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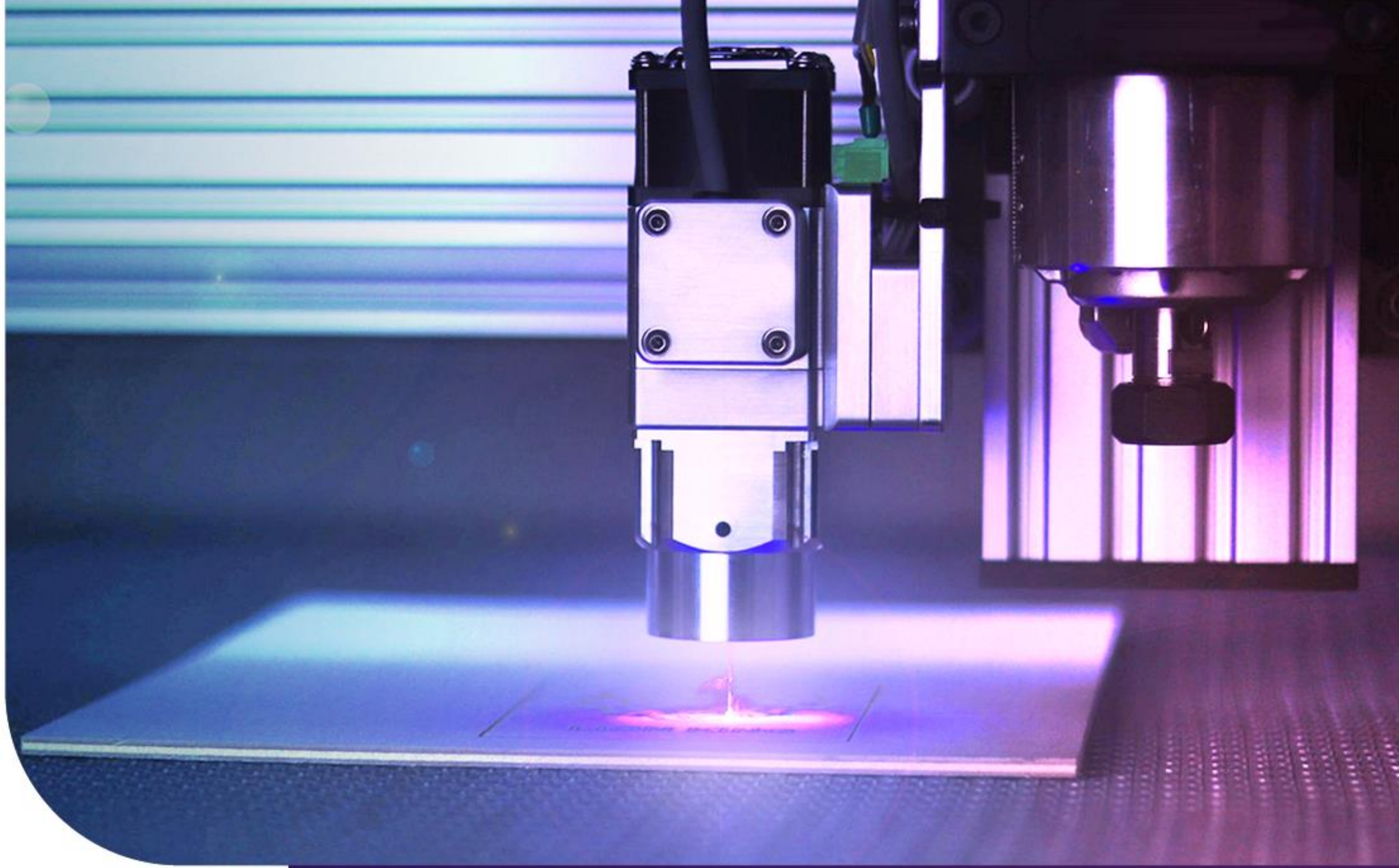

LCA Workshop – Session 1
Theoretical Introduction to LCA

21st May 2024

3drivers QUADRANTE · aimen CENTRO TECNOLÓGICO · ATS · cailabs SHAPING THE LIGHT · UNIVERSITÀ DEGLI STUDI DI PALERMO · diamoutils · IMA AUTOMATION · DePuy Synthes · University of HUDDERSFIELD Inspiring tomorrow's professionals · COSMOS THRACE · Prima Additive · ROBUST AO · SYNOVA · TOFAŞ · EWF · mtc

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3Drivers Team

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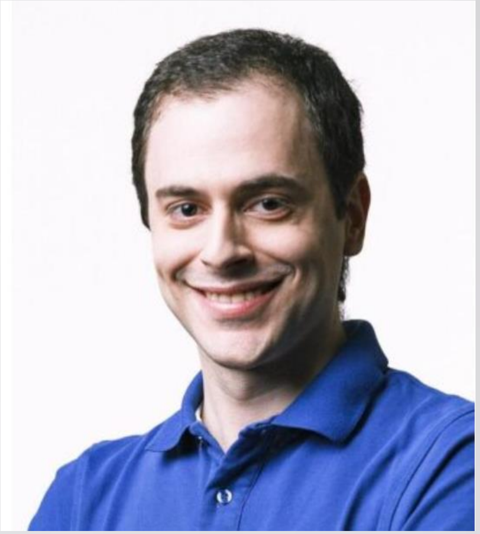

João Duarte

Francisco Reis

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Initial Remarks

- Training session will be recorded for dissemination purposes
- Any restricted content will be edited out
- Each partner will have the opportunity to check the recording and indicate if there are some parts to remove, prior to publication on Flash social networks
- EWF will gather the partners´ recommendations and edit in accordance
- The recording will be divided and published in short videos, corresponding to LCA theoretical contents agenda
- Case study sessions will not be recorded

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AGENDA

14h30 – 14h40	Workshop objectives and outline
14h40 – 15h20	Introduction to LCA
15h20 – 15h30	(Short break)
15h30 – 16h20	LCA example
16h20 – 16h30	Final remarks

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Workshop goals

Objectives

- Understand **what LCA is** and how it is conducted
- Understand the **type of data** needed to conduct an LCA
- Get to know existing **tools** to conduct an LCA
- Gather initial insights of the **use cases** for LCA within the project

You will learn to

- Define the **objective and scope** of an LCA
- Define the **functional unit**
- Develop **data inventories** for materials and processes
- Quantify the **environmental impacts**
- Interpret the **results**
- Understand why it is important to **take a whole-life approach** to calculate environmental impact
- **How to apply LCA to the use cases**: e.g., what is the stage with the greatest impact and possible mitigation strategies

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Getting Acquainted with LCA

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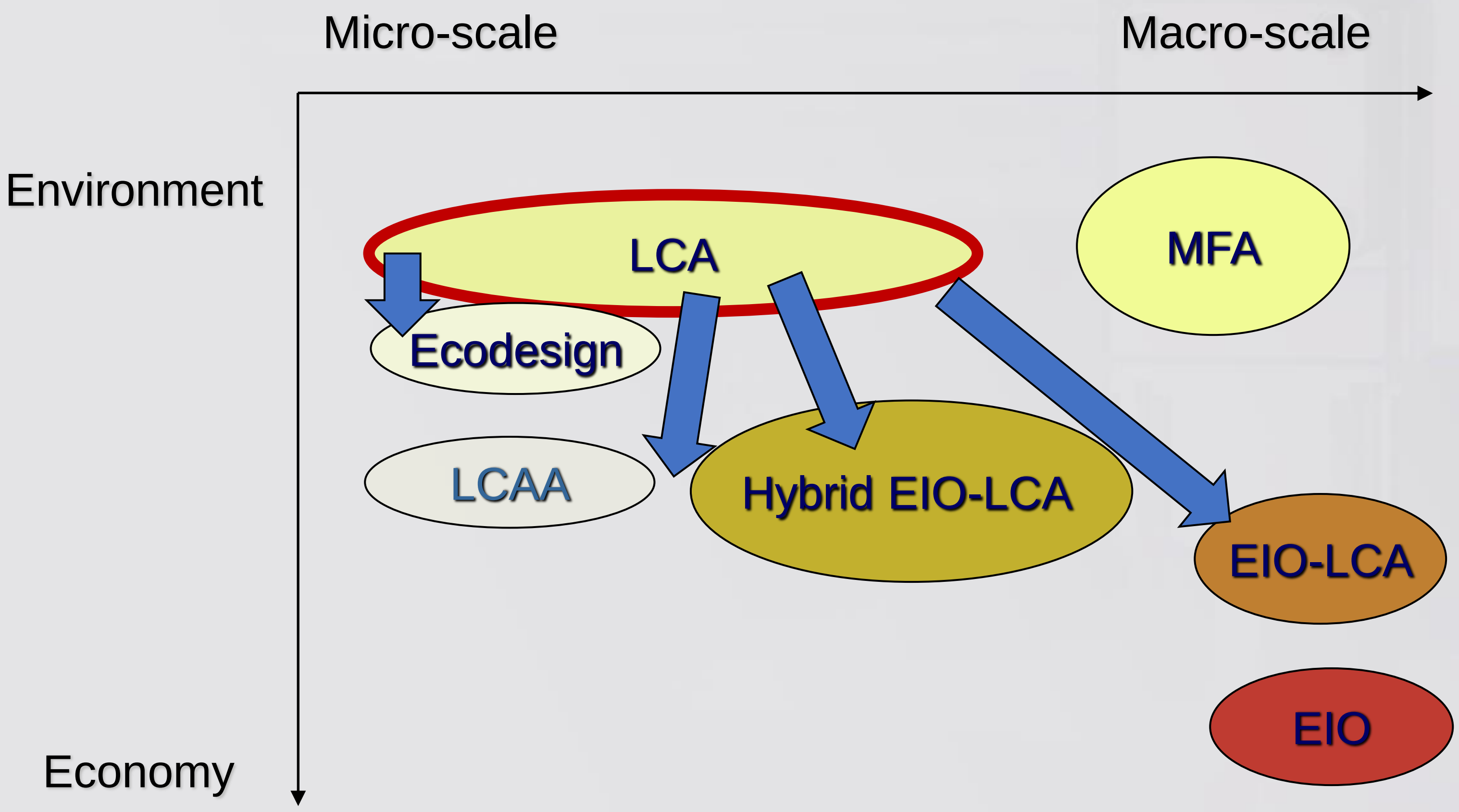
LCA within Industrial Ecology tools



- One of the Industrial Ecology tools
- Constitute the base for other methodologies
  - LCA based methodologies, sometimes called “process based LCA”
- Perspectives
  - “Cradle to grave”
  - “Cradle to gate”

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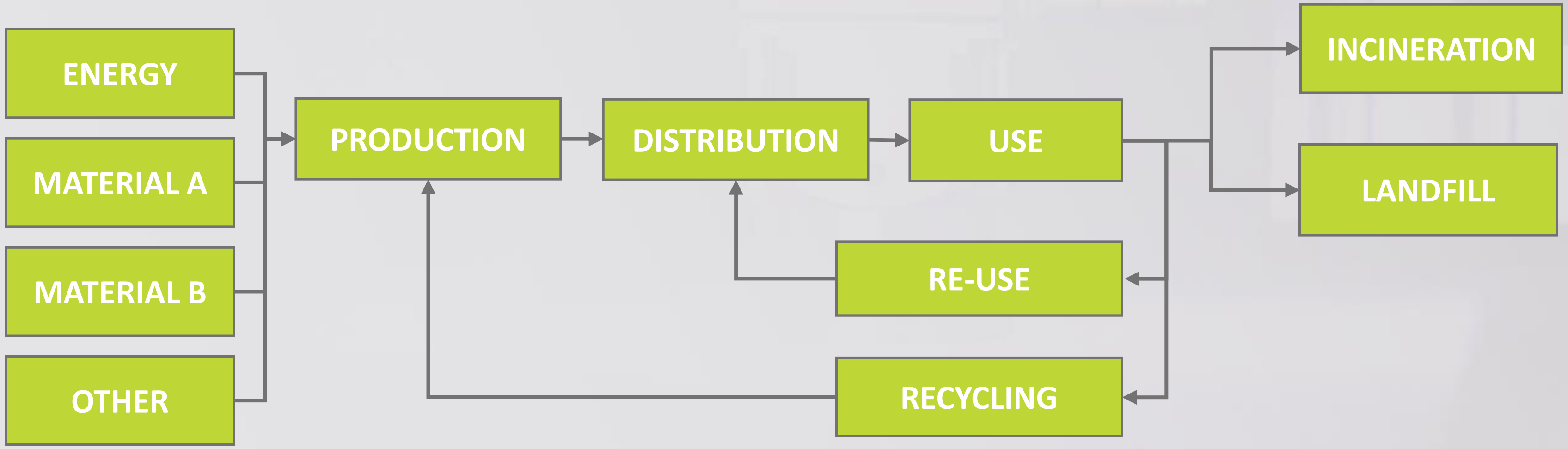
Definitions of LCA

Definition of Life Cycle: "Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal"

Definition of Life Cycle Assessment (LCA) according to ISO 14040 (2006): "Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"



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Standards

Normative references – two procedural LCA standards

- ISO 14040 – Principles and framework (2006)
- ISO 14044 – Requirements and guidelines (2006)

Other standards with relevance to LCA

- ISO 14025 – Environmental product declaration (2006)
- ISO 14064 – Quantification and mitigation of greenhouse gases (2006)

Important aspects of LCA ISO standards

- LCA cannot be certified, as in ISO 14001
- LCA is a relative methodology due to its nature
- Recommendations and guidelines are goal and scope dependent (e.g., considered processes, geographical representativeness

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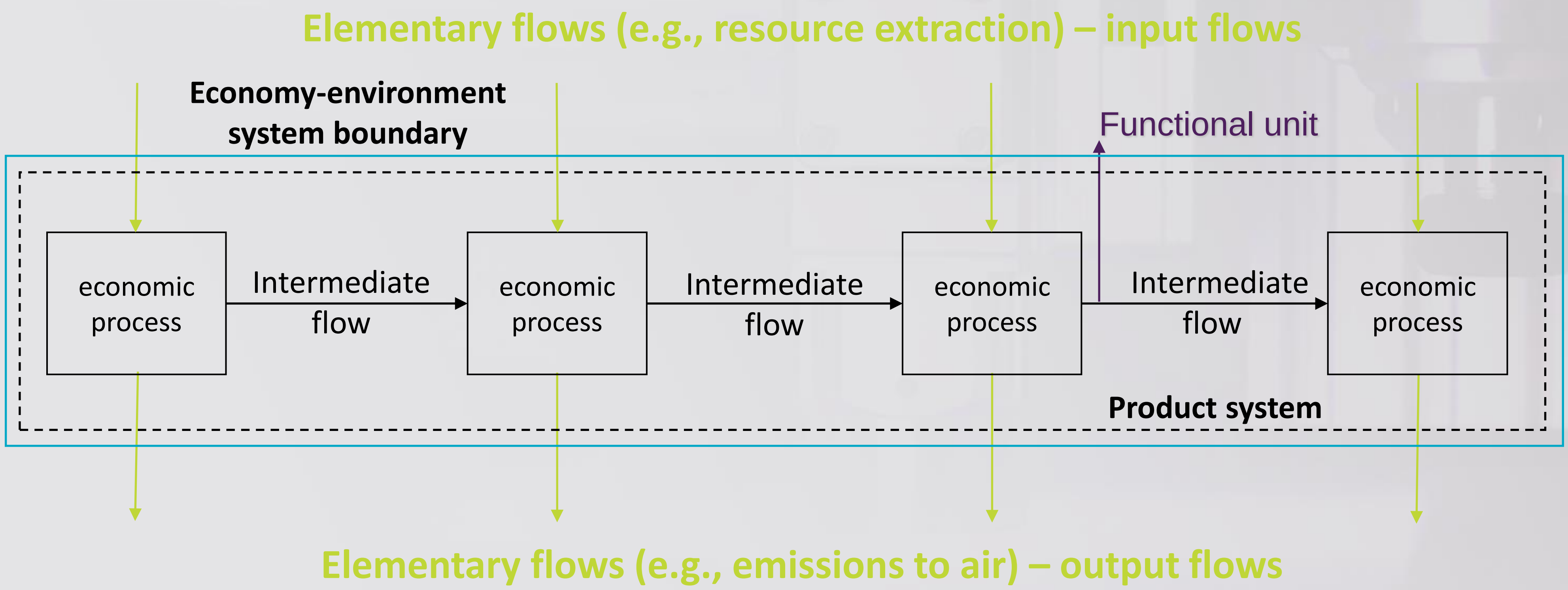
LCA terminology (ISO 14040:2006)



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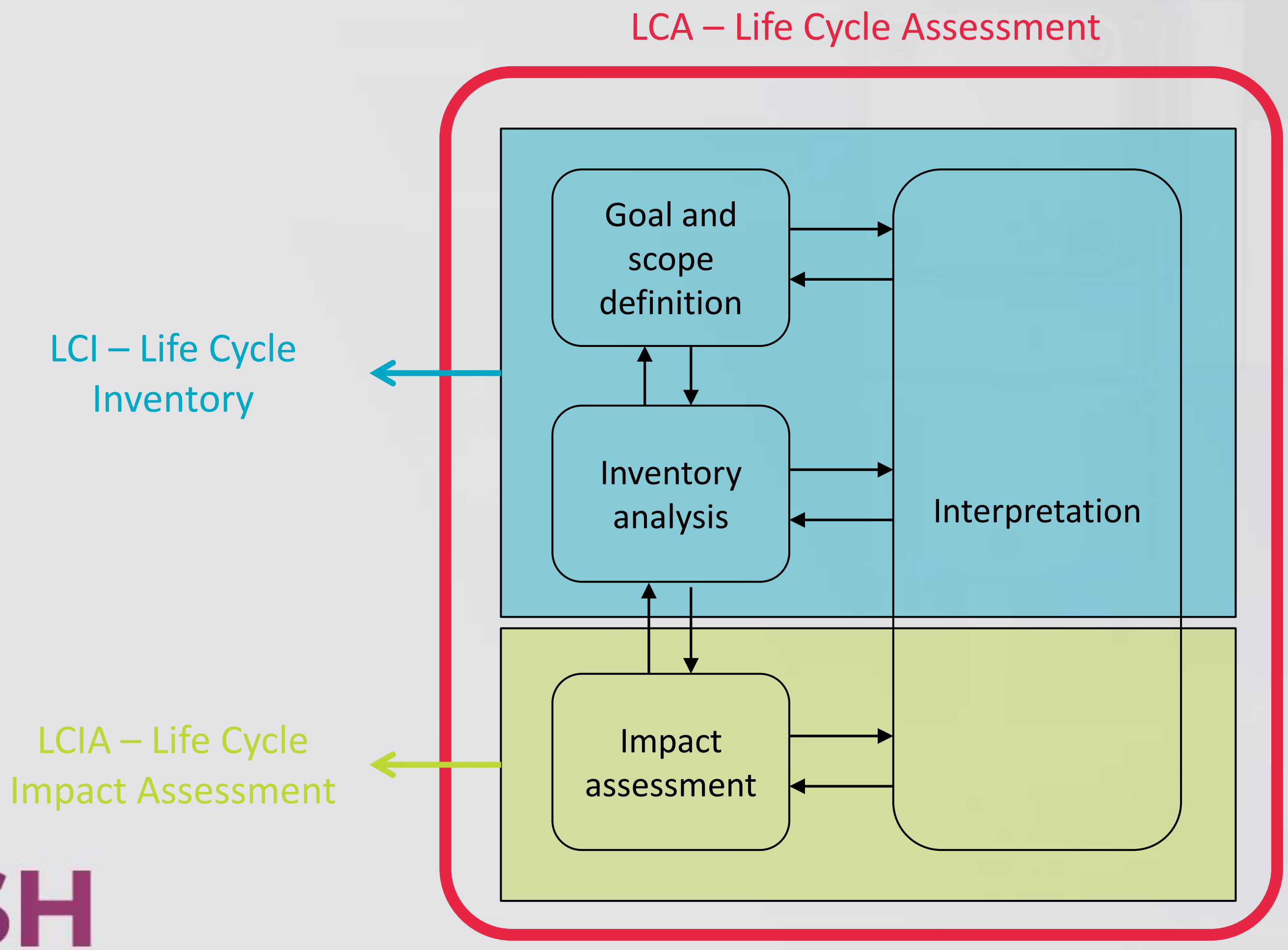
LCA main stages



Fundamental concept always associated

<u>Product (Service) - Functional Unit</u>

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LCA main stages

- Goal and scope in which the reasons for the study, the intended audience, the functional unit, etc. are defined
- Inventory in which the data describing the system is collected and converted to a standard format to provide a description of the physical characteristics of the system of interest
- Impact assessment in which the physical flows are translated into potential environmental impacts
- Interpretation in which the results are evaluated and interpreted in context of their significance, uncertainty, etc.
- Improvement in which the system is modified in some way to reduce or ameliorate the observed environmental impacts

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Principles of LCA

- Life cycle perspective: Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided
- Environmental focus: Address the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA for more extensive assessments
- Relative approach and functional unit: Relative approach, structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit
- Iterative approach: Approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results
- Transparency: Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCA, in order to ensure a proper interpretation of the results
- Comprehensiveness: Considers all attributes or aspects of natural environment, human health and resources. By considering all attributes and aspects within one study in a cross-media perspective, potential trade-offs can be identified and assessed.

According to ISO 14040 (2006)

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Principles of LCA

Scientific approach

- Decisions within an LCA are preferably based on natural science
- If this is not possible, other scientific approaches (e.g., from social and economic sciences) may be used or international conventions may be referred to
- If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices

When LCA could be useful

Internally

- Compare environmental impacts of different products with the same function
- Compare a product environmental impact with reference to a standard
- Identify the environmentally most dominant phases in a product life cycle
- In eco-design, identify opportunities for improvement
- Help the company internal strategy definition

Externally

- Marketing
- Information and education
- Lobbying
- Labeling purposes

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When LCA should not be used

- Compare environmental impacts of products with distinct functionalities or uses
- It is not a substitute for location dependent assessments (e.g., EIA – Environmental Impact Assessment), but can be complementary
- It is not a substitute for other types of assessments such as risk analysis or strategic assessments, but can help support them

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Some LCA resources

http://eplca.jrc.ec.europa.eu/	EU website on LCA & LCI database
http://eplca.jrc.ec.europa.eu/ELCD3/	EU LCA Database
http://www.lcacenter.org/	American Center for LCA
https://www.lifecycleinitiative.org/	UNEP/SETAC life cycle initiative
http://www.nrel.gov/lci/	US LCI Database
http://www.ecoinvent.org	Ecoinvent - LCI data
https://simapro.com/	SimaPro website
http://www.openlca.org/	openLCA
https://nexus.openlca.org/	openLCA Nexus

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LCA stages

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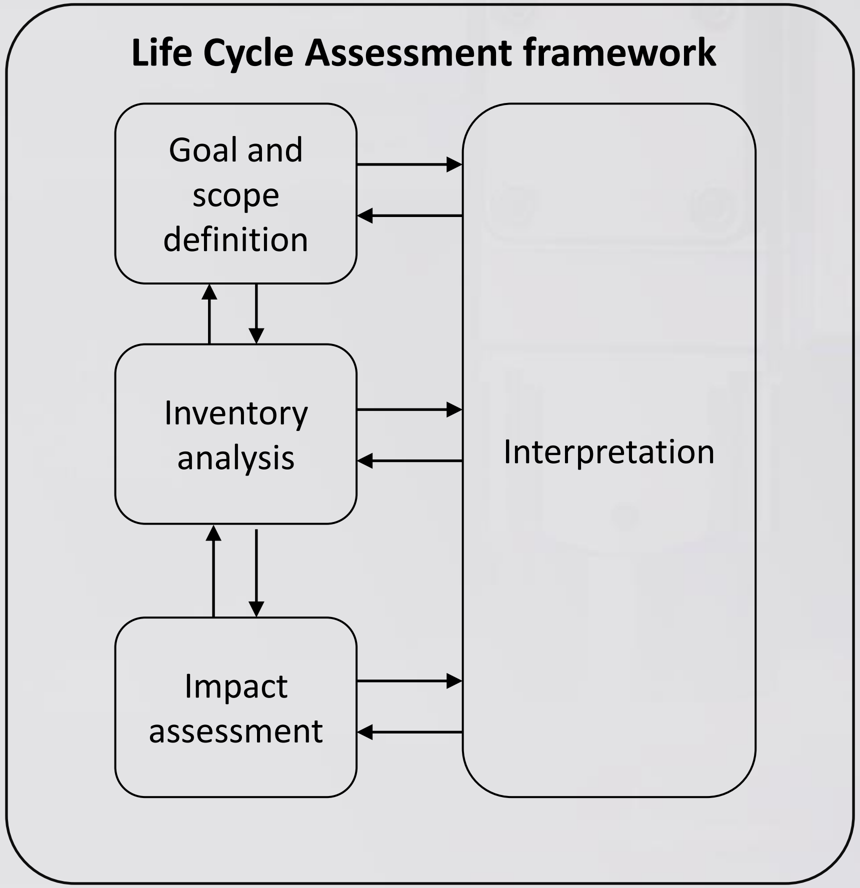
Overview of LCA stages



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1. Goal and Scope

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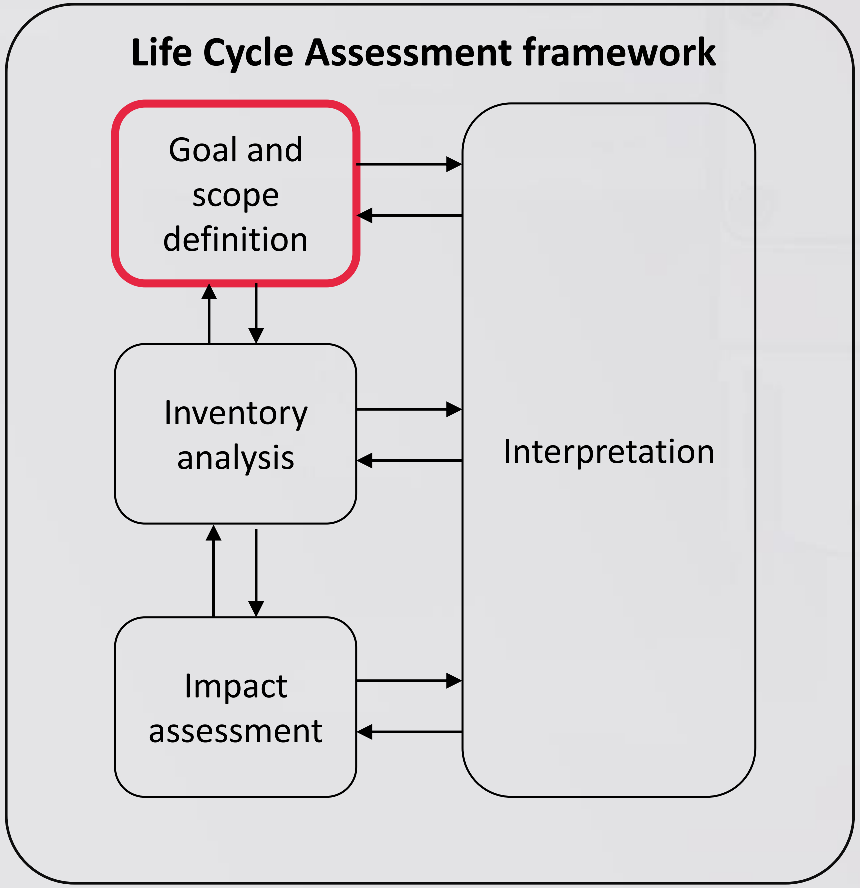
LCA step 1 – Goal and Scope Definition



- The purpose of the analysis
- The uses of the results
- The study stakeholders
- Scope

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Goal definition

ILCD Handbook establishes 4 types of "goals" – A, B, C1, C2

<table>
<tr><td rowspan="4">Decision support?</td><td rowspan="3">Yes</td><td colspan="2">Kind of process changes in background systems / other systems</td></tr>
<tr><td>None or small-scale</td><td>Large-scale</td></tr>
<tr><td>Situation A

"Micro-level decision support"</td><td>Situation B

"Meso/macro-level decision support"</td></tr>
<tr><td>No</td><td colspan="2">Situation C

"Accounting"

(with C1: including interactions with other systems, C2: excluding interactions with other systems)</td></tr>
</table>

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Scope definition

- Product system to be studied
- Functions of the product system or, in the case of comparative studies, the systems
- Functional unit
- System boundary (process included) – foreground and background processes
- Allocation procedures
- Methodology of impact assessment, impact categories selected and subsequent interpretation to be used
- Data requirements (temporal, spatial and technological coverage)
- Assumptions
- Limitations
- Type of critical review, if any
- Type and format of the report required for the study

- The scope should be **sufficiently well defined** to ensure that the depth and detail of the study are compatible and sufficient to address the stated goal

- Nevertheless, the initial goal and scope definition (LCA step 1) is to be **revised iteratively**, according with intermediary and final results, as well with choices made during the LCA (e.g., allocation made in specific process)

- **Document, Document, Document…**

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2. Inventory Analysis

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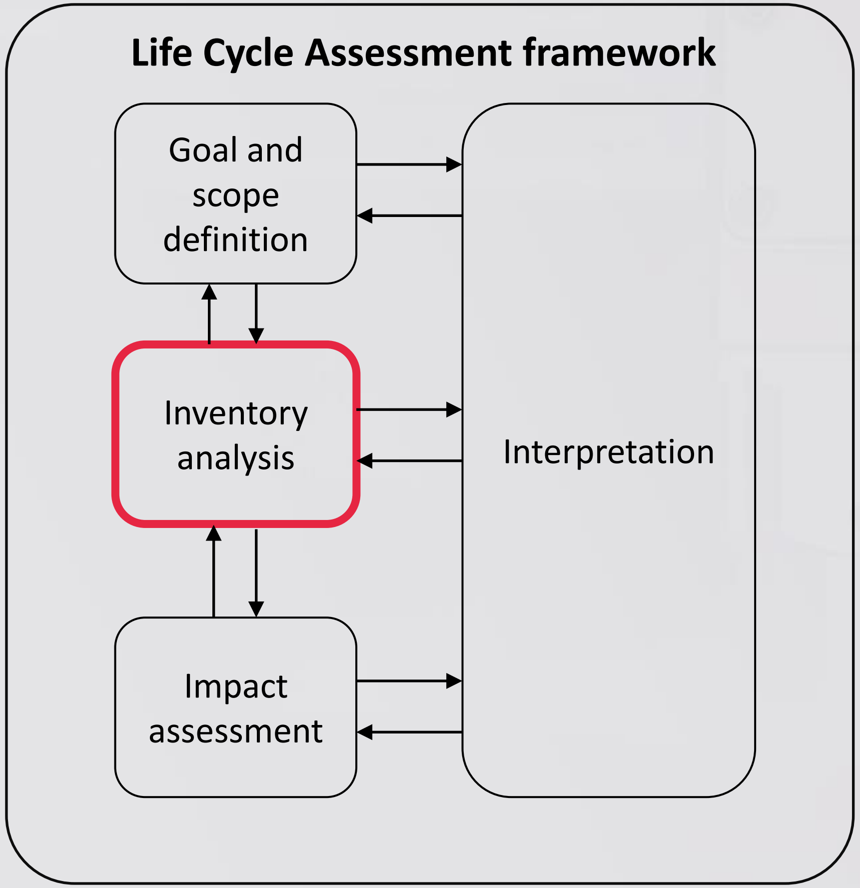
LCA step 2 – Inventory analysis



- **LCI – Life Cycle Inventory Analysis**

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Inventory analysis

- The inputs and outputs of all life-cycle processes must be determined in terms of material and energy
- Produce a process tree or a flow-chart classifying the events in a product life-cycle which are to be considered in the LCA, plus their interrelations
- Next, start collecting the relevant data for each event: the emissions from each process and the resources (back to raw materials) used
- Establish (correct) material and energy balance(s) for each process stage and event

Example

Resources		Atmospheric emissions		Water emissions	
Hydroelectric energy	594,0 MJ	CO2	748 000,0 g	Residual water	1,7 m3
Natural gas (vol)	14,5 m3	SOx	2 690,0 g	Cl	63 900,0 g
Uranium	4,8 g	NOx	2 310,0 g	Inorganic subst.	39 500,0 g
Process water	1,0 m3	VOC	1 640,0 g	Suspension solids	5 030,0 g
Glass cullet	625,0 kg	Dust	1 300,0 g	Sulphates	627,0 g
Sand	253,0 kg	CO	787,0 g	Oils	283,0 g
Fuel oil	183,0 kg	Methane	781,0 g	VOC	74,0 g
Limestone	110,0 kg	HCl	67,9 g	Metallic ions	59,3 g
Rock salt	108,0 kg	Pb	44,6 g	NH4+	29,3 g
Calcium carbonate	80,5 kg	Ammonia	38,2 g	Ba	24,3 g
Coal	49,1 kg	HF	15,8 g	Fe	23,6 g
Rock	35,5 kg	Metals	4,2 g	Al	20,3 g
Anthracite	13,0 kg	CxHy aromatic	3,8 g	Ntot	9,9 g
		N2O	2,0 g	COD	9,6 g
		Benzene	1,9 g	CxHy aromatics	7,8 g
		Ni	0,4 g	Nitrates	6,3 g

Data

Data collection

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs
- Products, co-products and waste
- Emissions to air, discharges to water and soil
- Other environmental aspects

Data calculation

- Validation of raw data
- Relating data to unit process
- Relating data to functional unit and reference flow

Intensive aspect – constrains should be stated in the report (goal and scope)

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Allocation

Allocation

- Most industrial processes yield more than one product, and they recycle intermediate or discarded products as raw materials
- Examples:

  Apiculture: honey, natural wax

  Salt electrolysis: chlorine, caustic soda and hydrogen

What we are talking about is how to divide environmental impacts between each product

- As the functional unit, “good” allocation procedures are essential for an effective LCA study
- Probably the most controversial aspect in LCA

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Allocation

How to proceed?

1. **Avoid allocation in the first place**
2. Divide impacts over products (allocation)

Avoid allocation

- By splitting the process in such a way that it can be described as two separate processes that each has a single output
- Often this is not possible, for example, wooden planks and saw dust are both economic outputs of a sawmill, but one cannot split the sawing process into a part that is responsible for the saw dust and one that is responsible for the planks

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Allocation

When we must divide impacts over products (allocation)

1. Use of physical causality (mass allocation, but energy could also be applied, e.g. incineration – electricity and heat), and if not possible
2. Use other relationships (economic allocation)

Avoid double counting!

	Mass allocation (mass percentage)	Economic allocation (income allocation)
Wooden planks	60%	95%
Saw dust	40%	5%

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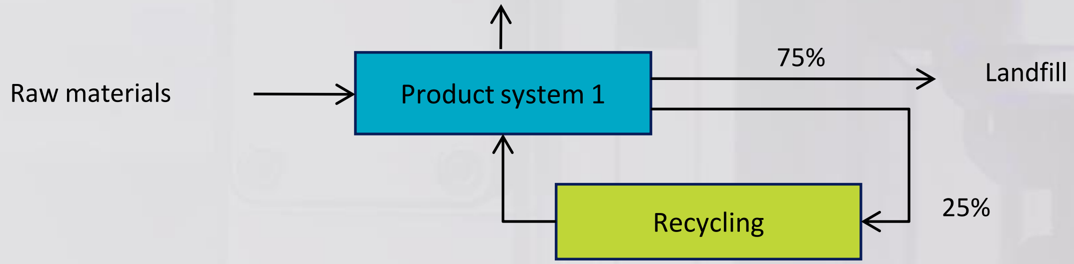
Allocation

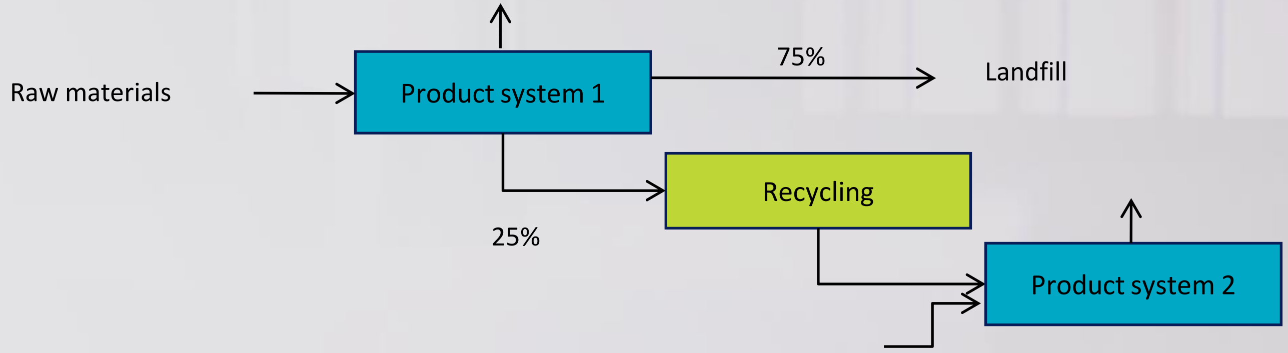
End-of-life allocation (recycling and incineration)

- Special case of allocation
- Same rules apply, but with additional measures (“who gets the gain”)

Closed loop (no problem)



Open loop (possible allocation problems)



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Allocation

- Where no changes occur in the inherent properties of the recycled material, the allocation problem is avoided because the use of secondary material displaces the use of virgin (primary) materials
  - However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure

- When changes occur in open-loop system, there should be allocation based on the following order:
  - Physical properties (e.g., mass), Economic properties, Number of subsequent uses of the recycled material

- How to do economic allocation?
  - Market value of the scrap material or recycled material in relation to market value of primary material
  - Ratio between waste (Product system 1 to recycling) or secondary material (recycling to Product system 2) prices, in relation with their sum

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3. Impact assessment

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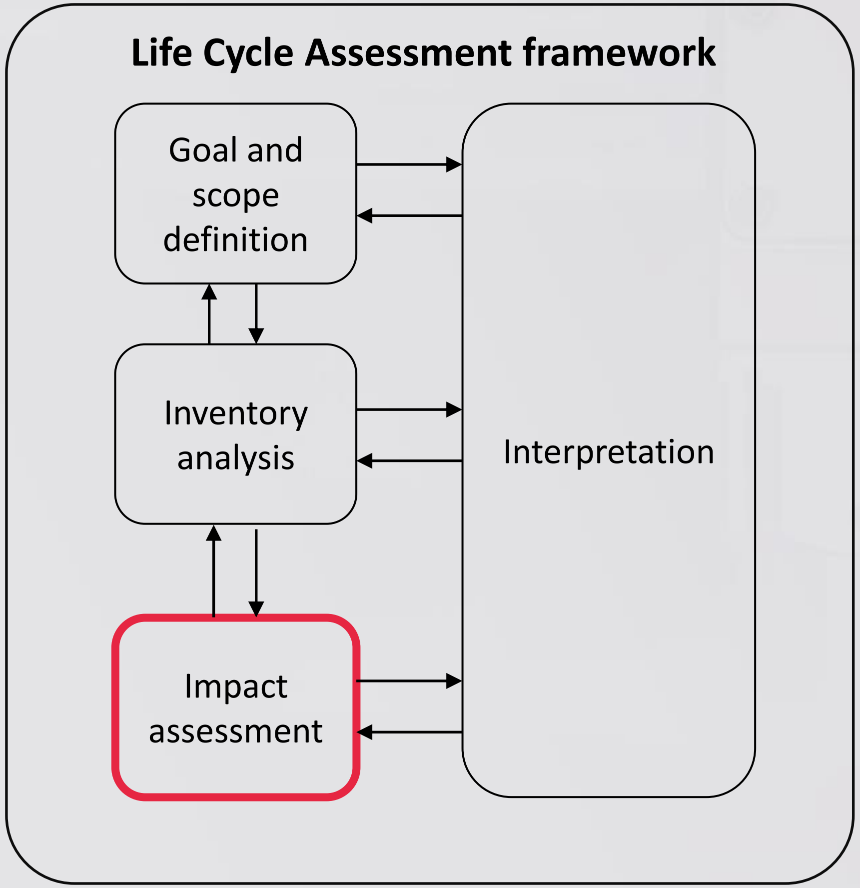
LCA step 3 – Impact assessment



- **LCIA – Life Cycle Impact Assessment**

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Impact assessment

- Selection of the impact categories and best available models for their quantification. This is generally related to the selection of the environmental models used to promote the characterization of the environmental impacts
- Identification of the environmental interventions that contribute to a given impact category (**Classification**)
- Quantification of the environmental interventions' contribution to a given impact category (**Characterization**)
- Normalization of the results of the previous phase, making use of reference values (**Normalization**)
- Aggregation of the different impacts to reduce the number of the impact categories in the final result (**Weighting**)

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Classification and characterization

Classification

- The LCI results must be assigned to impact categories. For example, CH_4 or CO_2 could be assigned to an impact category called "Climate change"
- It is possible to assign emissions to more than one impact category at the same time. For example, SO_2 is simultaneously responsible for impacts on "Acidification" as well as in "Human health" or "Respiratory diseases"

Characterization

- Once the impact categories are defined and the LCI results are assigned to the impact categories, it is necessary to define characterization factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result
- For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 25 times higher than the emission of 1 kg CO_2
- This means that if the characterization factor of CO_2 is 1, the characterization factor of CH_4 is 25. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor

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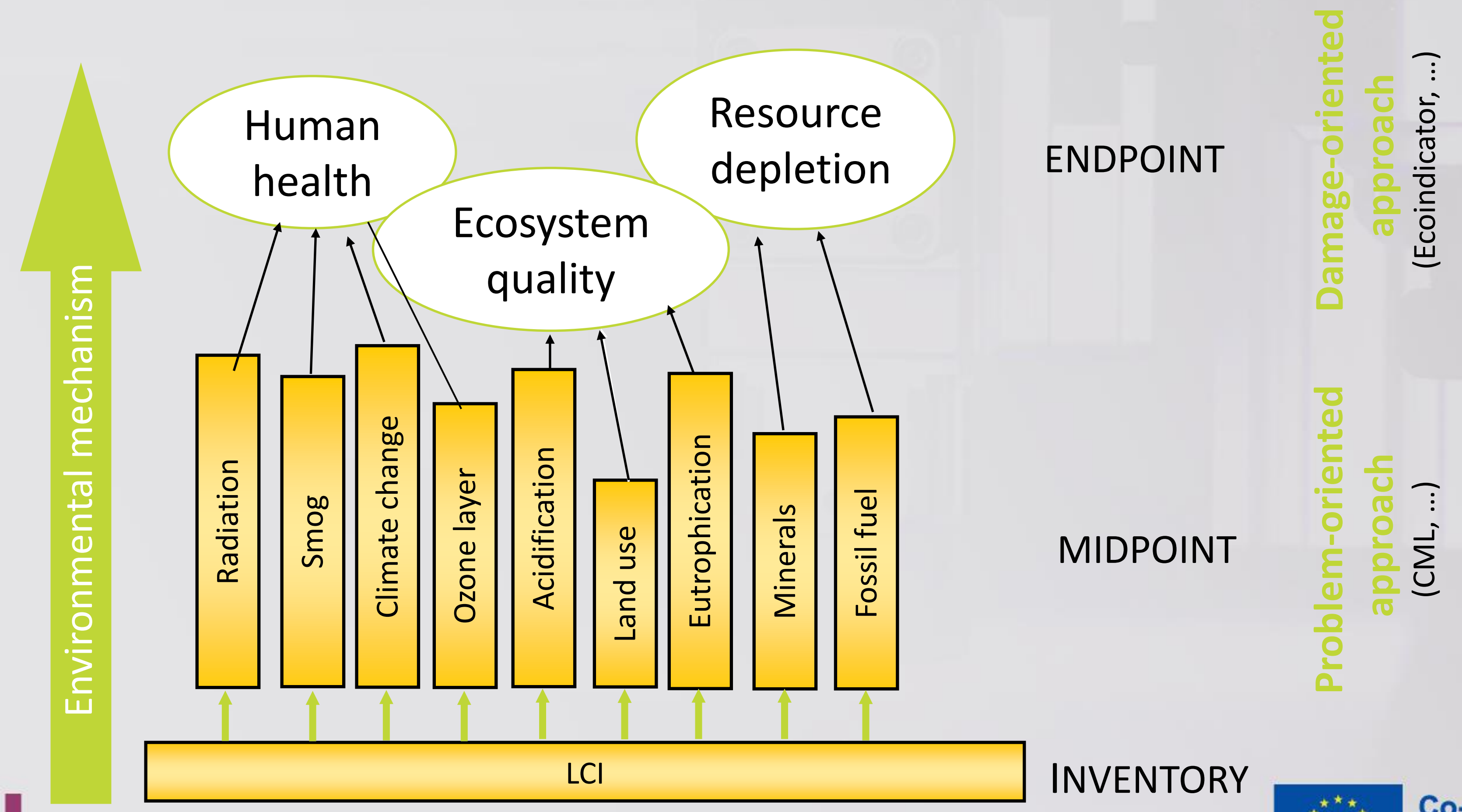
IPCC Characterization factors

Characterization factors for some GHG according with IPCC (global warming potential)

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b] 1.4×10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7×10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181

Midpoint vs. Endpoint indicators



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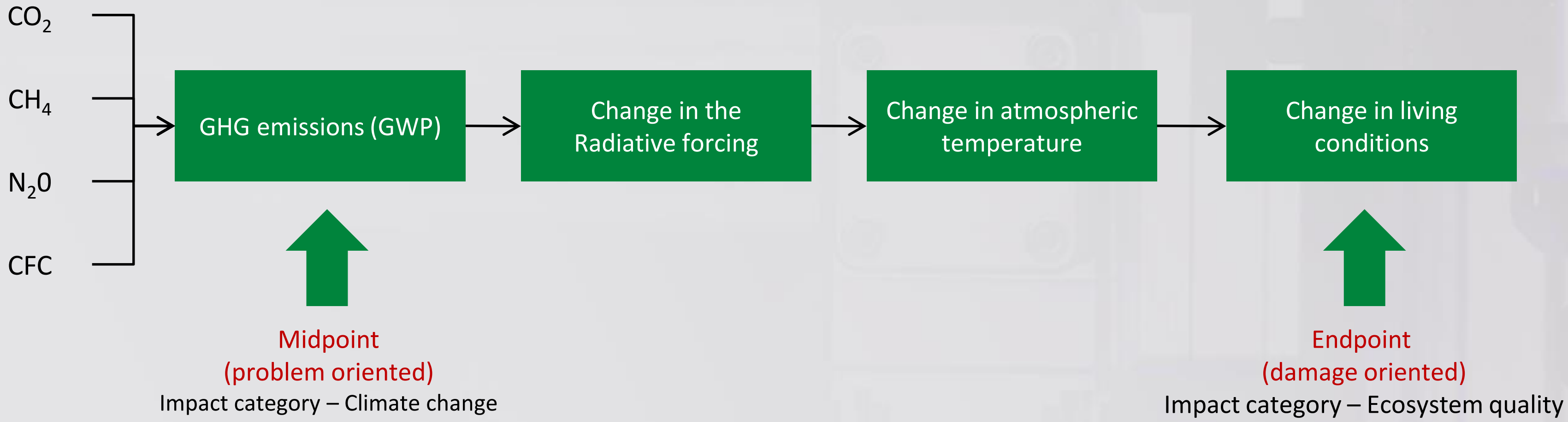
Midpoint vs. Endpoint indicators



Term	Atmospheric emissions
Impact category	Climate change
LCI results	Amount of a greenhouse gas per functional unit
Characterization model	Baseline model of 100 years of the Intergovernmental Panel on Climate Change
Category indicator	Infrared radiative forcing (W/m2)
Characterization factor	Global warming potential (GWP100) for each greenhouse gas (kg CO2 equivalent/kg gas)
Category indicator result	Kilograms of CO2 equivalent per functional unit
Category endpoints	Coral reefs, forests, crops
Environmental relevance	Infrared radiative forcing is a proxy for potential effects on the climate depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat absorption

Source: ISO 14044 (2006)

Midpoint vs. Endpoint indicators

Problem vs. Damage oriented

- In the problem-oriented approaches, flows are classified into environmental categories to which they contribute
- Categories covered in most LCA studies are: Greenhouse effect (or climate change), Natural resource depletion, Stratospheric ozone depletion, Acidification, Photochemical ozone creation, Eutrophication, Human toxicity, Aquatic toxicity
- These methods aim at simplifying the complexity of hundreds of flows into a few environmental areas of interest.

- The damage-oriented methods also start by classifying the system's flows into various environmental categories, but they model each environmental category's damage to human health, ecosystem health or to resources use
- For example, acidification - often related to acid rain - may cause damage to ecosystems, but also to buildings or monuments
- In essence, this method aims to answer the question: Why should we worry about climate change or ozone depletion?
- Ecoindicator is an example of a damage-oriented indicator.

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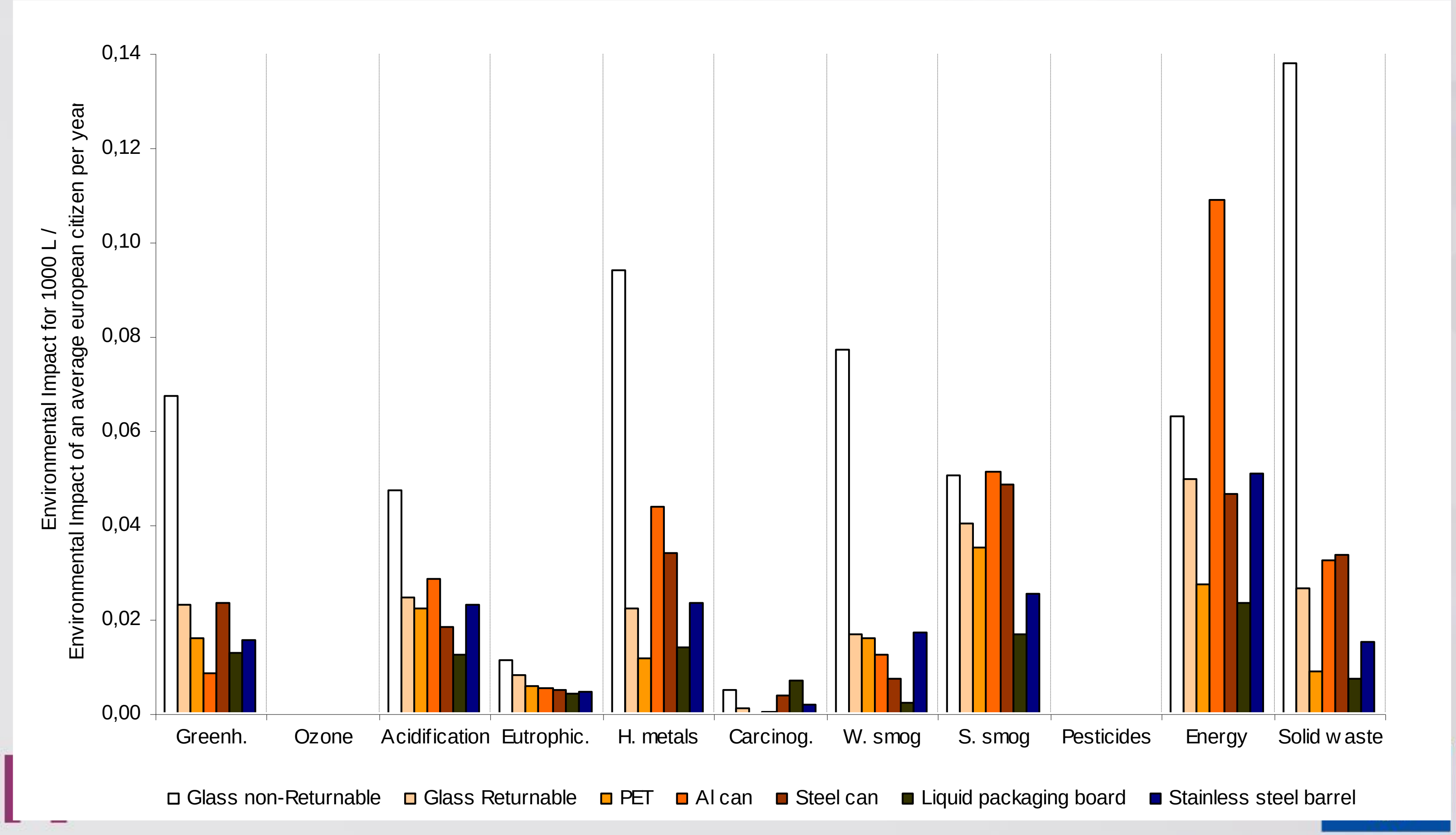
Normalization

- Normalization is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem
- This is done by dividing the impact category indicators by a “Normal” value
- There are different ways to determine the “Normal” value. The most common procedure is to determine the impact category indicators for a region during a year and divide this result by the number of inhabitants in that area
- It serves 2 purposes:

  Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated

  The normalized results show the order of magnitude of the environmental problems generated by the product life cycle, compared to the total environmental loads in Europe

Normalisation (comparing materials for beverage containers)



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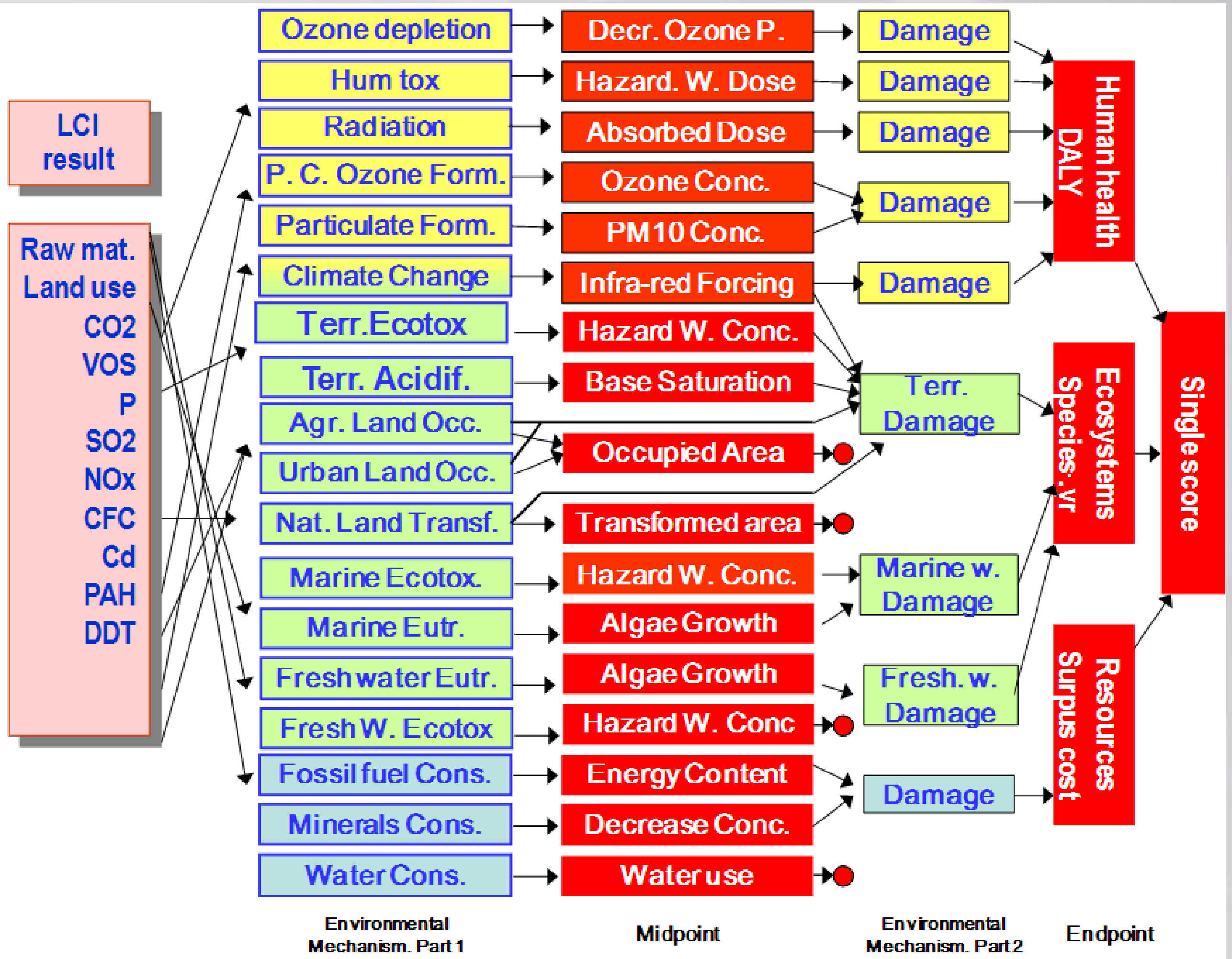
Damage assessment

Damage assessment

- In these methods, the category indicators are defined close to an endpoint to achieve an optimum environmental relevance
- The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same. Thus, allows addition of the indicator results per group
- This means that the indicator results can be presented as a set of indicators at endpoint level without any subjective weighting
- Interpreting less indicators (3 in Eco-indicator) instead of a multiple set of indicators is much easier

Weighting

Aggregation of the different impacts (midpoint) to reduce the number of the impact categories in the final result (endpoint), by weighting the respective relevance in each Eco-indicator and in a damage-oriented basis.



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4. Interpretation of results

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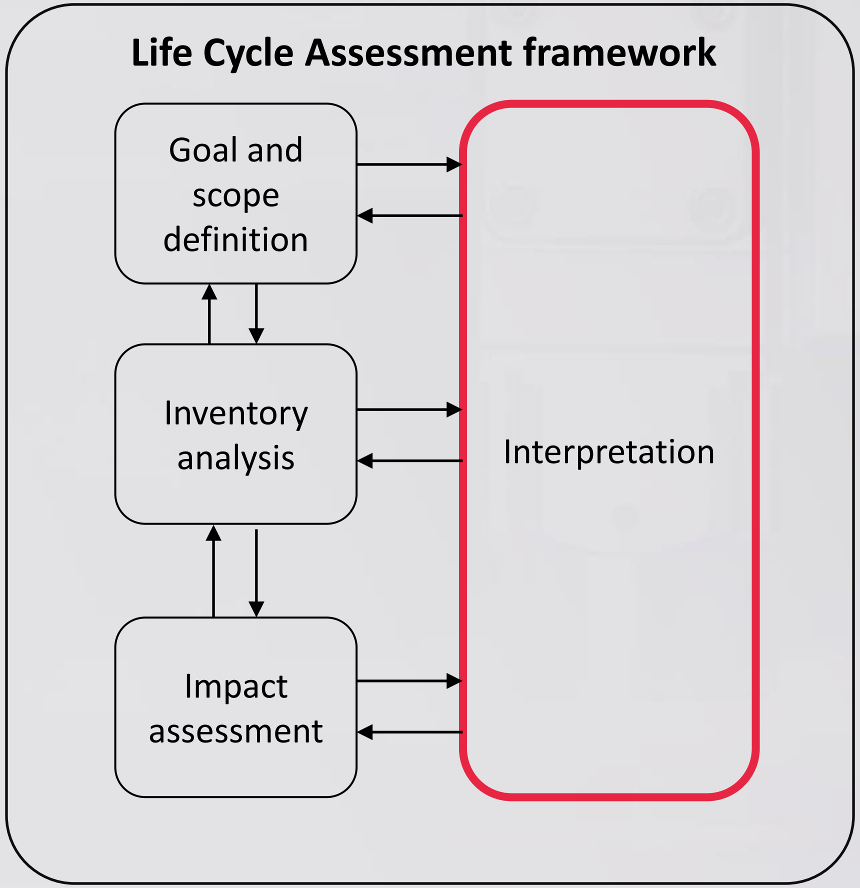
LCA step 4 – Interpretation of results



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Interpretation of results

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA
  - Inventory data
  - Impact categories
  - Significant contributions from LCA stages and process to the results
- Evaluation that considers completeness, sensitivity and consistency checks
  - All relevant information for interpretation is available?
  - Reliability of results and conclusions considering uncertainty in data, allocation methods and calculation of category indicators
  - Assumptions, methods and data are consistent with the goal and scope?
- Conclusions, limitations, and recommendations.

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Short Break

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LCA example
Olive oil for cooking

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Stages for life cycle assessment

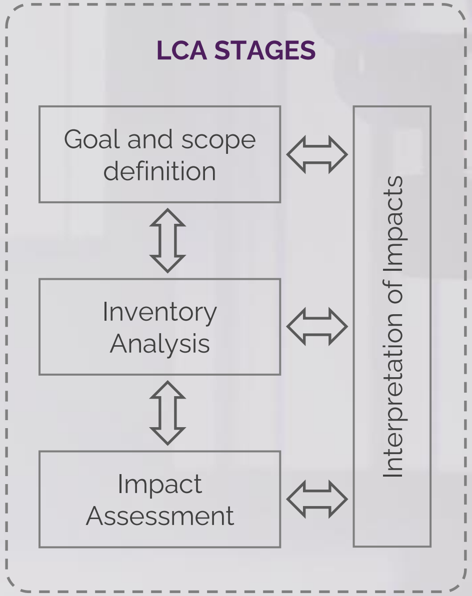
To fill in excel file

- Define goal & scope
- Develop life cycle inventory
- Calculate the environmental impacts
- Interpret the results

    Original olive oil

    Comparison with other cooking oils (rapeseed oil, palm oil)

    Improvement scenario – for a more sustainable olive oil



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Goal and Scope

- To determine the environmental impacts of the use of olive oil for cooking
- From the olive (raw material) production to the end-of-life of the used olive oil, that is for the entire life cycle – Cradle to grave approach
- Considering use of 1 Liter of olive oil for deep frying (ex., industrial kitchens) → **Functional unit**
- To compare its impact with other cooking oils and determine the main causes that contribute to its impact – for purpose of comparison & improvement

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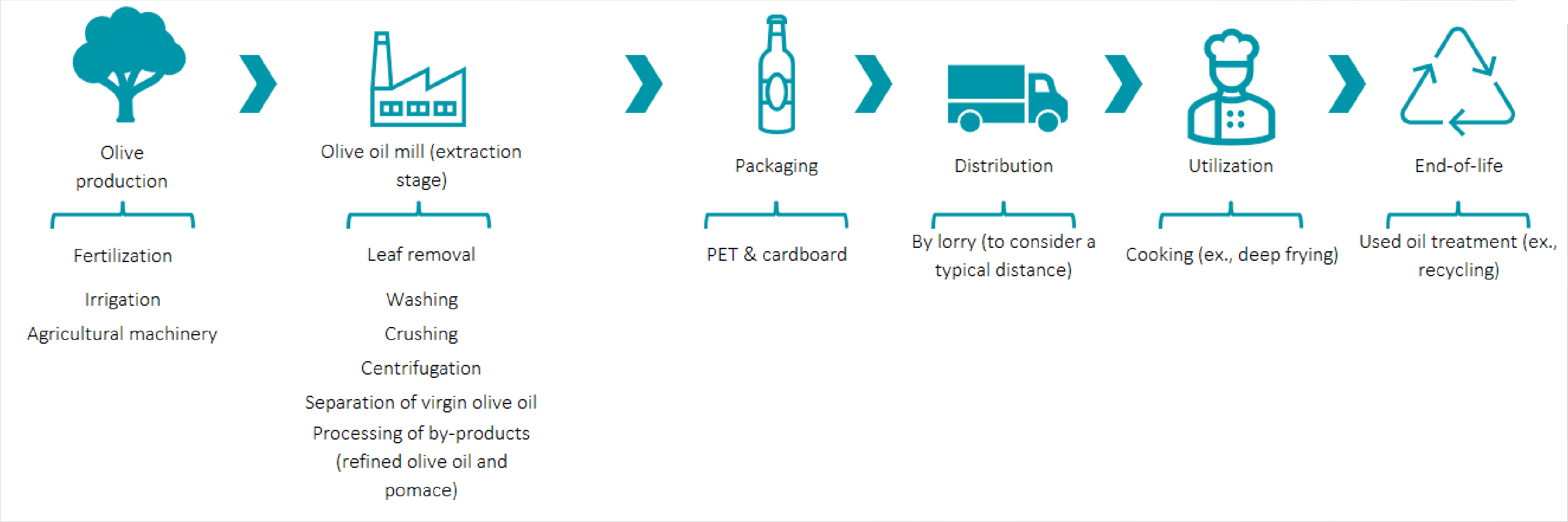
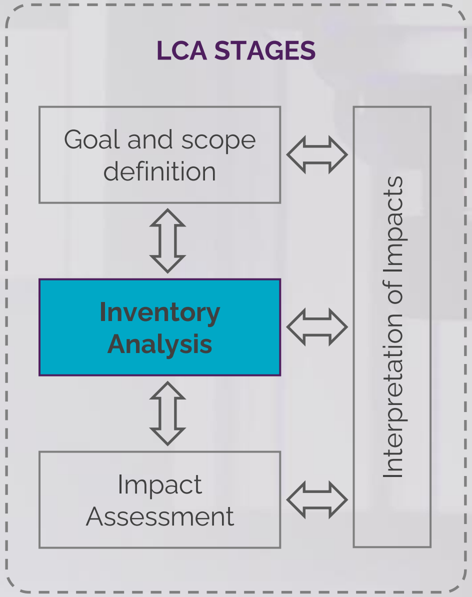
Life cycle of olive oil

Life cycle for the production of 1 Liter of olive oil



Inventory analysis

- Inputs from nature (natural resources)
- Inputs from technological sphere (materials, water, fuels)
- Inputs from technological sphere (energy)
- Outputs (wastes, emissions)



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Olive production

- Carbon dioxide (in air), 0.55 kg
- Occupation permanent crop, 1.98 m2
- Fertilizers, 0.046 kg
- Application of plant protection product, by field sprayer, 0.001 ha
- Irrigation, 0.074 m3
- Transport, tractor and trailer, agricultural, 0.002 tkm

- Ammonia, 0.001 kg
- Carbon dioxide, 0.002 kg
- Nitrate, 0.01 kg
- Waste wood, 0.26 kg

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Olive oil extraction

- Olive, 5.22 kg
- Water, 0.0054 m3
- Propane, 0.016 kg
- Hexane, 0.0004 kg
- Electricity from conventional mix, 0.249 kWh

- Carbon dioxide (biogenic), 2.87 kg
- Wastewater from vegetable oil refinery, 0.01 m3
- Biowaste, treatment of biowaste industrial composting, 3.33 kg

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Packaging and distribution

- PET bottle grade, 0.036 kg
- Cardboard box, 0.009 kg
- Lorry, 0.2 tkm
- Electricity, 0.003 kWh

- Considered emissions inside these processes

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Use (cooking) and End of Life (treatment)

- Heat from natural gas, 2.62 MJ

- Used vegetable oil for treatment, 0.918 kg

- Used vegetable oil, 0.918 kg
- Consumables, 0.12 kg
- Electricity 0.04 kWh

- Treatment wastes, 1.20E-6 kg
- Considered emissions inside these processes

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Impact assessement

- LCIA calculation and results
- Midpoint method

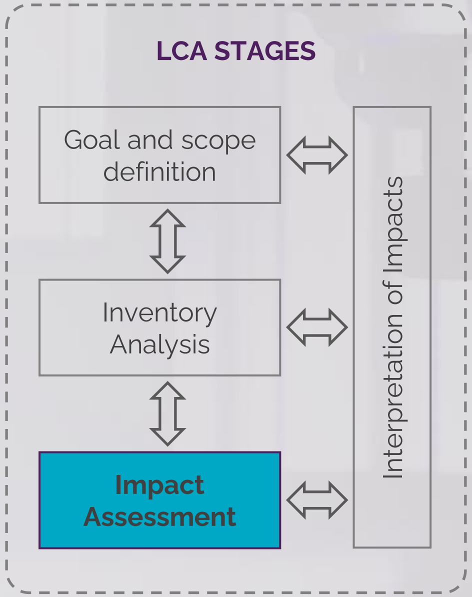
  Impact categories of global warming potential, terrestrial ecotoxicity, mineral resource scarcity and water consumption

  Characterization results

  Normalization results: in relation to the impact of an average European citizen during a year
- Endpoint method

  Impact categories human health, ecosystems, resources

  Normalization results



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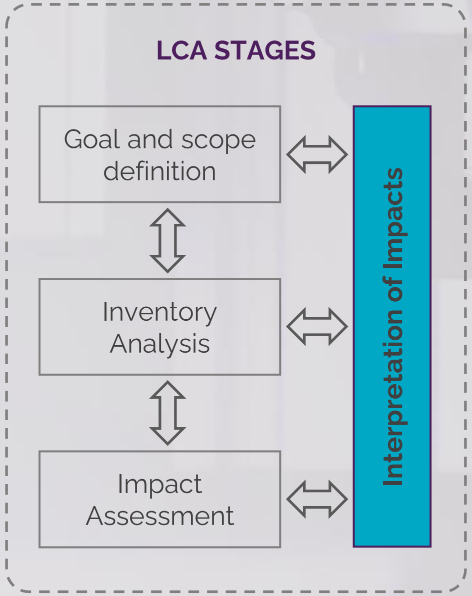
Interpretation of results

What do we want to analyze

- To compare the impact of olive oil with other cooking oils, that is, other equivalent products
- To understand which impact categories contribute more to the overall impact of olive oil
- To identify the life cycle stages that have greater weight in these impact categories
- Which process variables in each life cycle stages can be changed to improve the overall environmental performance of olive oil



Final remarks

Flexible Laser-Based Manufacturing

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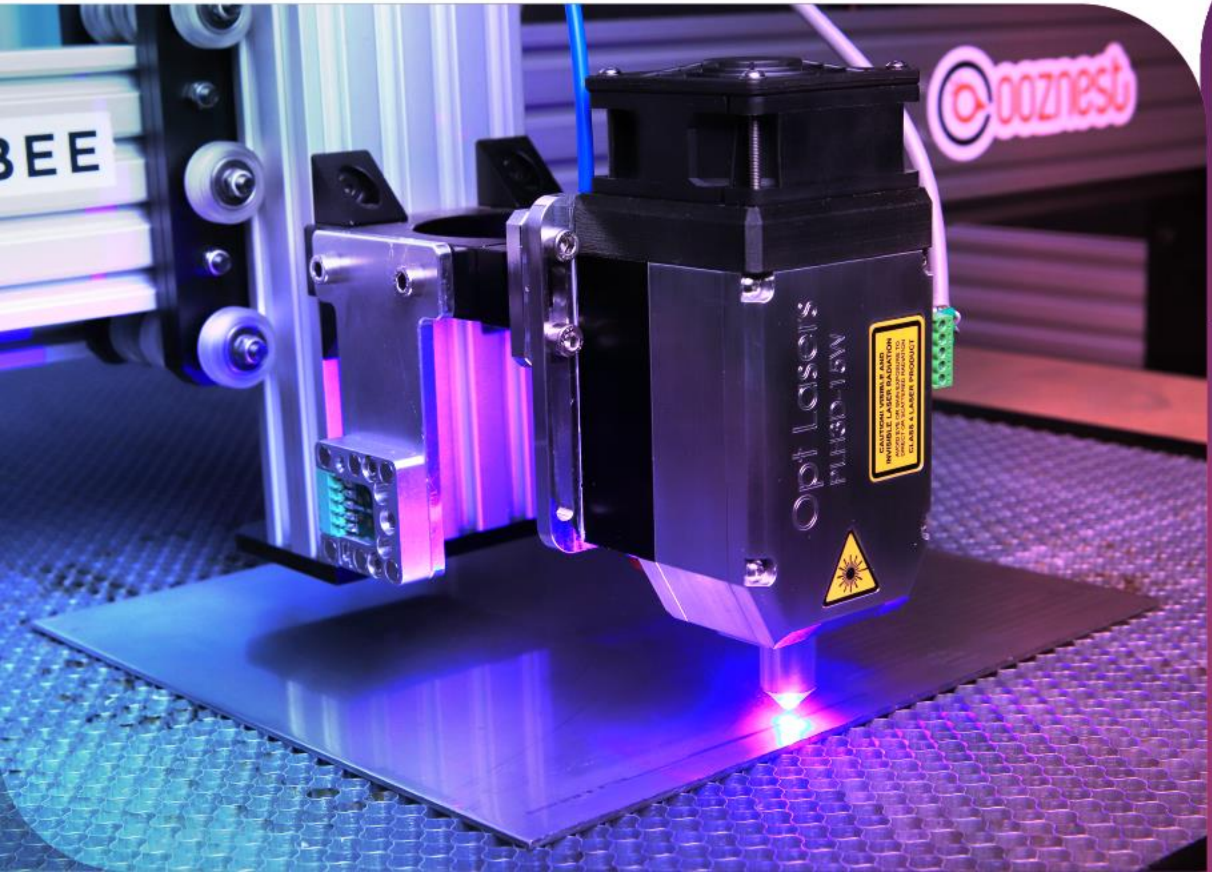
Flexible Laser-Based Manufacturing

Any Question?



"If there are any questions or if something needs further explanation, please, **don't hesitate to ask**!"

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