weight set to each criterion (weights can be set by different methods) and summed for each alternative "j";
d. Single scores are ranked.

The main advantages of this method are: (i) it is intuitive; (ii) the calculations are simple and can be performed through common software tools, e.g., spreadsheets. An example on how to apply SAW is provided in **Table 43.**

Table 43: Characterized impact assessment results and the ranked alternatives after applying the SAW method.

	Indicators	i1	i2	i3	i4	**SAW**	**RANK**
	Weights	*0.2*	*0.1*	*0.3*	*0.4*		
Alternatives (already normalised)	j1	5	4	5	8	**6.1**	**2**
	j2	4	6	3	7	**5.1**	**3**
	j3	3	2	10	7	**6.6**	**1**

AHP (Analytical Hierarchy Process) by Saaty (1980) is a structured technique for multiple criteria decision analysis based on pairwise comparisons of alternative elements. It is sometimes referred to as a weighting method as it can be used as a procedure for obtaining weighting factors. When using AHP, the first step is to break down a complex decision-problem into a hierarchical structure consisting of an overall goal (e.g., sustainability assessment), several criteria contributing to this goal (e.g., sustainability pillars) and a number of attributes (e.g., indicators). The second step requires comparisons in a pair-wise fashion of each element within the same level in the hierarchy (e.g., sustainability pillar). The comparisons are performed by an expert or group of experts, who must answer two questions: "Which of these two elements is more important?", "By how much?". A qualitative scale is used to perform these comparisons. As an illustration, an example is provided below with a set of values ranging from 1 to 9:

1: Both criteria are equally important;
3: One criterion is slightly more important than the other;
5: One criterion is more important than the other;
7: One criterion is much more important than the other;
9: One criterion is extremely more important than the other;
2,4,6,8: Intermediate values.

These comparisons result in a series of reciprocal squared matrices. The third step involves undertaking consistency checks of the obtained matrices, measured through the consistency ratio (C.R.), which depends on the maximum eigenvalue of the matrix (λmax), a mathematical calculation associated to the AHP method, and also on the number of criteria considered. In case of inconsistencies, iterations of the questionnaires with the specific expert need to be undertaken. Once the consistency is verified, the weights of each criteria (i.e. the sustainability pillars in this case), are obtained by calculating the eigenvector (Gan et al., 2017b). An example, based on a fictional scenario, on how the reciprocal squared matrices are created after consultation with experts and how the relative weights are obtained is provided in Figure 26.

Answer Expert 1 (A1)

Sust. Pillar	Soc.	Environ.	Econ.	Eigenvector (λmax)	Eigenvector (λmax) (normalized) = weights
Soc.	1	1	5	5.31	0.444
Environ.	1	1	6	5.65	0.472
Econ.	0.2	0.17	1	1	0.084
		<0.1 OK	0		

Answer Expert 2 (A2)

Sust. Pillar	Soc.	Environ.	Econ.	Eigenvector (λmax)	Eigenvector (λmax) (normalized) = weights
Soc.	1	0.2	0.11	0.09	0.060
Environ.	5	1	0.33	0.4	0.268
Econ.	9	3	1	1	0.671
		<0.1 OK	0.03		

Answer Expert 3 (A3)

Sust. Pillar	Soc.	Environ.	Econ.	Eigenvector (λ_{max})	Eigenvector (λ_{max}) (normalized) = weights
Soc.	1	6	1	1.14	0.483
Environ.	0.1	1	0.25	0.22	0.093
Econ.	1	4	1	1	0.424
		<0.1 OK	0.02		

Final weights (A1 + A2 + A3)

Soc.	0.329
Environ.	0.278
Econ.	0.393

Figure 26 Reciprocal squared matrices for obtaining the relative weights for each sustainability pillar taking into consideration 3 different expert opinions.

In the example provided, the application of AHP focuses on the obtention of weighting factors that, on a further step, can be used for obtaining a single score in comparative studies, as shown in Table 36.

Table 44 Using the relative weights obtained through AHP to obtain a single score indicator.

Sust. Pillar	Weight 1 (AHP)	Sub-criteria (Indicators)	Weight 2	Alt.1 n	Alt.2 n	Alt.1 w	Alt.2 w
Soc.	0,329	Indicator 1	1	0.427	0.573	0.141	0.189
LCA/Env.	0,278	Indicator 2	0,378	0.765	0.235	0.080	0.025
		Indicator 3	0,115	0.594	0.406	0.019	0.013
		Indicator 4	0,087	0.769	0.231	0.019	0.006
		Indicator 5	0,113	0.795	0.205	0.025	0.006
		Indicator 6	0,170	0.467	0.533	0.022	0.025
		Indicator 7	0,138	0.722	0.278	0.028	0.011
LCC/Econ.	0,393	Indicator 8	1	0.523	0.477	0.205	0.187

Single score per Alternative	0.587	0.413

Legend to the table: **Alt.** = Alternative, **n**= normalized, **w**= weighted. **Weight 1** = weights for each of the sustainability pillars obtained through the application of AHP; **Weight 2** = weights for the indicators within the sustainability pillars obtained through the application of another weighting method (e.g. PEF, AHP). The summation of the weights for the indicators within the LCA/Env. domain is one.

The popularity of AHP is due to its applicability to various decision-making situations, flexibility regarding data availability as it can be used solely relying on expertise and judgement of the participants, and the relative simplicity of its use. The downside of AHP is that the amount of necessary pair-wise comparisons can easily become difficult to manage if several indicators and more than one product option, for example, need to be compared.

MAUT/MAUT is a theory for measuring value or utility (value of uncertain outcome) based on multiple criteria/attributes and preference information. It presents conditions under which there exists a cardinal value function (**Equation 1**.) which can be used to give single scores to actions/alternatives using multiple criteria, weights and value or utility functions:

$$V^N(x) = \sum_{i=1}^{n} w_i v_i^N(x_i) \quad (\mathbf{1})$$

where $x = (x_1, \dots, x_n)$ is the alternative, $V^N(x)$ is the normalised overall value function, w_i the weight of criterion *i*, and $v_i^N(x_i)$ the normalised value function of criterion *i*.

The overall value of an ideal alternative, that has highest value in every criterion equals therefore one. The alternative with worst performance in all criteria has the overall value of zero.

The attribute weight w_i describes the change of overall value when the value of a criterion is changed from worst $v_i(x_i^0)$ to best $v_i(x_i^*)$ level. Therefore, the weight cannot be meaningfully produced without considering the quantitative performances of the alternatives in the criteria. For instance, instead of measuring if climate impacts are more important than economic welfare, it is more meaningful to ask if improving climate impacts from worst to best level is more valuable than increasing economic welfare from worst to best level.

In practice, the MAVT/MAUT is similar to the SAW method, apart from the concept of value function $v_i(x_i)$. Moreover, by assuming the value functions are linear, the two aggregation methods produce same results (for a numerical example of SAW, see **Table 43**). Therefore, using MAVT/MAUT calls for effort to be put in eliciting the value functions or at least their approximation in sufficient detail. Depending on context, a piece-wise linear approximation of a value function may be used. The most simple example would be to define x_i^a so that a change from worst value $v_i(x_i^0)$ to $v_i(x_i^a)$ is equally preferred to a change from $v_i(x_i^a)$ to best value $v_i(x_i^*)$ and assume that $v_i(x_i)$ is linear when $x_i^0 < x_i < x_i^a$ and $x_i^a < x_i < x_i^*$.

For example, let's assume that three alternatives are compared using two criteria, which have the following value functions:

Criterion 1: $v_i(x_i) = \begin{cases} 2 + 0{,}7 * x_i \; when \; x_i \leq 1 \\ 2{,}7 + 2 * x_i \; when \; x_i > 1 \end{cases}$

Criterion 2: $v_i(x_i) = x_i^{1{,}2}$

The performance of the three alternatives regarding the two criteria are presented in Table 45, along with the criteria weights and resulting value functions. With these assumptions, the normalised overall value (see Equation 1) of Alternative A is 1, while the value of Alternative B is 0 and the value of Alternative C is 0,4.

Table 45 **Numerical example of MAVT: Alternatives, weights w_i and normalised value functions $v_i^N(x_i)$.**

	Alternative A	Alternative B	Alternative C	w_i	$v_i^N(x_i)$, Alternative A	$v_i^N(x_i)$, Alternative B	$v_i^N(x_i)$, Alternative C
Criterion 1	1,5	0,5	5,0	0,6	0,3	0	1
Criterion 2	6,0	3,0	2,0	1	1	0,2	0

Similar to AHP, the methodology is intended for comparative decision-making. Assuming the value/utility functions and attribute weights can be meaningfully elicited, the additive value function provides a single score also in single product studies. In summary, using additive value aggregation, MAUT/MAVT generates single scores for the alternatives based on the evaluated criteria and on preference information but it does not stipulate the methods for elicitation of the decision maker´s preferences (Dyer & Sarin, 1979), (Keeney & Raiffa, 1994).

A2: INTERNAL NORMALISATION + WEIGHTING: Outranking methods + panel based weighting or own criteria weighting.

This section describes some MCDA methods that fit under the classification of Group A2 integration approaches.

A2: Outranking models provide a ranking of the alternatives based on pair-wise comparisons amongst each alternative. These approaches differ from those in A1 (value-based) in that the output of the analysis is an outranking relation on the set of alternatives. An alternative is said to outrank another if taking into account all available information, there is a strong enough argument to support as a conclusion that one is at least as good as the other and no argument to the contrary. Examples of these methods include ELECTRE, PROMETHEE and VIKOR. As follows, an explanation of their concept, integration procedure and other related features are included for each method.

ELECTRE (Elimination of Choice Translating Reality), is an outranking method, of which 6 versions exist (Abounaima, Lamrini, Makhfi, & Ouzarf, 2020). The internal normalisation is performed through pairwise comparisons and then weights are to be assigned to each criterion. A criterion could be a high performance in one of the midpoint impact categories considered in the analysis. The common goal is to show the preference of an alternative over the other alternatives by pairwise comparison of alternatives through outranking relations. These relations are used to produce the most possibly accurate and desirable set of alternatives by the elimination of alternatives under the influence of conflicting criteria. An example of the application of the ELECTRE II method can be found in (Tonini et al., 2020) and (Sanjuan-Delmás et al., 2021), who applied the sustainability framework as developed in (Taelman, Sanjuan-Delmás, Tonini, & Dewulf, 2020), relating to the quantitative sustainability assessment of different European waste management systems. Positive aspects of this method include that it was developed to allow the ranking of alternative waste management scenarios from best to worse and that there is a freely available tool (excel format, see annex of (Taelman et al., 2020)) to allow for the mathematical implementation of the method which, on the other hand, is considered medium-complex. The mathematical implementation on the method is summarised in the following 5 main steps described in detail in (Taelman et al., 2020):

1. Internal normalisation of the characterized indicators' results with the min.-max. method, generating strictly positive normalised values.
2. Deriving the concordance and discordance matrix:
    a. The concordance matrix *"C"* is constructed based on the pairwise comparison of each indicator *I* between two alternatives A_x and A_y, scoring with 1 for each indicator for which alternative A_x is better than alternative A_y. The concordance index *c* of a pair of alternatives (A_x, A_y) is the sum of the scores obtained from this comparison.
    b. The assignment of weights to each indicator are applied at this stage, using panel-based weighting, in this case.
    c. The discordance matrix *"D"* is constructed based on the differences between the values of the indicators of two alternatives A_x and A_y. The discordance index *d* for a pair of alternatives (A_x, A_y) is the maximum value obtained from all the differences (across normalised and weighted indicator results) between A_x and A_y.
3. Correcting the concordance and discordance matrix by introducing thresholds, obtaining two corrected matrices C' and D'.
4. Aggregating matrixes. Once the corrected matrices C' and D' are obtained, they can be aggregated. The aggregated matrix E is obtained as the product between the xy^{th} concordance and discordance index.
5. Deriving the ranking of alternatives. The aggregated score associated with an alternative Ax can then be derived and the set of alternatives can finally be ranked, per each alternative, based on the score obtained. The aggregation proposed in this framework allows obtaining a single composite index (Aggregated Index) and relative rankings of the scenarios (A1 to A3) assessed, as shown **Table 46**, in which the preference ranking of the alternatives is shown by the lowest value of the indicator and rank.

Table 46: Table showing the characterized impact assessment results and the ranked alternatives after applying the ELECTRE MCDA method.

Characterized results							Aggregation Results			
							Aggregated Index		**MCDA- ELECTRE II**	
	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**Aggregated I1-I6**	**Rank**	**Score**	**Rank**
Alternative 1	10	10	10	10	10	10	0	**1**	2	**1**
Alternative 2	100	100	100	100	100	100	0.0197	**2**	1	**2**
Alternative 3	1000	1000	1000	1000	1000	1000	0.2171	**3**	0	**3**

Legend to the table: I= indicator. Panel-based weights used amongst the indicators: I1: 0.217, I2: 0.090, I3: 0.090, I4: 0.180, I5: 0.206, I6: 0.216. Note that the method also works with net savings (e.g negative values such as -10) in an impact category.

PROMETHEE (Brans, Vincke, & Mareschal, 1986) is considered in this section as a family of outranking methods for multi-criteria decision assessment. In PROMETEE, all alternatives are pairwise compared within every criterion (e.g. sustainability pillar, indicator, etc.), and the implications of their differences are determined based on a preference function for each criterion. For instance, the preference function may set a threshold "***q***" value that makes the ranking indifferent for smaller differences within a criterion. Similarly, a preference threshold "***p***" can be set to mark the highest possible meaning for all differences above that level. A preference function produces a value between 0 (difference is meaningless) and 1 (difference has the highest meaning) called a unicriterion preference degree. Typical forms of preference functions are reported in literature (Ishizaka & Nemery, 2013), for instance and not limiting to:

- Quasi criterion: The preference produced either 0 or 1 depending on the indifference threshold "**q**". It can be used with qualitative criteria, for example.
- Criterion with linear preference: Contains only the preference threshold "***p***".
- Criterion with linear preference and indifference area: Contains both the indifference threshold "***q***" and preference threshold "***p***".

In order to give an example of ranking alternatives with PROMETHEE, consider the five alternatives presented in Table 47. In this case, linear preference functions with indifference areas are assumed.

Table 47. Criteria values, weights, indifference thresholds and preference thresholds.

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
min/max	minimize	minimize	maximize	maximize
preference	linear	linear	linear	linear
weight	0,1	0,4	0,3	0,2
p	5000	1	2	20
q	2000	0,5	1	10
Alternative 1	16000	7,5	1	50
Alternative 2	27000	9	4	110
Alternative 3	39000	8,5	10	90
Alternative 4	23000	8	8	75
Alternative 5	24500	7	8	85

The unicriterion preference degrees form matrixes from each criterion (**Table 48**). The preference degrees are used to calculate positive, negative and net preference flows for each alternative. Positive preference flow measures how much on average an alternative is preferred over other alternatives within a criterion. Negative flow measures the opposite, and the net flow is the difference between positive and negative flow.

Table 48. The unicriterion preference degrees and preference flows.

Criterion 1	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Positive	Negative	Net Flow
Alternative 1	**0,00**	1,00	1,00	1,00	1,00	1,00	0,00	1,00
Alternative 2	0,00	**0,00**	1,00	0,00	0,00	0,25	0,46	-0,21
Alternative 3	0,00	0,00	**0,00**	0,00	0,00	0,00	1,00	-1,00
Alternative 4	0,00	0,67	1,00	**0,00**	0,00	0,42	0,25	0,17
Alternative 5	0,00	0,17	1,00	0,00	**0,00**	0,29	0,25	0,04
Criterion 2	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Positive	Negative	Net Flow
Alternative 1	**0,00**	1,00	1,00	0,00	0,00	0,50	0,00	0,50
Alternative 2	0,00	**0,00**	0,00	0,00	0,00	0,00	0,75	-0,75
Alternative 3	0,00	0,00	**0,00**	0,00	0,00	0,00	0,50	-0,50
Alternative 4	0,00	1,00	0,00	**0,00**	0,00	0,25	0,25	0,00
Alternative 5	0,00	1,00	1,00	1,00	**0,00**	0,75	0,00	0,75
Criterion 3	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Positive	Negative	Net Flow
Alternative 1	**0,00**	0,00	0,00	0,00	0,00	0,00	1,00	-1,00
Alternative 2	1,00	**0,00**	0,00	0,00	0,00	0,25	0,75	-0,50
Alternative 3	1,00	1,00	**0,00**	1,00	1,00	1,00	0,00	1,00
Alternative 4	1,00	1,00	0,00	**0,00**	0,00	0,50	0,25	0,25
Alternative 5	1,00	1,00	0,00	0,00	**0,00**	0,50	0,25	0,25
Criterion 4	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Positive	Negative	Net Flow
Alternative 1	**0,00**	0,00	0,00	0,00	0,00	0,00	1,00	-1,00
Alternative 2	1,00	**0,00**	1,00	1,00	1,00	1,00	0,00	1,00
Alternative 3	1,00	0,00	**0,00**	0,50	0,00	0,38	0,25	0,13
Alternative 4	1,00	0,00	0,00	**0,00**	0,00	0,25	0,38	-0,13
Alternative 5	1,00	0,00	0,00	0,00	**0,00**	0,25	0,25	0,00

In addition to preference functions, criteria weights can be used. The PROMETHEE methods are neutral to how the preference functions and weights are elicited. Regardless of the selected methods to define the preference information, the level of worst and best criteria values should be taken into account during the weighting, as discussed in the previous section on MAVT/MAUT (the weights describe the importance of a change from worst to best level within a criteria).

The overall or partial ranking of the alternatives is determined by the weighted sum of the positive and negative preference flows. The PROMETHEE I method provides a partial ranking by visualizing the global positive and negative flows (**Figure 27**). An alternative is better than another is both positive and negative flows are better. If the global positive and negative flows are not simultaneously better, the two alternatives are incomparable. Naturally, the alternatives are considered indifferent if they have same global positive and negative flows. The PROMETHEE II method produces a full ranking by considering only the global net preference flows (see **Figure 27**).

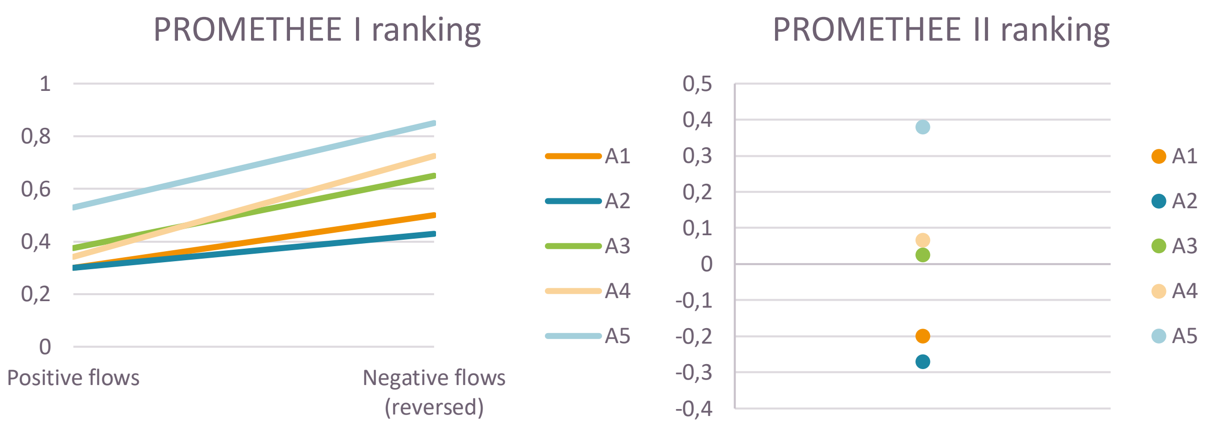


Figure 27. Example of a partial and full ranking by PROMETHEE I and II.

As a summary, alternatives are pairwise compared to assess whether one alternative is at least as good as another. An alternative outranks another if it performs better in more criteria or in the most voted criteria and at least equally as good in the rest. Alternatives are evaluated in three steps: (i) establishing a preference function for each criterion; (ii) calculating the preference index and the positive and negative preference flows and; (iii) ranking the alternatives. The process of pairwise comparisons effectively normalises the criteria values and therefore separate normalisation is not needed.

VIKOR is a MCDM method developed to classify a set of alternatives, whose performances are evaluated against various criteria; ranking of alternatives is performed by comparing the measure of "closeness" to the "ideal" solution, thus a compromise solution is identified (San Cristóbal, 2011).

The application of VIKOR method starts with the development of the decision matrix which shows the performance of the "j" alternatives with respect to various criteria (i). The compromise ranking algorithm VIKOR consists in four steps during which the best and the worst values of all criterion functions i = 1, 2, . . ., n are compared with the values that each alternative has with respect to each criterion. Normalisation and weighting are performed to calculate three parameters (S, R and Q) by which alternatives are ranked and then the compromise solution is identified when two conditions of the algorithm are satisfied. The set of weights could be identified by means of external methods like AHP and fuzzy logic. A full description of the mathematical steps to follow for the application of VIKOR is provided in D1.5 - Critical valuation of sustainability integration approaches (ORIENTING, 2021).

A3: INTERNAL NORMALISATION + WEIGHTING: Internal normalisation + Distance to Target (DtT).

This section describes some MCDA methods that fit under the classification of Group A3 integration approaches, such as **Distance to Target methods**, which measure how well the assessed alternatives fulfil a set of targets, as explained further in the examples provided.

The **TOPSIS** (Technique for Order Preference by Similarity to Ideal Solution) method provides the ranking of alternatives depending on their performances with reference to a set of criteria and the importance that such criteria have according to different kinds of judgment. In general, a multi-criteria decision problem consists of determining the optimal alternative *"A"* among a discrete set of m alternatives *ai*, (I = 1, 2,..., m), which are evaluated with respect to a set of n criteria Cj, (j = 1, 2,..., n) formulated in a matrix format. The TOPSIS method is based on the following principle: "the best alternative should have the shortest distance from the positive ideal solution in geometrical sense and the longest distance from the negative ideal solution" (Wang, Jing, Zhang, & Zhao, 2009).

The procedure of TOPSIS can be expressed in a series of steps described in the following (Zanchi, Dattilo, Zamagni, Delogu, & Del Pero, 2021): The procedure of TOPSIS can be expressed in a series of steps described in the following (Zanchi et al., 2021):

1. Create a decision matrix $[A]_{m\times n}$ which shows performance of the m alternatives with respect to a finite set of n criteria (e.g., indicators).
2. Calculate the normalized decision matrix applying a specific equation to obtain normalized values. This process converts the various indicator dimensions into non-dimensional criteria.
3. Calculate the weighted normalized decision matrix$[V]_{m\times n}$. It is generated by multiplying the columns of the normalized indicators with the weights of criteria vector whose sum is equal to 1. The weights need to be calculated beforehand and are normally obtained using other methods such as AHP, which has been introduced before in this section, or others.
4. Determine the positive ideal $(A^{+})$and negative ideal solutions(A^{-}), applying a mathematical formula.
5. Calculate the distance measures from the positive ideal $S_i^{+}$and negative solutionS_i^{-}applying the formulas for the purpose.
6. Calculate the relative closeness coefficient C_{i+} to the ideal solution, applying a specific mathematical formula.
7. Rank the alternatives in decreasing order according to C_{i+} value; the best alternative is the one with the higher C_{i+}.

Table 49 shows an example of the application of TOPSIS to a fictional scenario in which 3 alternatives and different indicators under two sustainability domains are assessed (environmental and economic). The results shown relate to steps 1 and 2 above.

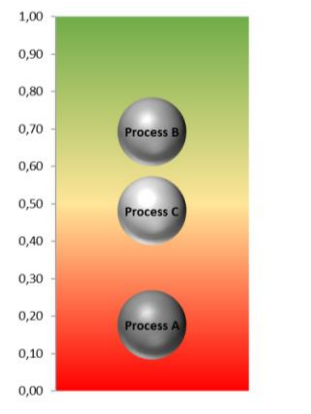
Table 49: TOPSIS: characterized and normalized impact assessment results for the 3 alternatives and the weights.

		Characterized results			Normalised results			
Indicator	Unit	Process A	Process B	Process C	Process A	Process B	Process C	Weights
Environ. indicator 1	a	2.00E-05	1.65E-05	7.03E-06	0.74	0.62	0.26	0.05
Environ. indicator 2	b	8.06E+00	1.20E+01	4.91E+00	0.53	0.79	0.32	0.08
Environ. indicator 3	c	5.88E-01	9.81E-01	1.20E-01	0.51	0.85	0.1	0.2
Environ. indicator 4	d	3.95E-07	8.59E-08	1.12E-08	0.98	0.21	0.03	0.03
Environ. indicator 5	e	1.80E-04	7.48E-05	3.84E-04	0.42	0.17	0.89	0.05
Environ. indicator 6	f	4.29E-03	5.31E-03	9.68E-03	0.36	0.45	0.82	0.05
Environ. indicator 7	g	1.63E-03	1.50E-03	2.39E-04	0.73	0.67	0.11	0.05
Economic indicator	€	2	10	5	0.18	0.28	0.44	0.5

After the calculation of the weighted normalized matrix (Step 3), the positive ideal and negative ideal solutions (Step 4), the distance measures to the positive and negative ideal solutions (Step 5) and the relative closeness coefficient (C_{i+}) (Step 6), the different alternatives assessed can be ranked using this value as a reference (Step 7), as shown in see **Table 50**.

Table 50: TOPSIS: Table showing the weighted normalized results and other parameters to calculate closeness coefficient for the 3 alternatives considered.

	Process Aw	Process Bw	Process Cw
Environ. indicator 1	3.70E-02	3.10E-02	1.30E-02
Environ. indicator 2	3.98E-02	5.93E-02	2.40E-02
Environ. indicator 3	1.02E-01	1.70E-01	2.00E-02
Environ. indicator 4	2.45E-02	5.25E-03	7.50E-04
Environ. indicator 5	2.10E-02	8.50E-03	4.45E-02
Environ. indicator 6	1.80E-02	2.25E-02	4.10E-02
Environ. indicator 7	3.65E-02	3.35E-02	5.50E-03
Economic benefit	9.00E-02	1.40E-01	2.20E-01
Si^+	0,1	0,39	0,14
Si^-	0,36	0,05	0,27
$Si^+ + Si^-$	0,46	0,43	0,41
C_{i+}	**0.79**	**0.1**	**0.66**



Legend to the table: w= weighted, Si^+ = Geometric distance to the best option, Si^- = Geometric distance to the worst option, Si+ + Si- = Total geometric distance, C_{i+} = Closenness coefficient. Green marked values indicate the positive ideal solution, red marked values indicate the negative ideal solution.

Its advantages, in relation to other methods, include that its mathematical operations and data could be easily handled and programmed since the number of steps remains the same regardless of the number of criteria. Also, when a high number of indicators are used, the mathematical operations and data could be easily handled in an Excel programmed workbooks; however, also specific software have been developed to support the use of TOPSIS (e.g. open-source software named PyTOPS from (Yadav, Karmakar, Kalbar, & Dikshit, 2019).

25.5 Annex E: Supplementary information on the ORIENTING land use impact assessment framework

Building on the EF recommendations as well as the findings of ORIENTING D1.1, the land use impact framework buildings on LANCA®, a framework owned and developed by Fraunhofer. It provides impact assessment calculations for five indicators of land using processes impacting soil quality (erosion, mechanical filtration, physicochemical filtration, groundwater regeneration and biotic production), and provides them as country average characterisation factors for the land use elementary flows of the ELCD, that are mandatorily applied in PEF studies. In ORIENTING, the CFs are updated and an advanced framework to allow for better representative impact calculation is developed and applied. For the update, the following major improvements have been applied:

- Improved aggregation approach (land cover based, only calculating the impact for the areas where specific land use activities are reported, compared to calculating the whole country in the old LANCA® version)
- Improved sealing factor (using a GIS input instead of assigning sealing factors to land use types)
- Erosion model update (optimising input data and model resolution)
- Including Soil organic carbon as new indicator
- Replacing biotic production by HANPP and excluding it from the SQI
- Including biodiversity

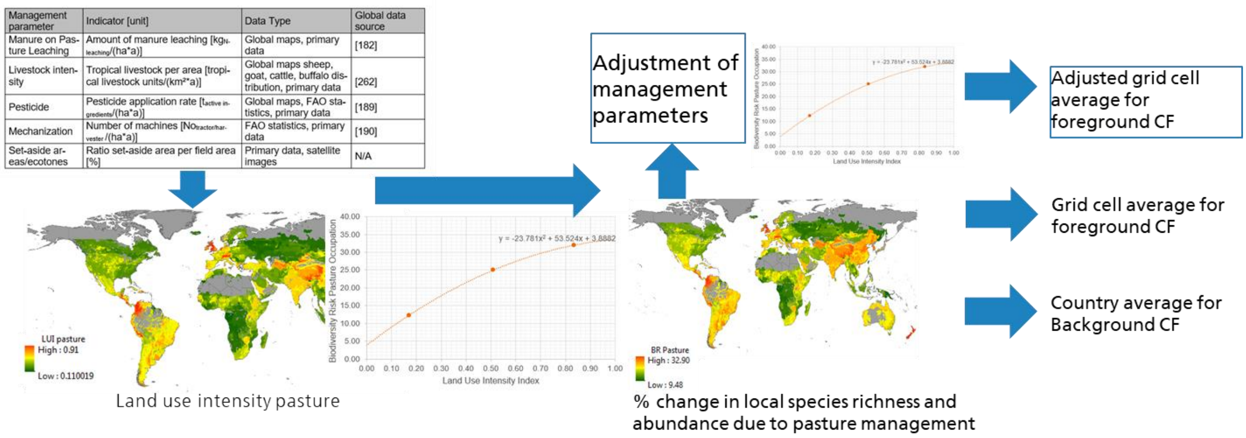


Figure 28: Multiscale Framework (Maier 2022, submitted)

The advanced framework builds on the multiscale framework as developed by Maier (2022, submitted) (see main text, **Figure 28**). It offers three levels of assessment detail. The first level corresponds to the current modelling practice, using country average characterisation factors on a distinct set of elementary flows. For the first level, the LCA practitioner chooses land use type, country and area (occupation+transformation). When further information is available or the impact of the process is identified as significant, a more detailed assessment can be performed, using either level 2 or level 3. In level 2, the same models and data as for level 1 are used, but instead of using a country average value, a geospecific characterisation factor can be used when the location of a process is known. If in addition to the location specific data on the soil or management practices are available, or if own models are used to calculate any of the LANCA® indicators, then in level 3 the input data of the LANCA® models can be modified as well, allowing to provide a characterisation representing the actual conditions on the field. **Table 51** provides an example of data needs and result specification for the three presented levels of specification. For the data collection on level three, a template will be provided in WP4.

Table 51. Examples of data needs and potential data sources for land use activities

Level description	Example of input data requirements	Example for input data	Potential data sources
Level 1 – country average background CF	Land transformation: area, country, land use type	Transformation from grassland (regionalized, Spain): 44m2 Transformation to arable (regionalized, Spain): 44m2	Area either from primary data or from secondary sources such as statistics (e.g. from FAO) Land use type selection using the available flows as defined in Koellner et al. (2013)
	Land occupation: area x time, country, land use type	Occupation, Arable (regionalized, Spain): 41m^{2}* year	Occupation also considering growth period Land use type selection using the available flows as defined in Koellner et al. (2013)
Level 2 – georeferenced average CF	Land transformation: area, geolocation, land use type	Transformation from grassland: 44m2 (42.758341, -1.7641742 as geolocation flow property) Transformation to arable: 44m2 (42.758341, -1.7641742 as geolocation flow property)	Additional to level 1: specific location of area under consideration, either from primary data or from land cover maps (e.g., COPERNICUS, USGS or others)
	Land occupation: area x time, country, land use type	Occupation, Arable: 41 m^{2}* year (42.758341, -1.7641742 as geolocation flow property)	

Level 3 – local level CF (foreground system)	Land transformation: area, geolocation, land use type Additional specification of available input parameters for all land use impact assessment models (e.g. intensity and management practices based on conservation evidence database for biodiversity or soil properties for erosion resistance)	Transformation from grassland: 44m2 (42.758341, -1.7641742 as geolocation flow property) Transformation to arable: 44m2 (42.758341, -1.7641742 as geolocation flow property, sealed area share as management practice flow property)	Additional to level 2: Primary data on management practices and primary data on soil properties (field level).
	Land occupation: area x time, country, land use type Same additional specifications apply for occupation	Occupation, Arable: 41 m^2 * year (42.758341, -1.7641742 as geolocation flow property, sealed area share as management practices flow property)	

25.5.1 Erosion Resistance

The capability to resist erosion treated as an essential indicator in the LANCA®(Bos et al. 2016). The LANCA® characterisation factors consider topographical and climatic variables, soil texture, as well as management of the land (Bos et al. 2016). The soil properties were considered that originated from the revised version of Universal Soil Loss Equation (RUSLE) model (Renard et al. 1991). These parameters delivered from the Harmonized World Soil Database (HWSD) and averaged per country (Bos et al. 2016). The land management parameters include as a crop management factor based on Kuok et al. (2013) and a conservation practice factor based on several literature sources (Trahan and Ouyang 2002;Kuok et al. 2013; Panagos et al. 2015) and are complemented by internal expert estimations (Bos et al. 2016). The parameters and calculation procedure for erosion resistance are depicted in **Figure 29**, input data for erosion resistance presented in **Table 52**.

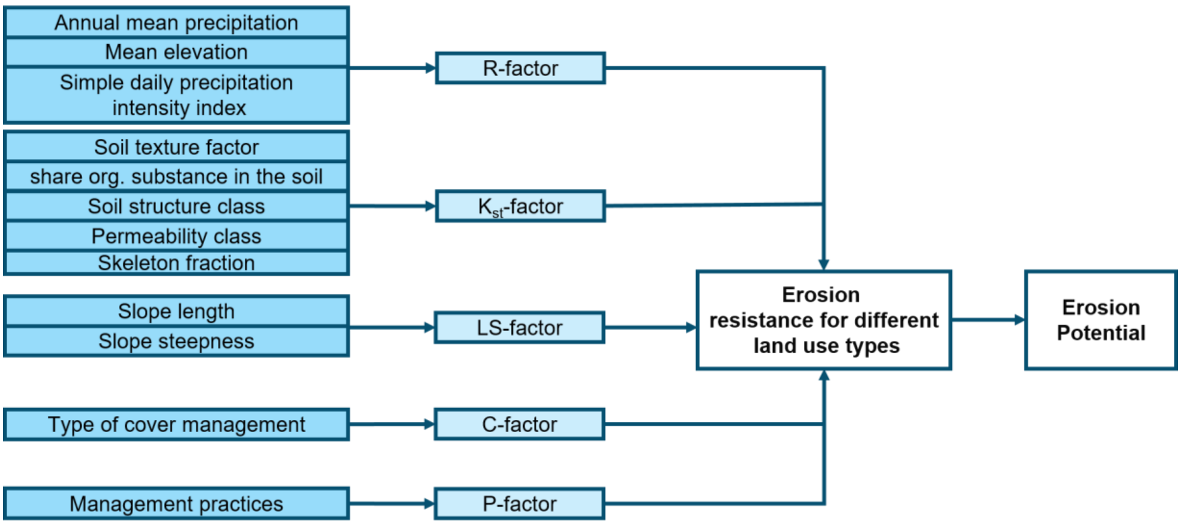


Figure 29: Input parameters for the calculation of erosion resistance (Bos et al. 2020)

Table 52 Data input for erosion resistance

Input parameter	Reference	Description	Unit	Other input sources
R factor	Borelli et al	Rainfall-runoff erosivity	MJ mm / h ha yr	Own calculation for R factor based on Annual mean precipitation, elevation And simple daily precipitation intensity index (SDPII) is possible
K_{st} factor	Borelli et al	Soil erodibility	Mg h / MJ mm	Own calculation possible based on soil texture, org substance share, soil structure, permeability and skeleton fraction
LS factor	Borelli et al	Slope length and steepness factor	-	Own calculation possible based on elevation maps
C-factor	Multiple references	Land cover and management factor	-	Can be calculated directly for foreground systems or chosen from literature
P-factor	-	Conservation practice factor	-	Not applied, can be included for foreground systems (maps for Europe are available)

Sealing factor	Elvidge et al 2007	Sealing factor	%	Can be derived from remote sensing or primary information

25.5.2 Mechanical Filtration

The abilities of water permeability of soil are different by the land use activities (Bos et al. 2016). The amount of water that can be infiltrated into a given soil can be explained as the Mechanical filtration (Marks et al. 1989; Klink and Leser 1988; Bastian and Schreiber 1999; Baitz 2002). The characterisation factor in Mechanical Filtration is so called infiltration-reduction potential in LANCA®, that is calculated by the parameters soil type, depth to the groundwater table and a sealing factor according to Beck et al. (2010). The parameters and calculation process for mechanical filtration are depicted in **Figure 30**, input data is presented in **Table 53**

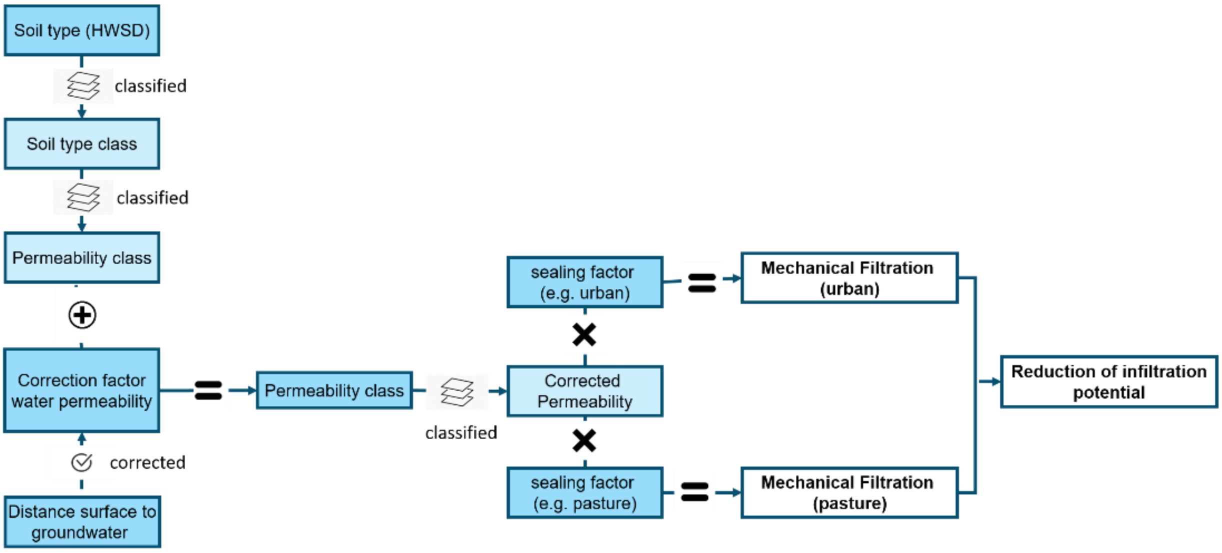


Figure 30: Calculation of mechanical filtration (Bos et al. 2020)

Table 53 Data input for mechanical filtration

Input parameter	Reference	Description	Unit	Other input sources
Soil type	HWSD	Clay, silt and sand content of soil and assigned soil texture class	%	Primary data on soil composition
Depth to groundwater table	Fan et al. 2013		Cm/d	Primary data on groundwater table
Sealing factor	Elvidge et al 2007	Sealing factor	%	Can be derived from remote sensing or primary information

25.5.3 Physicochemical Filtration

The physicochemical filtration capacity of a soil takes into account the amount of absorbable cationic pollutants to fix and exchange cations (Bos et al. 2016). The physicochemical filtration-reduction potential is calculated in LANCA® which refers effective cation exchange capacity by using information on soil properties and surface sealing (Bos et al. 2016). Soil classification is following the Environmental Atlas Berlin (Arbeitsgruppe Bodenkunde 2013) and the Federal Institute for Geosciences and Natural Resources(Bundesanstalt für Geowissenschaften und Rohstoffe 2005). Since this indicator is also mainly influenced by specific soil properties and the sealing factor, hence in the current system it is mainly the sealing factor that determines differences between management practices (Horn et al. 2022). The calculation steps are depicted in **Figure 31**, input data is presented in **Table 54**.

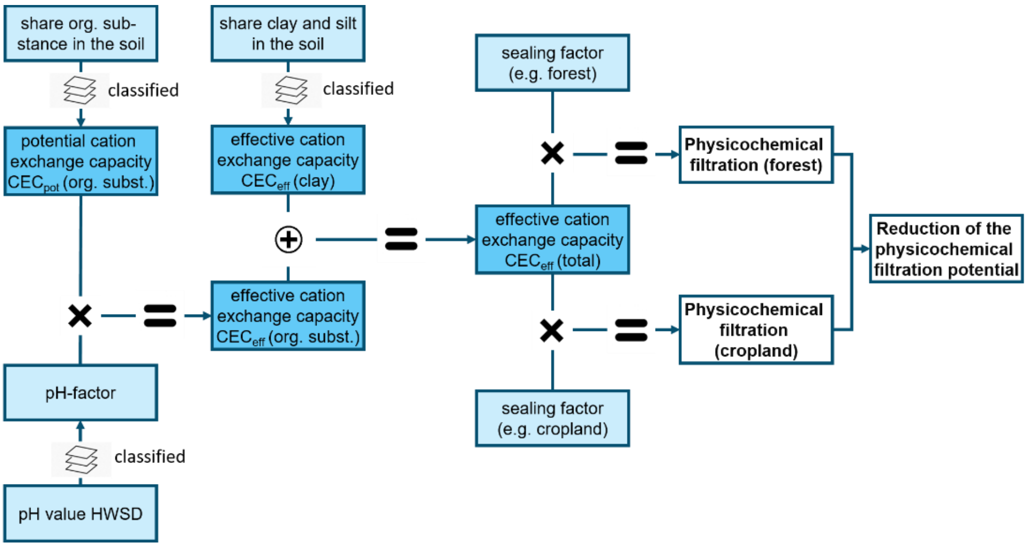


Figure 31: Calculation of physicochemical filtration (Bos et al. 2020)

Table 54: Data input for physicochemical filtration

Input parameter	Reference	Description	Unit	Other input sources
Soil texture clay	HWSD	Share of clay content in soils	-%	Primary data on soil composition
Soil texture silt	HWSD	Share of silt content in soils	-%	Primary data on soil composition
Humus content	HWSD	Humus content of soils	%	Primary data on soil composition
pH value	HWSD	pH value of soils		Primary data on pH value
Bulk density	HWSD	Bulk density of soils	-%	Primary data on bulk density
Sealing factor	Elvidge et al 2007	Sealing factor	%	Can be derived from remote sensing or primary information

25.5.4 Groundwater Regeneration

The ability of soil to regenerate groundwater sources describes the potential of regenerating groundwater in an area. The existing surface vegetation, the climate zone and the structure of the soil are crucial indicators (Bos et al. 2016). Sealing or the modification of vegetation activities influence the infiltration of rainwater and the associated evapotranspiration. The characterisation model for groundwater regeneration is the runoff-corrected groundwater regeneration rate, expressed in millimetres per year (Bos et al. 2016). For this purpose, the mean annual precipitation (Hijmans et al. 2005; Hijmans et al. 2015) and the evapotranspiration (Allen 1998; Mu et al. 2011) in an area are determined. The runoff is calculated with runoff coefficients based on Williamson and Klamut (2001) and with the information on soil properties, slope and type of land use (Bos et al. 2016). The steps for calculating the indicator groundwater regeneration are depicted in **Figure 32**, and the input data is presented in **Table 55**.

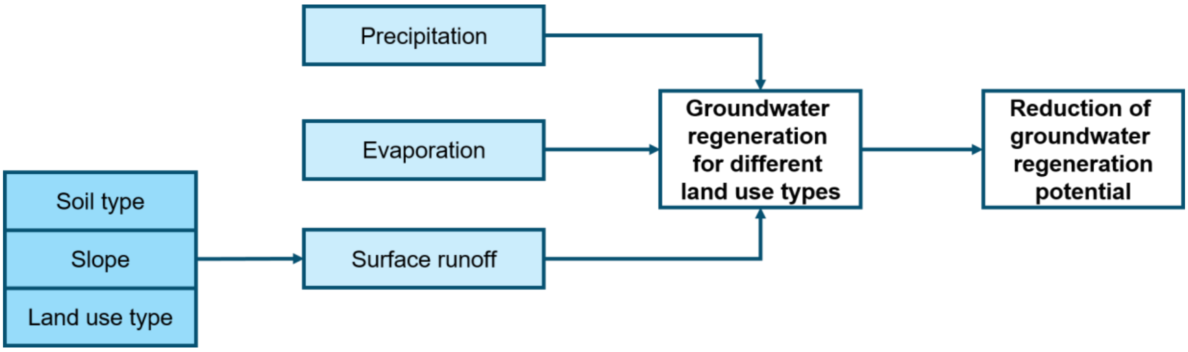


Figure 32: Calculation of groundwater regeneration (Bos et al. 2020)

Table 55: Data input for groundwater regeneration

Input parameter	Reference	Description	Unit	Other input sources
Precipitation	WorldClim 2.1 (2020)	Average precipitation per year	-mm/a	Primary data
Evaporation	Etact, FAO	Average evaporation per year	-mm/a	Primary data
Soil type	HWSD	Share of clay content	-%	Primary information on clay content in soils
Slope	IIASA/FAO	Slope in an area	-%	Primary data
Sealing factor	Elvidge et al 2007	Sealing factor	%	Can be derived from remote sensing or primary information

25.5.5 Biotic resources - Human appropriated net primary production

To calculate CF for HANPP in forestry, (Alvarenga et al. 2015) differentiated between (1) the NPP of PNV that produced biomass by plants in certain circumstances under no land use activity (so called NPP_{pot}) and (2) remaining NPP of current land use with or without after harvest (so called NPP_{act}). The difference between NPPs and NPP of PNV denote as $\Delta HANPP_{luc}$. As the first step, HANPP map delivered from the NPP maps (e.g., (Imhoff et al. 2004). The different land use regimes (e.g., Kehoe et al. 2017) maps are multiplied by obtained HANPP map to calculate specific HANPP values for each land use flow. For the midpoint CF for HANPP, the delta between the natural potential NPP and actual NPP per land use flow is calculated. To aggregate the CF within each country for the background calculation, a country specific average CF value and type of land use is calculated, excluding areas where the specific land use type does not occur, similar to the approach of (Maier et al. 2019). The calculation steps for the indicator change in NPPs are depicted in **Figure 33**.

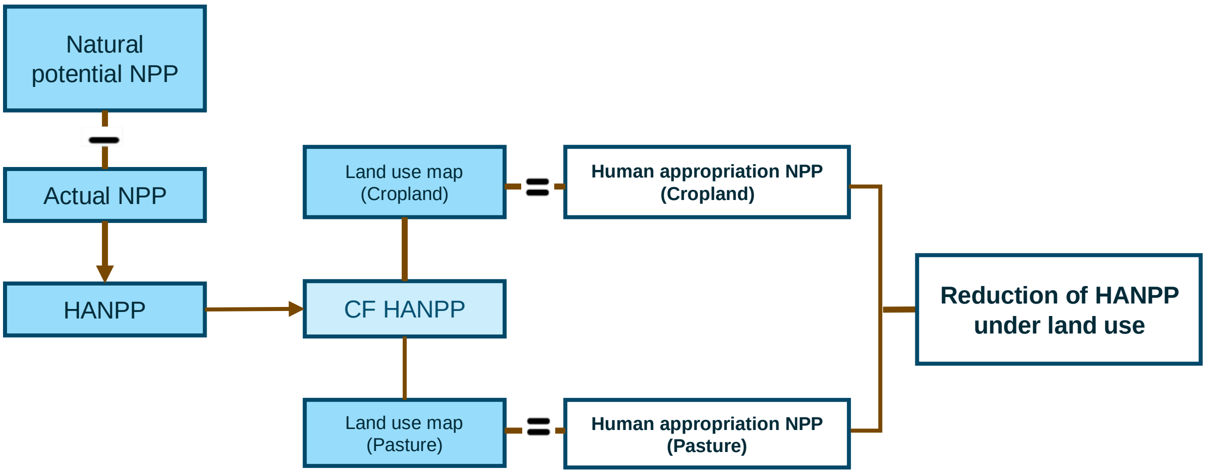


Figure 33: Calculation of HANPP for LANCA®

25.5.6 Soil organic carbon

Based on de Laurentiis et al. (submitted, 2022) SOC CFs are calculated by matching the IPCC factors for SOC inventory changes under different land use regimes and in different climate zones and soil types with the existing EF land use flow list in the LCA. Maps for each land use flow are derived from the matching table and IPCC SOC change factors per climate and soil type zone and land use flow are generated (Calvo Buendia E. et al. 2019). These maps are then multiplied by the SOC stock map (under natural vegetation) to obtain specific results for the SOC content for each land use flow. To obtain the CFs, the delta between the SOC content under natural vegetation and the SOC content under each land use flow is calculated. To aggregate the CF per country for the background database, an average CF value per country and type of land use is calculated, masking out all areas where the specific land use type does not occur, similar to the approach of (Maier et al. 2019).

The calculation steps for the indicator change in soil organic carbon are showed in **Figure 34** and the input data is presented in Table 56

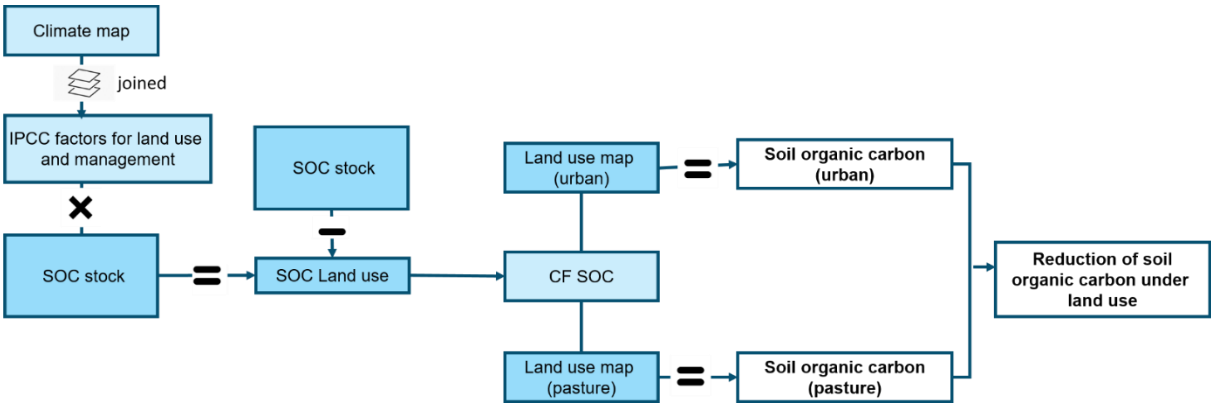


Figure 34: Calculation of CFs for soil organic carbon

Table 56 Data input for change in soil organic carbon

Input parameter	Reference	Description	Unit	Other input sources
SOC stock	IPCC (2019)	Potential carbon stock	Kg/C per ha	Could be provided with IPCC tier 2 or 3 models
Climate-soil type zone	Hiederer et al. (2010), IPCC (2006), IPCC (2019)	Information on climate zone and soil type	-	Not necessary if higher IPCC tier models are used
SOC change factor	IPCC (2019)	Values of change in SOC stock under different land management regimes	Kg/C per ha	Could be provided with IPCC tier 2 or 3 models

25.5.7 Biodiversity

The BioMAPS method is a multi-scale method that accounts for different spatial and organizational scales. For the analysis of global and local biodiversity risks, this method takes into account land use activities in proactive and reactive conservation schemes as well as specific biodiversity impacts due to the land use type, intensities and management parameters. For the analysis of regional impacts, local biodiversity risks are scaled up to a broader landscape context. Herein, all land use types and their intensities that are part of the landscape are considered. Therefore, a landscape development index (LDI) is calculated in a GIS environment to derive the biodiversity risks at the landscape level. The LDI contains the shares of the individual land use types in the landscape as well as their land use intensities and the associated effects on biological diversity (Maier et al. 2019, Maier & Horn 2020, Maier submitted).

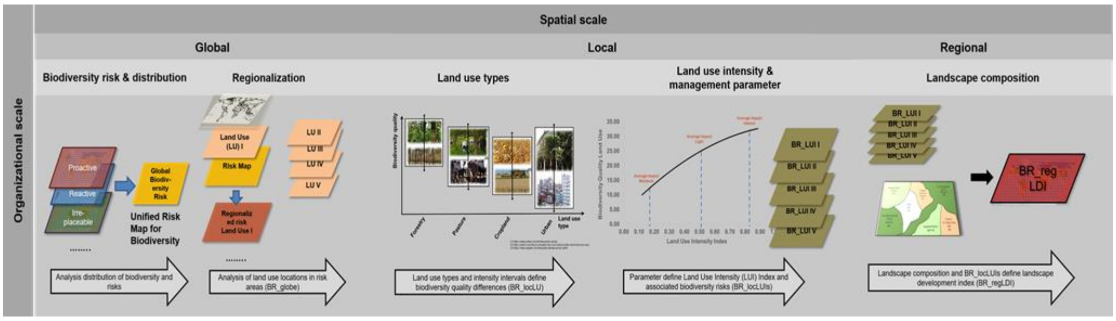


Figure 35 Three levels of details applied for biodiversity assessment in LANCA framework

It is applied using the abovementioned three levels of details, and can be applied consistently within the LANCA® framework (Figure 35). The characterization (both the country average CFs and the geospecific levels) include the local impact as GIS based average including through the Intensity score based on management practices, the regional average through a normalized landscape composition as well as the global impact based on conservation schemes aggregated in normalized form:

L * R * G = total Biodiversity impact

Furthermore, the following subindicators are provided for sensitivity analysis and detailed investigations:

L * R * G_abu = Biodiversity impact on abundance

L * R * G_sr = Biodiversity impact on species richness

(L * R * G_scheme = Biodiversity impact on specific scheme (most likely not available for case studies))

Data input for biodiversity indicator is described in **Table 57**.

Table 57: Data input for biodiversity

Input parameter	**Reference**	**Description**	**Unit**	**Other input sources**
Management practices	Multiple references mapped to conservation evidence databases entries	Either MP or Intensity	-multiple units	Primary data on MP
Land Use Intensity	Intensity calculated based on MP, scaling based on Newbold et al (Predicts)	Either MP or Intensity	- (between 0 and 1 for intensity)	Normalized primary information on land use intensity
Landscape intensity and composition	Own model based on Maier (2022, submitted) using data of Hurtt et al. 2011	Share of land use types within a landscape as well as land use intensity of individual patches	% (between 0 and 1 for intensity)	Normalized primary data on landscape composition

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