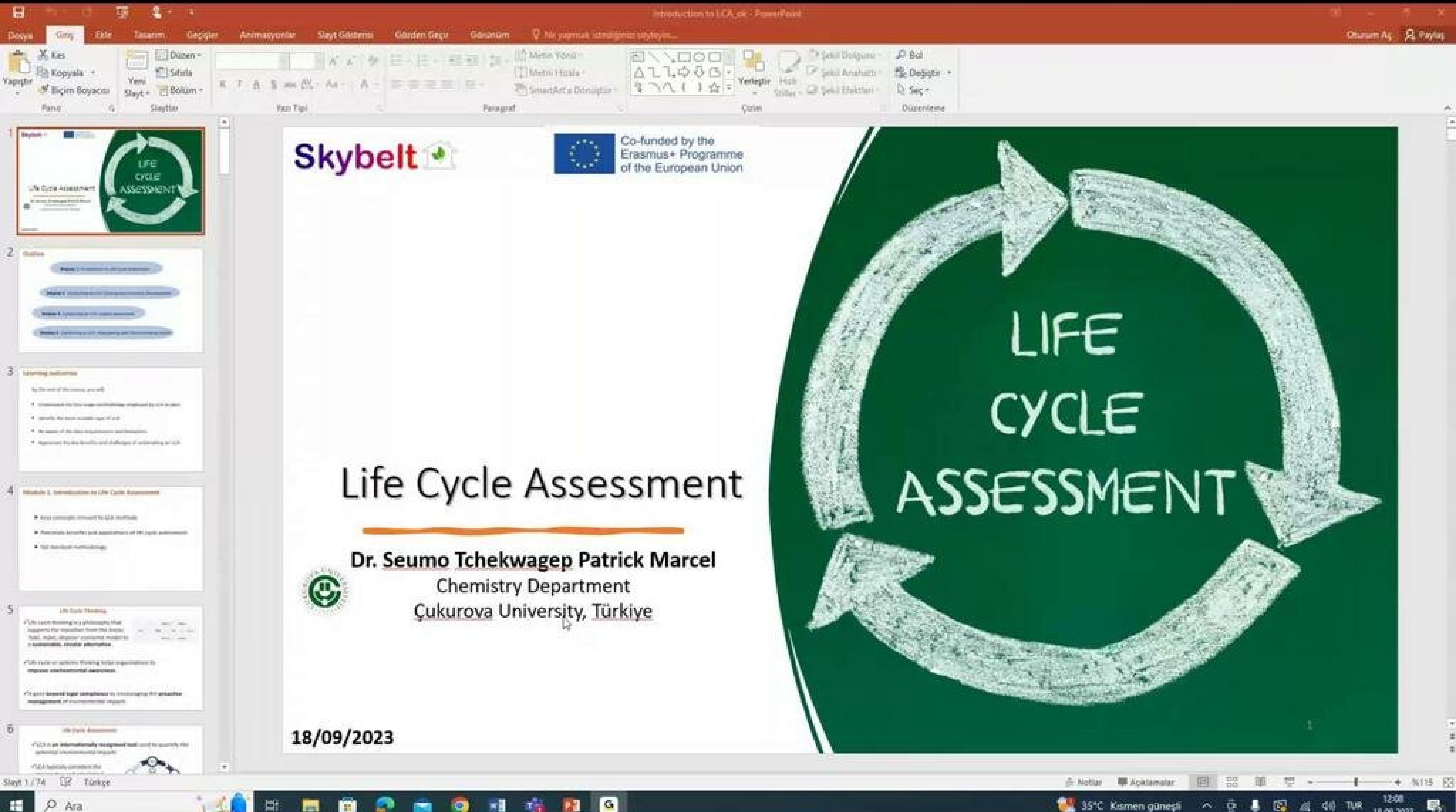
Introduction to LCA_ok - PowerPoint
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Life Cycle Assessment
Dr. Seumo Tchekwagep Patrick Marcel
Chemistry Department
Çukurova University, Türkiye
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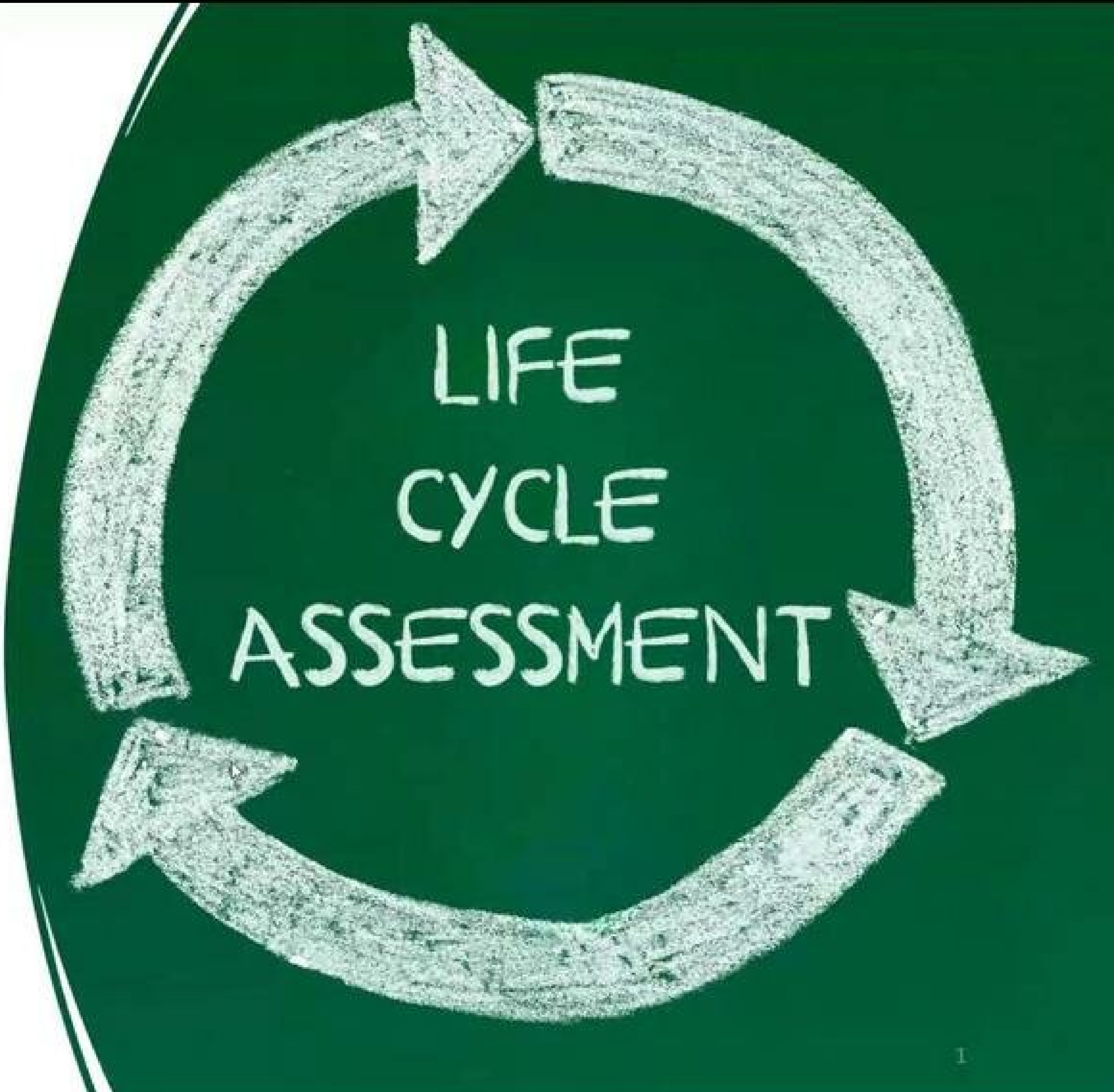

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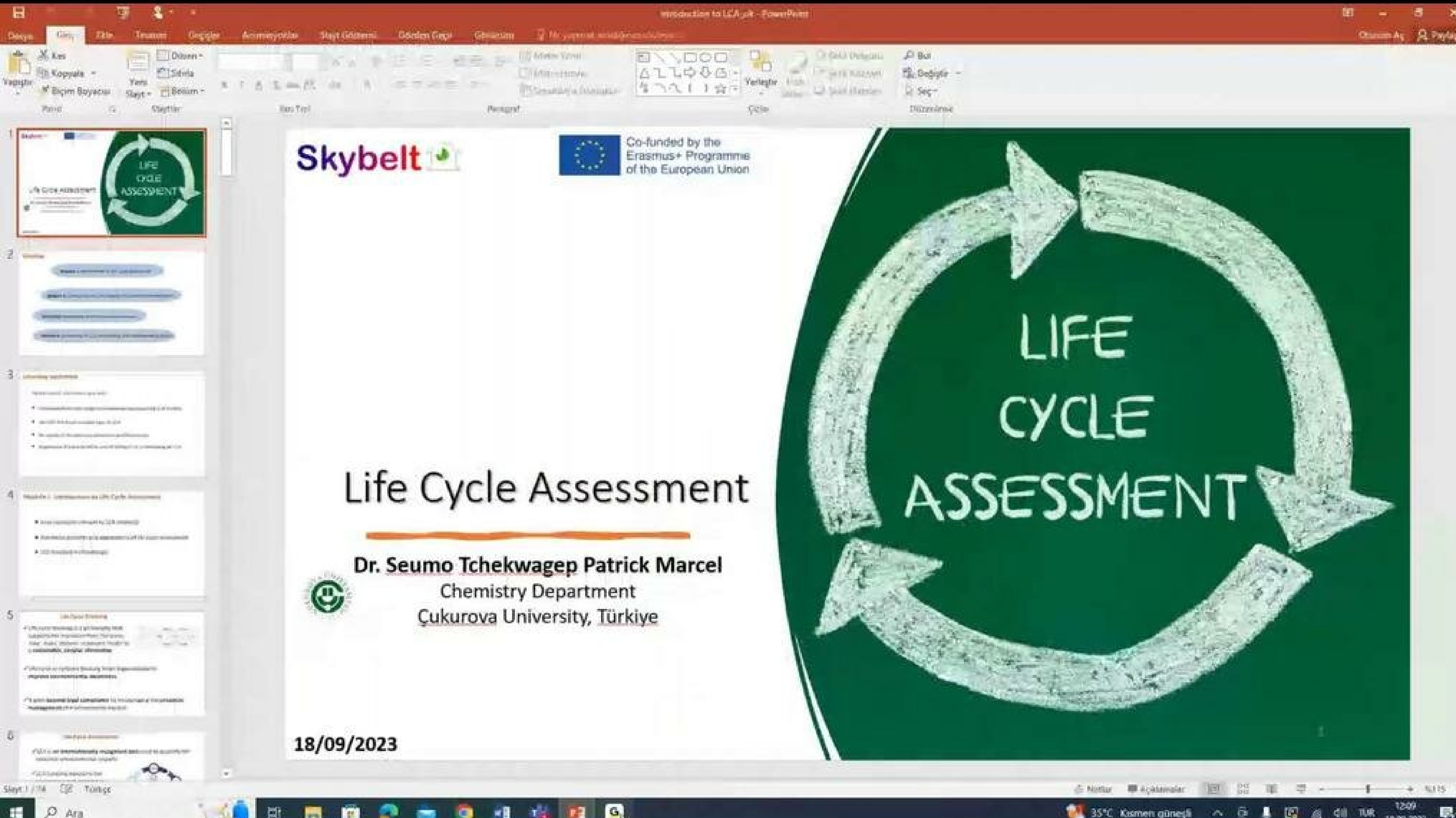
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Kes
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Outline

Module 1. Introduction to Life Cycle Assessment

Module 2. Conducting an LCA: Scoping and Inventory Development

Module 3. Conducting an LCA: Impact assessment

Module 4. Conducting an LCA: Interpreting and Communicating results

Learning outcomes

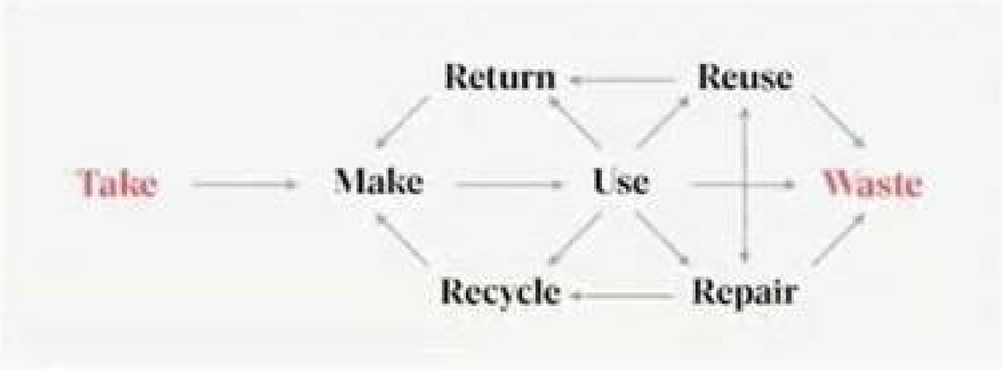
By the end of the course, you will:

- Understand the four stage methodology employed by LCA studies
- Identify the most suitable type of LCA
- Be aware of the data requirements and limitations
- Appreciate the key benefits and challenges of undertaking an LCA

Module 1. Introduction to Life Cycle Assessment

- Keys concepts relevant to LCA methods
- Potentials benefits and applications of life cycle assessment
- ISO standard methodology

Life Cycle Thinking



✓Life cycle thinking is a philosophy that supports the transition from the linear, 'take, make, dispose' economic model to a **sustainable, circular alternative**.

✓Life cycle or systems thinking helps organisations to **improve environmental awareness**.

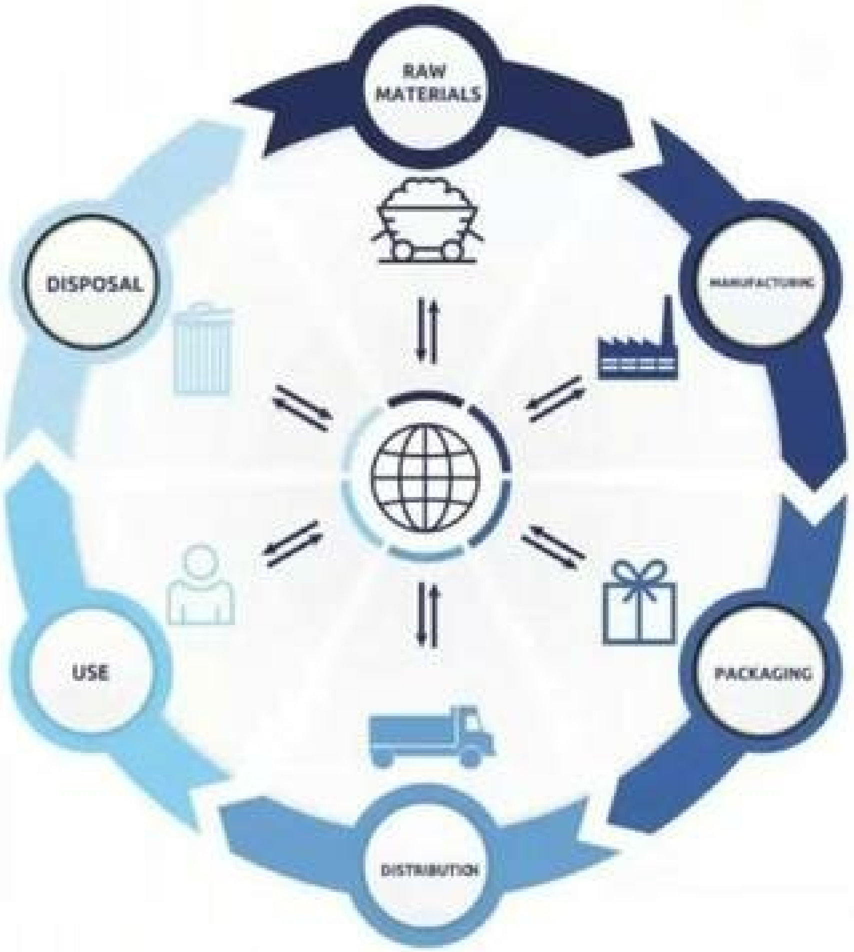
✓It goes **beyond legal compliance** by encouraging the **proactive management** of environmental impacts

Life Cycle Assessment

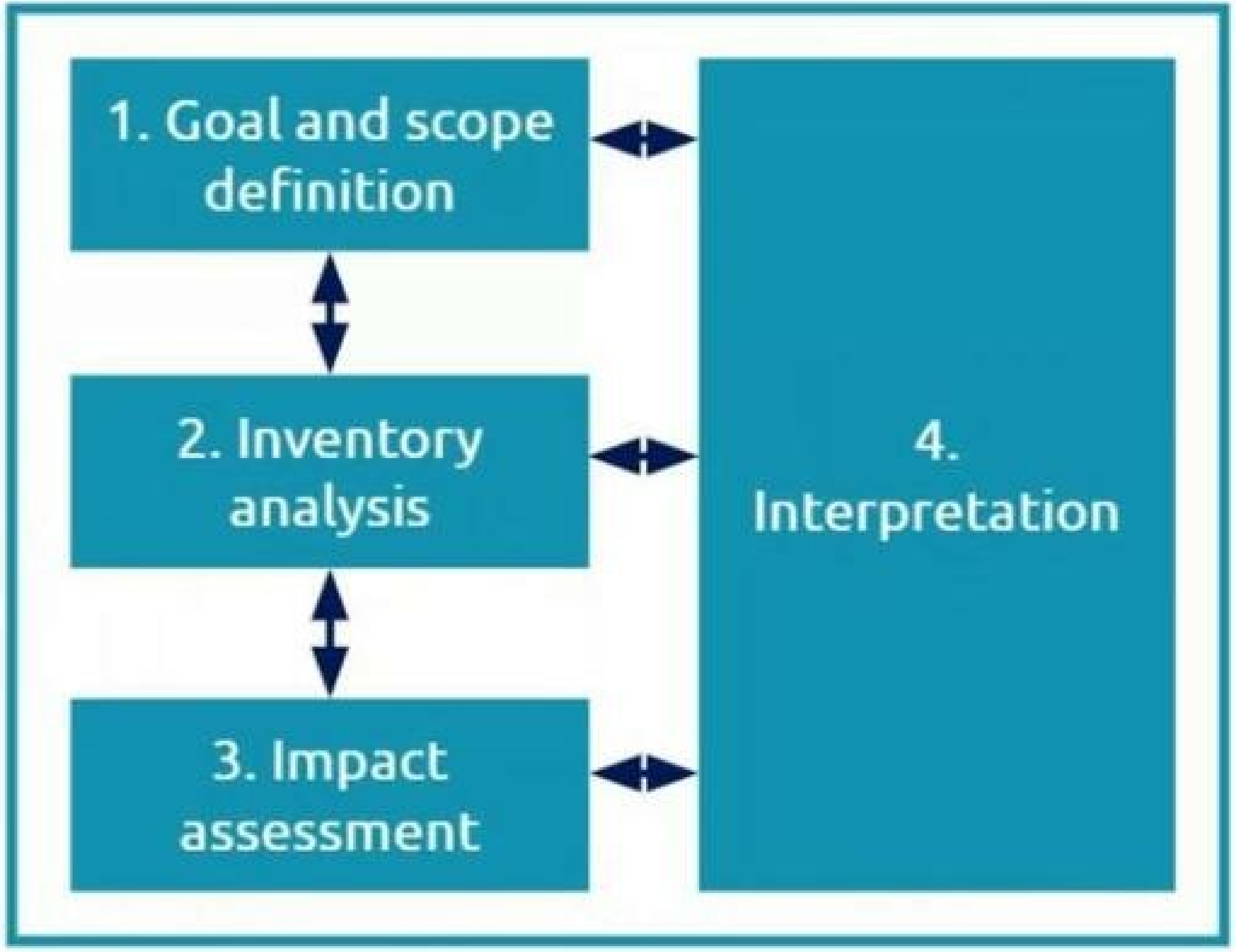
✓ LCA is **an internationally recognised tool** used to quantify the potential environmental impacts

✓ LCA typically considers the consecutive and interlinked stages of **a product system**

✓ From raw material and ingredient acquisition to its final disposal.
"cradle to grave" assessment
"cradle to cradle" assessment



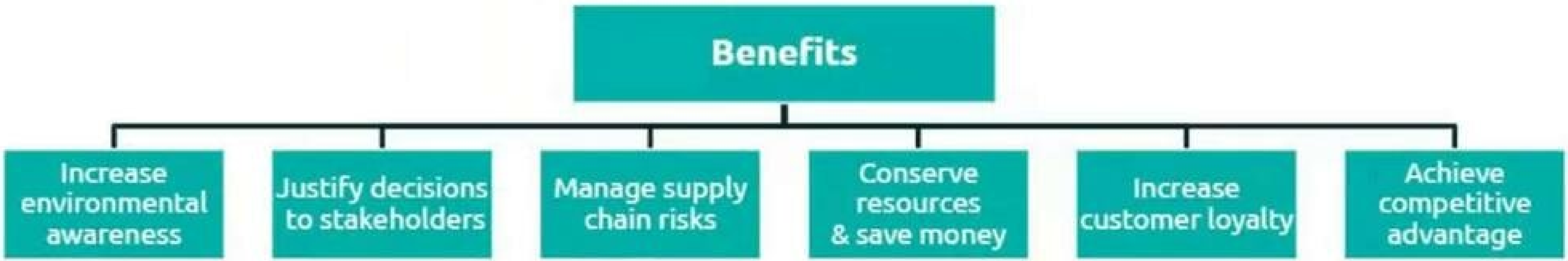
LCA framework



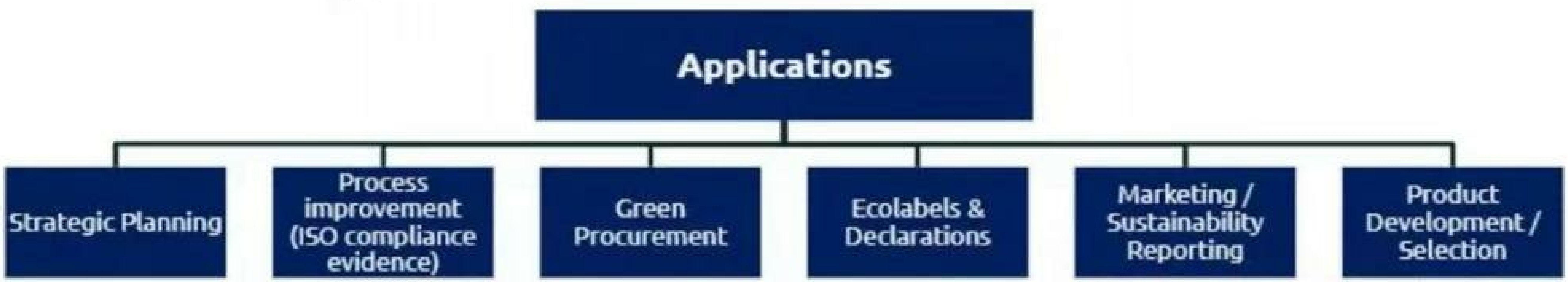
- The ISO 14040 standard defines a four stage framework

Benefits and Applications

LCA can bring organizational benefits



LCA have divers applications



Which is the environmentally preferable option? Example application: product selection

Applied Energy 237 (2019) 862–872

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

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Life cycle assessment of hydrogen from proton exchange membrane water electrolysis in future energy systems

Kay Bareiß[a], Cristina de la Rua[a], Maximilian Möckl[b], Thomas Hamacher[a]

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proton exchange membrane water electrolysis vs **steam methane reforming**

Conclusion: Hydrogen production via proton exchange membrane water electrolysis is a promising technology to reduce CO_2 emissions of the hydrogen sector by up to 75%,
<u>if the electrolysis system runs exclusively on electricity generated from renewable energy sources</u>

Which is the environmentally preferable option?
Example application: product selection

Average EU Conventional Car

2019 Nissan Leaf (40 kWh)

Life cycle emissions **45 – 75 % lower** for EV compared to EU Average car

Hall and Lutsey, 2018

Ionising radiation

Particulate matter formation

Climate change

Natural land transformation

Ozone depletion

Mineral resource depletion

Human toxicology

Photochemical oxidant formation

Water depletion

Summary

- ✓ LCA involves a four step methodology (ISO 14040)
- ✓ LCA is growing in popularity
- ✓ LCA has many business applications and creates value
- ✓ LCA's holistic approach prevents unintentional environmental impacts

Sources & Further reading

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- European Commission. ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance.
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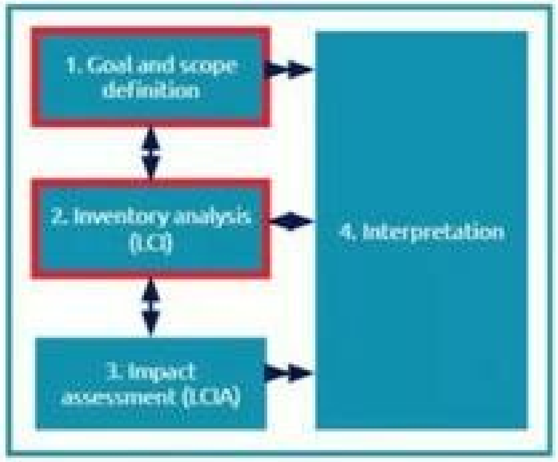
Module 2. Conducting an LCA: Scoping and Inventory Development



1. Review of the two stages
   - Scope
   - study purpose
   - function
   - functional units
   - System boundary

2. Life cycle inventory
   - Identification of processes, coproducts
   - Evaluation of the quality of the inventory data

Goal and scope definition

Goal definition

Clearly state:

- The reasons for carrying out an LCA (purpose)
- Your intended audience
- Type of LCA required to fulfil your purpose
- Whether results are to be use in comparative assertions released publicly

Aligning the study purpose and the LCA type

Type	Description	Purpose
Environmental Profile (EP)	Investigates supply chain impacts and identifies environmental hotspots.	Develops understanding of environmental performance of new and existing products including those currently under development.
Benchmarking LCA	Compares the environmental 'preferability' of two developed products with the same function.	Allows you to select products based on their environmental impact. Allows you to benchmark your product's environmental footprint against industry average or a competitor's product.
Environmental Scenarios Modelling (ESM)	Identifies the preferable product development options by comparing impacts given a range of inputs (choice of materials/ingredients, suppliers, locations, energy sources).	Identifies the best options for a product's development supporting R&D and ISO Management System goals.

Example…

Purpose	LCA type
▪ To determine my product's significant environmental impacts	✓ Environmental profile
▪ To evaluate how my product compares to a competitor's product?	✓ Benchmarking LCA
▪ To show that my product is environmentally superior to others on the market	✓ Benchmarking LCA
▪ To determine which product changes will result in the greatest overall environmental improvements?	✓ Enviromental scenarios modelling

Intended audience

- Information considered to be useful varies according to your audience
- Audience likely to comprise of interested parties who are affected by your products in some way
- Additional ISO obligations if results are to be disclosed to the public
- Third party expert involved from onset of a project

Scope definition

Clearly state:

- Definition system function and functional unit(s)
- System boundary
- Choose methodological approach
- Choose modelling framework

Functions

- Describes the service provided by the system of interest (e.g. skin mosturiser)

- Function = performance characteristics

Functional Units

- The measurable expression of the function

  - Provides a **quantified reference** to which inputs and outputs are related

  - It is the denominator in your inventory (e.g. input materials/functional unit, output emissions/functional unit)

- Enables different systems to be treated as **functionally equivalent**
  - The basis for product comparisons
- Poorly defined or incorrect functional units result in wasted effort

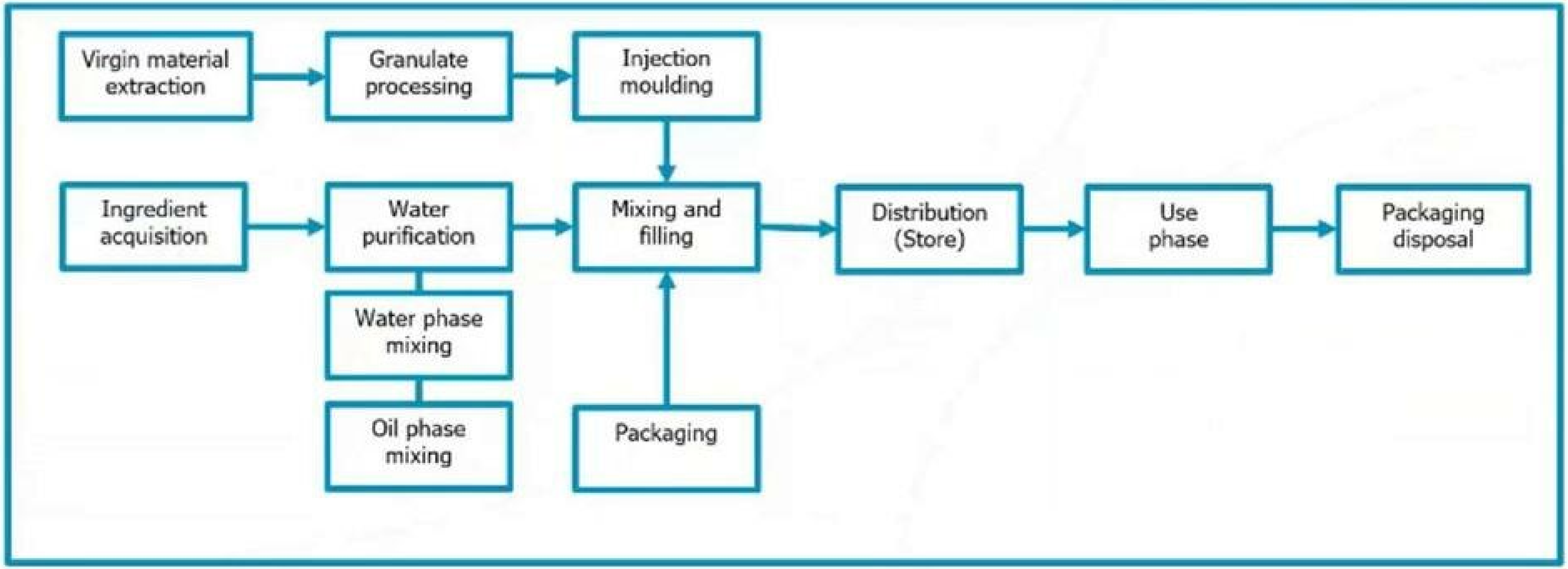
The importance of Functional Units

Functional Unit	Amount of wall paint required to cover 50 m^2
Product A	Input – 5 liters/ 50 m^2 (i.e. amount/functional unit)
Product B	Input – 4 liters/ 50 m^2

Examples of function and Functional Units

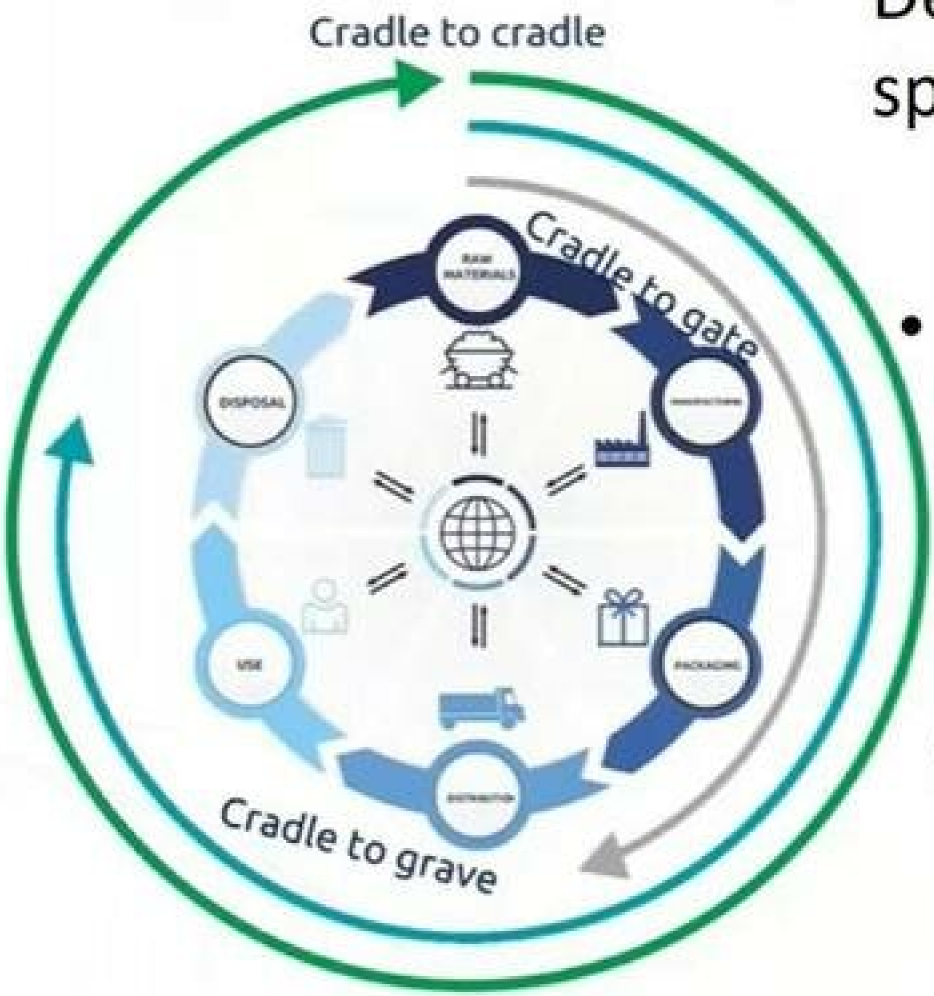
Product System	Function	Functional unit
Hand dryer	Drying hands	1 pair of hands dried
Wind turbine	Generating electricity	1 kWh of electricity generated
Light bulb	Providing light	100,000 lumen hours of light
Train	Transporting people	Transporting one person, 10,000 km
Chair	Support when sitting	Seating support for one person for five years

System boundaries



The **system boundary** defines which processes should be included in, or excluded from the system

Streamlined LCA



- Designed to deliver meaningful results in a short space of time, at a relatively low cost
- Focus on particular indicators (e.g. carbon footprint) or parts of the supply chain (e.g. cradle to gate)
- Ignore processes of life cycle stages that are identical in both systems

Streamlined LCA

Primary stakeholder concern	Related impact category
Protect the climate	Global Warming Potential
Protect fauna and flora	Ecosystem quality
Protect forests	Terrestrial Acidification
Protect rivers and lakes	Eutrophication
Save water	Water use
Better manage land use	Land use
Limit toxic emissions	Damage to human health
Improve outdoor air quality	Photochemical oxidant formation
Preserve raw materials / reduce waste	Resource scarcity

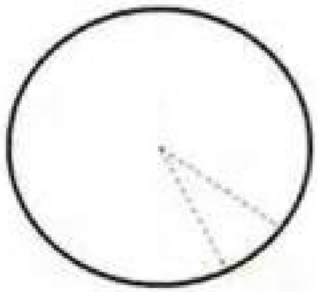
System boundaries

Things to consider

- Modelling approach
  - ➢ Attributional LCA (substitution is average)
  - ➢ Consequential LCA (substitution is marginal)

- Methodological approach
  - ➢ Allocation or expansion

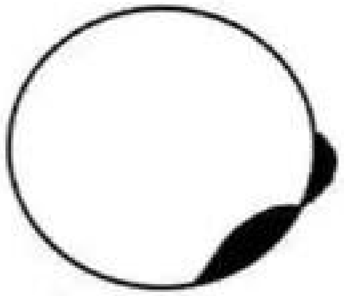
Modelling approaches



a-LCA

(Static)

- Depicts the system as it can be observed
- Used to assess the existing supply chain
- Communicates the share of the global impacts that can be associated with the product



c-LCA

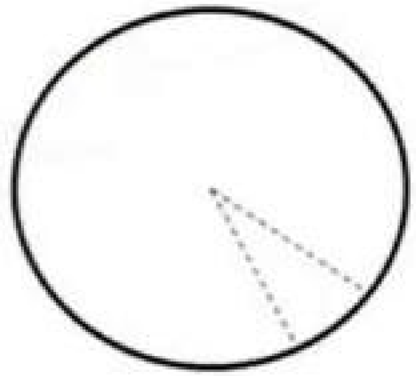
(Dynamic)

- Considers changes in relation to external market forces
- Used to assess the impact of a change in the supply chain
- Communicates the direct and indirect consequences of a decision

Modelling approaches and Decision -making

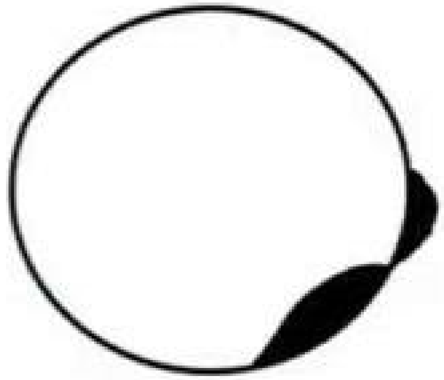
Attributional (a-LCA)

- Highlight environmental hotspots
- Compare a product to an alternative product



Consequential (c-LCA)

- Change a process in the product life cycle
- Substitute a product on the market



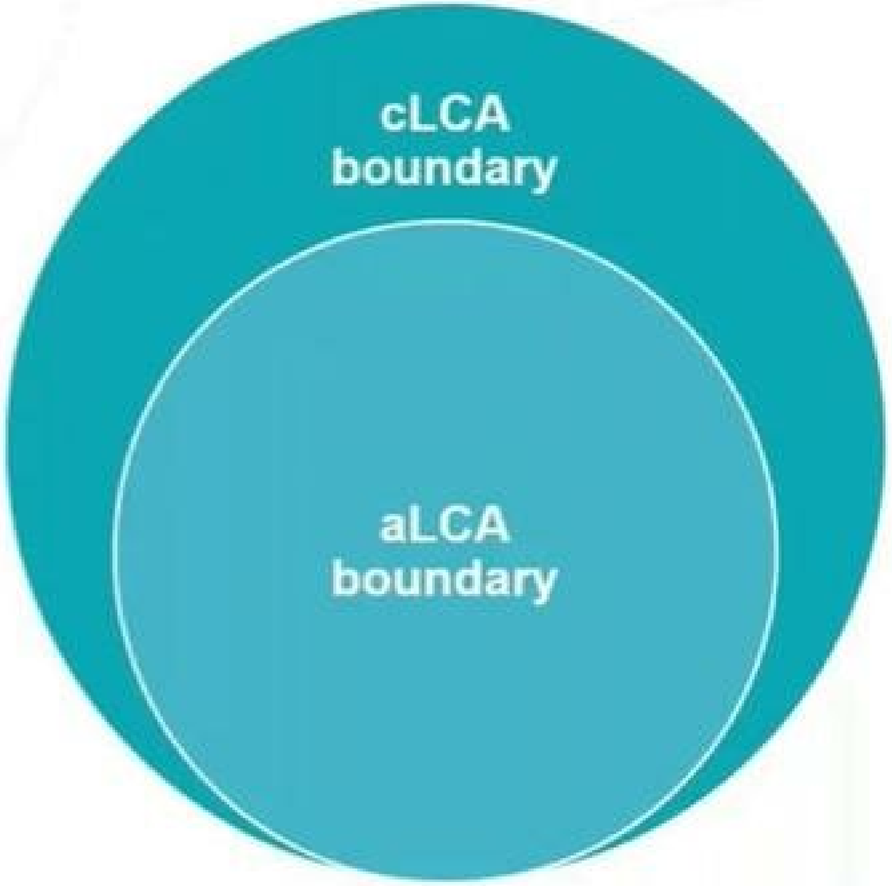
Comparing Modelling approaches

Attributional (a-LCA)

Narrower scope: inputs and outputs are attributed to the functional unit of the system by linking or partitioning the unit processes of the system

Consequential (c-LCA)

Wider scope: expands the system boundary beyond that of the existing supplychain



Life cycle inventory (LCI)

The catalogue of flows entering and leaving the system

- **Inputs**
  - Materials, ingredients, other resources (e.g. energy)

- **Outputs**
  - Parts
  - Products
  - Co-products
  - Waste
  - Emissions (gases, e.g. (CO_2, SO_2, SF_6) (substances, e.g. water, uranium)

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Example: Unit process flows

Remember to ensure that all data is **scaled** so that it serves the functional unit (e.g. 5 MJ of electricity per FU)

Data collection for LCI

- Must know what you are tracking for your inventory
  - i.e. only the relevant input and output flows

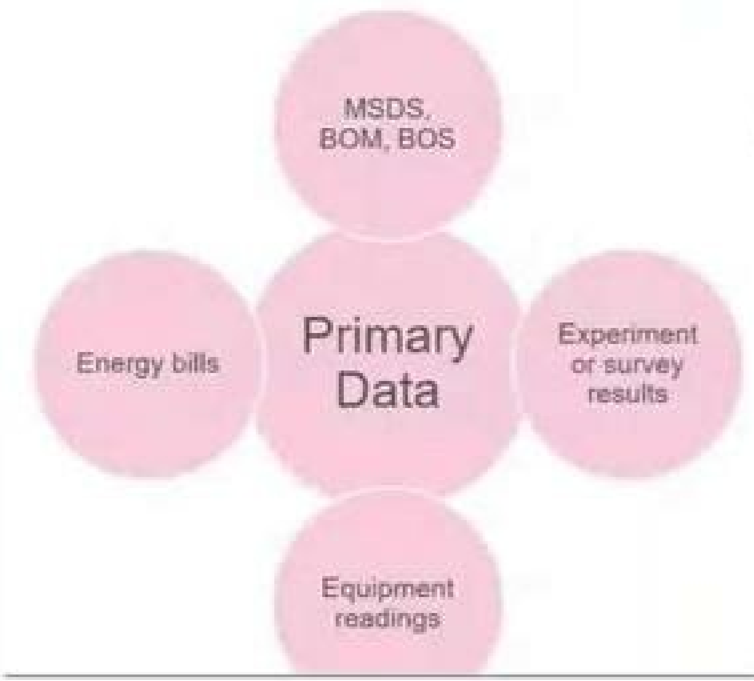
- Level of detail/aggregation may depend on:
  - Purpose of study
  - Data availability
  - Amount of uncertainty
- Fulfill data quality requirements

Knowledge of the key processes, product formulation, packaging materials, geographical context and so forth, allow you to create a representative product model

Data collection for LCI

Primary Data

Data collected / measured by you



Secondary Data

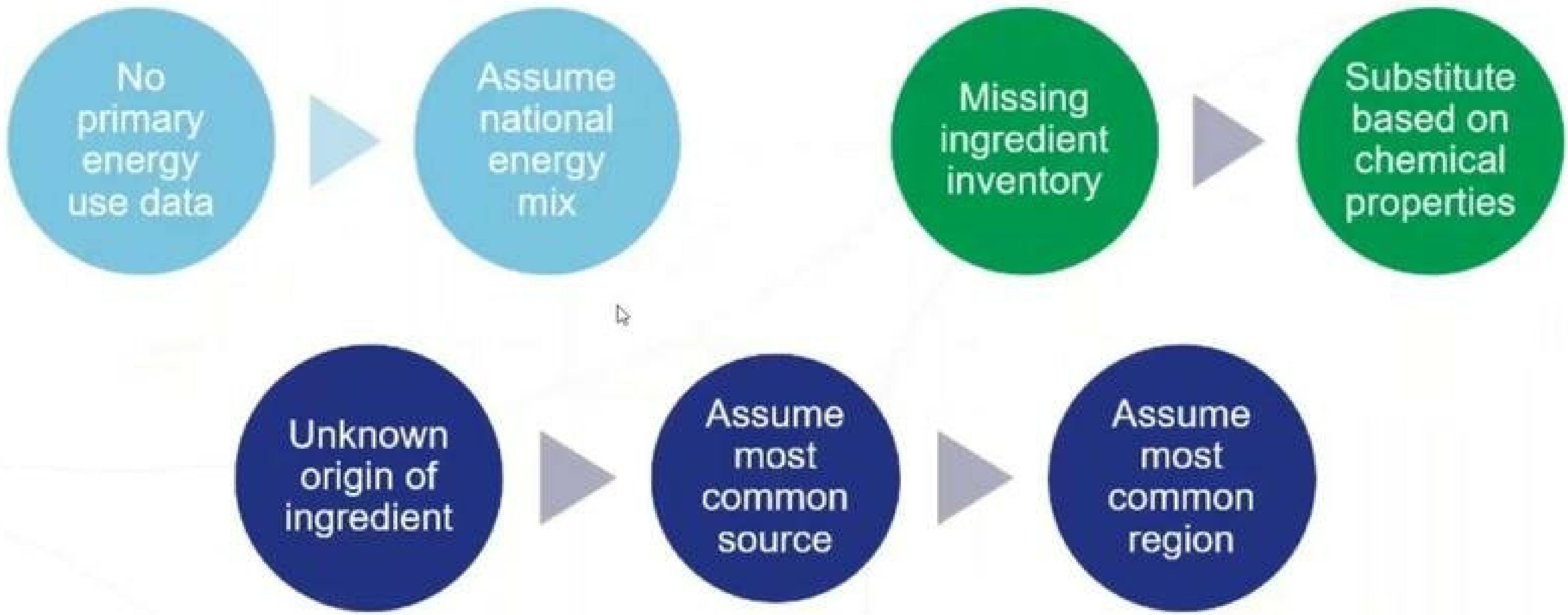
Data collected / measured by others

Data resources and Tools

GaBi database library: http://www.gabi-software.com/databases/gabi-databases/
European Commission, European Platform on LCA:
http://eplca.jrc.ec.europa.eu/?page_id=86
United Nations, Global LCA Data network (GLAD):
https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad/
USDA data catalogue: https://data.nal.usda.gov/life-cycle-assessment

thinkstep
a sphera company
SimaPro
openLCA

Dealing with data gaps



Summary

Streamlined LCA may be appropriate under some circumstances

Functional units allow for fair product comparison

Sources & Further reading

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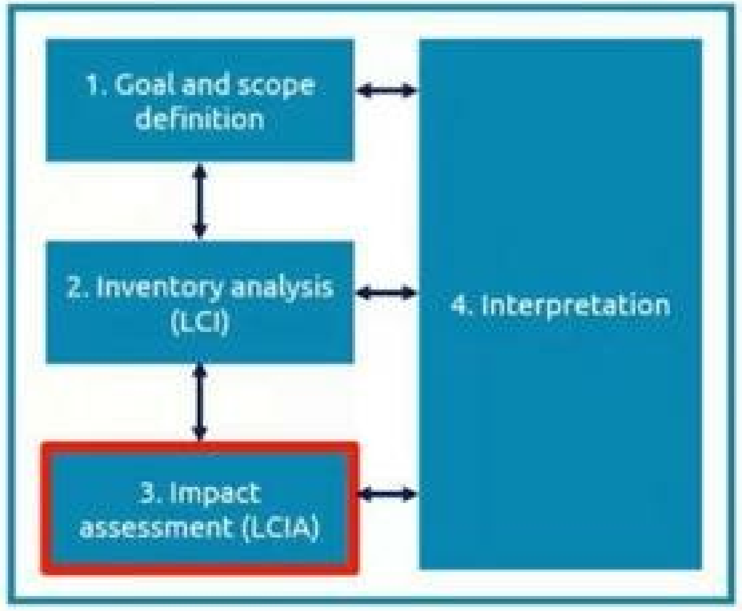
European Commission . ILCD Handbook : General guide for Life Cycle Assessment – Detailed guidance

Ercan, M., Malmodin, J., Bergmark, P., Kimfalk, E. and Nilson, E., 2016, August. Life cycle assessment of a smartphone. In ICT for sustainability 2016. Atlantis press.

Module 3. Conducting an LCA: Impact assessment (LCIA)

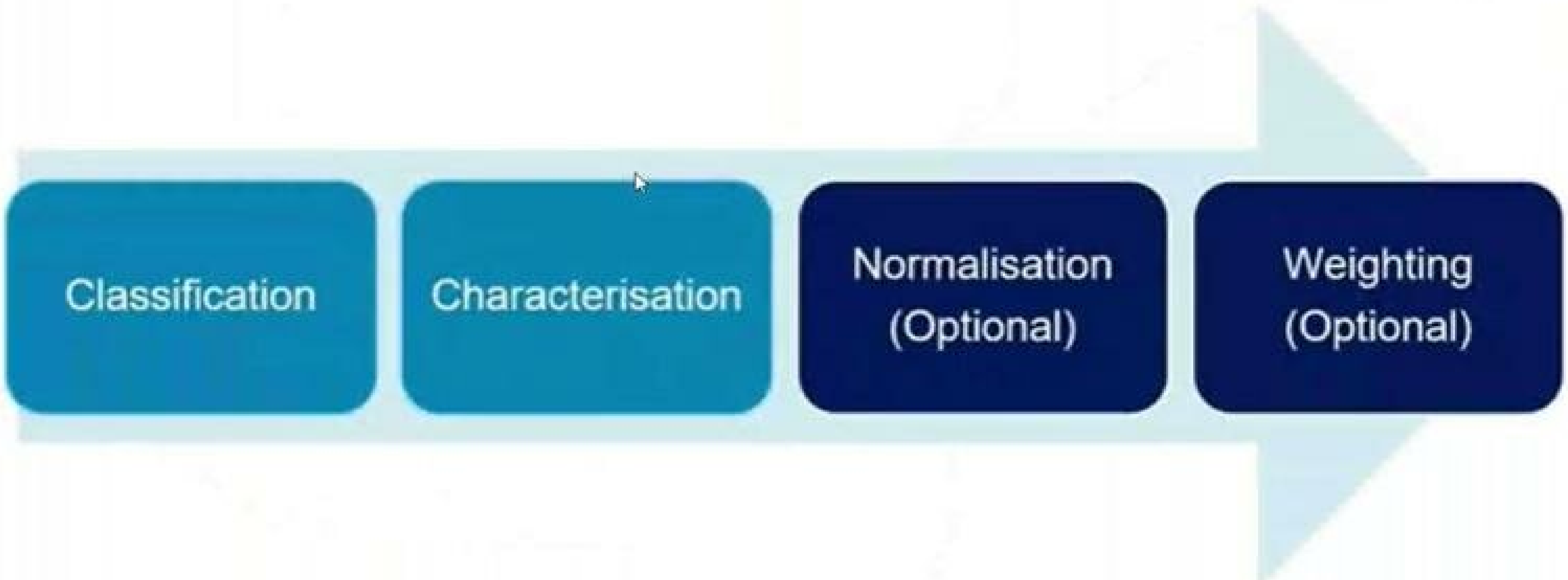
- Mandatory steps
  - ➢ Classification
  - ➢ Characterisation
  - ➢ Commonly used indicators



- Optional steps
  - ➢ Normalisation
  - ➢ Weighting

Overview of LCIA stage

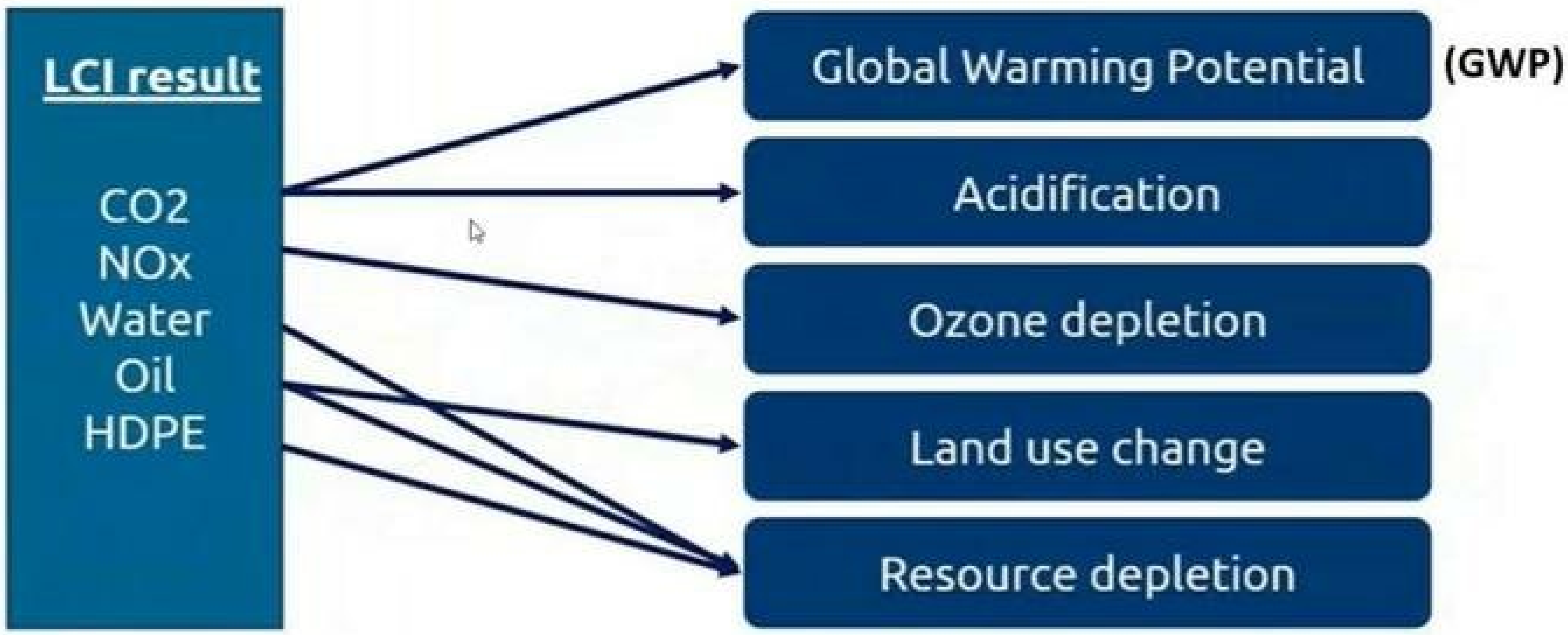
The LCA stage aims to understand and evaluate the magnitude and significance of the potential environmental impacts for a given product system



Mandatory LCIA steps

Classification

Classification - what does this contribute to?



Mandatory LCIA steps

Characterisation

Characterisation - how much does this contribute?

- Quantify contributions to the different impact categories
- LCI results are multiplied by a characterisation factor (CF) which reflect their relative contribution to the environmental impact

LCI results	
CO_2	1 kg
CO	1 kg
CH_4	1 kg

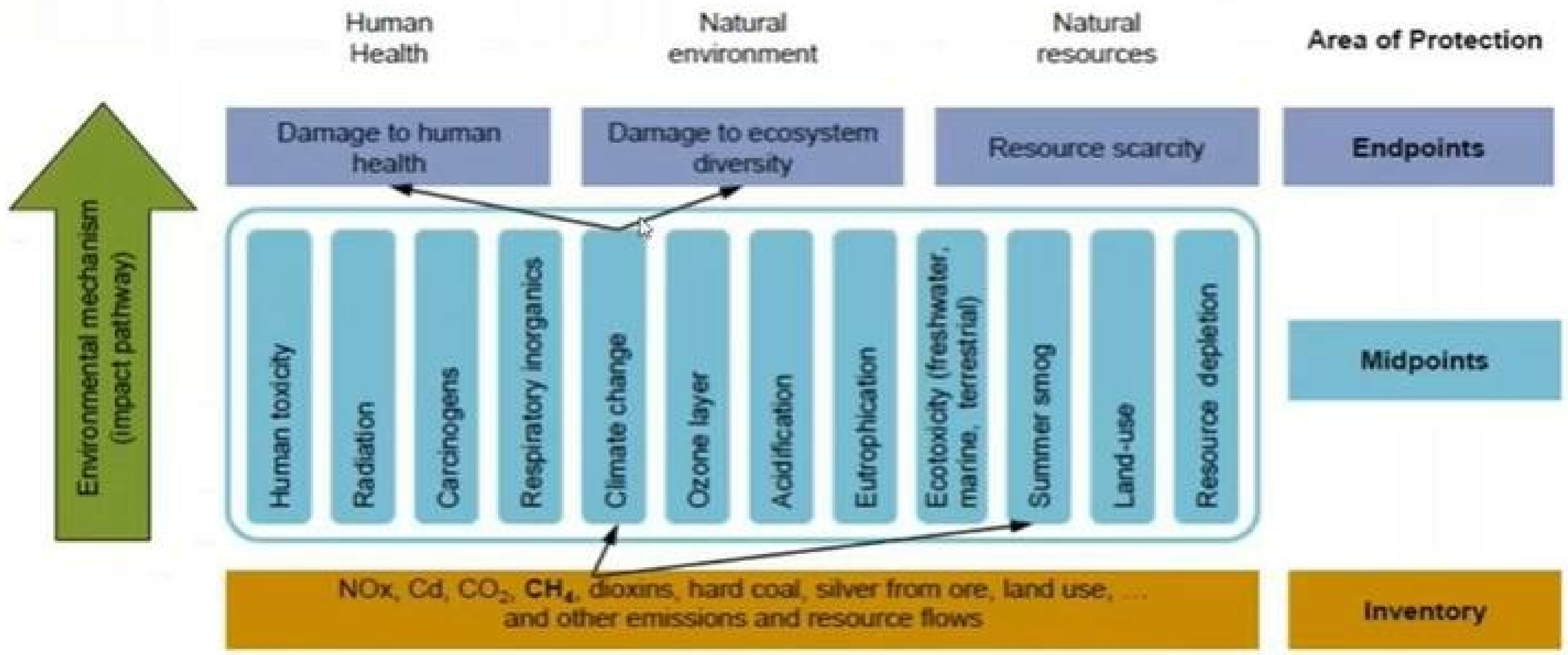
Impact Category

GWP

CF	LCIA
1	1 kg CO_2e
3	3 kg CO_2e
25	25 kg CO_2e

Mandatory LCIA steps

Characterisation Methods



Mandatory LCIA steps

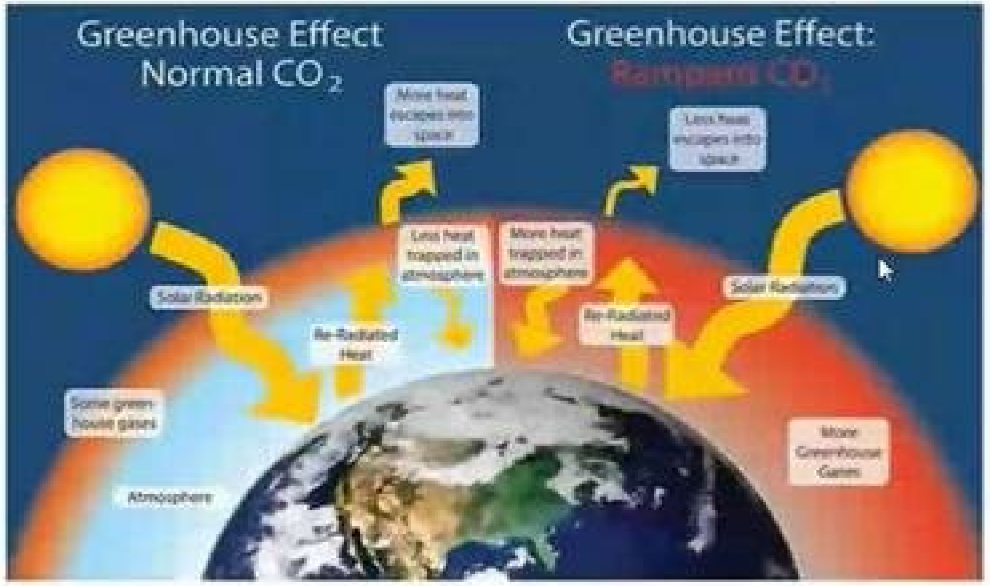
Harmonised models (e.g. ReCipe)

Midpoint Indicators
Global Warming Potential
Ozone Depletion
Human Toxicology
Photochemical Oxidant Formation
Particulate Matter Formation
Terrestrial Acidification
Freshwater Eutrophication
Marine Eutrophication
Terrestrial Eco-Toxicity
Freshwater Eco-Toxicity
Marine Eco-Toxicity
Ionising Radiation
Agricultural Land Occupation
Urban Land Occupation
Natural Land Transformation
Water Depletion
Mineral Resource Depletion
Fossil Fuel Depletion

Endpoint indicators
Damage to human health
Damage to ecosystem quality
Damage to resource availability

Commonly used Environmental Indicators

Global Warming Potential (GWP)



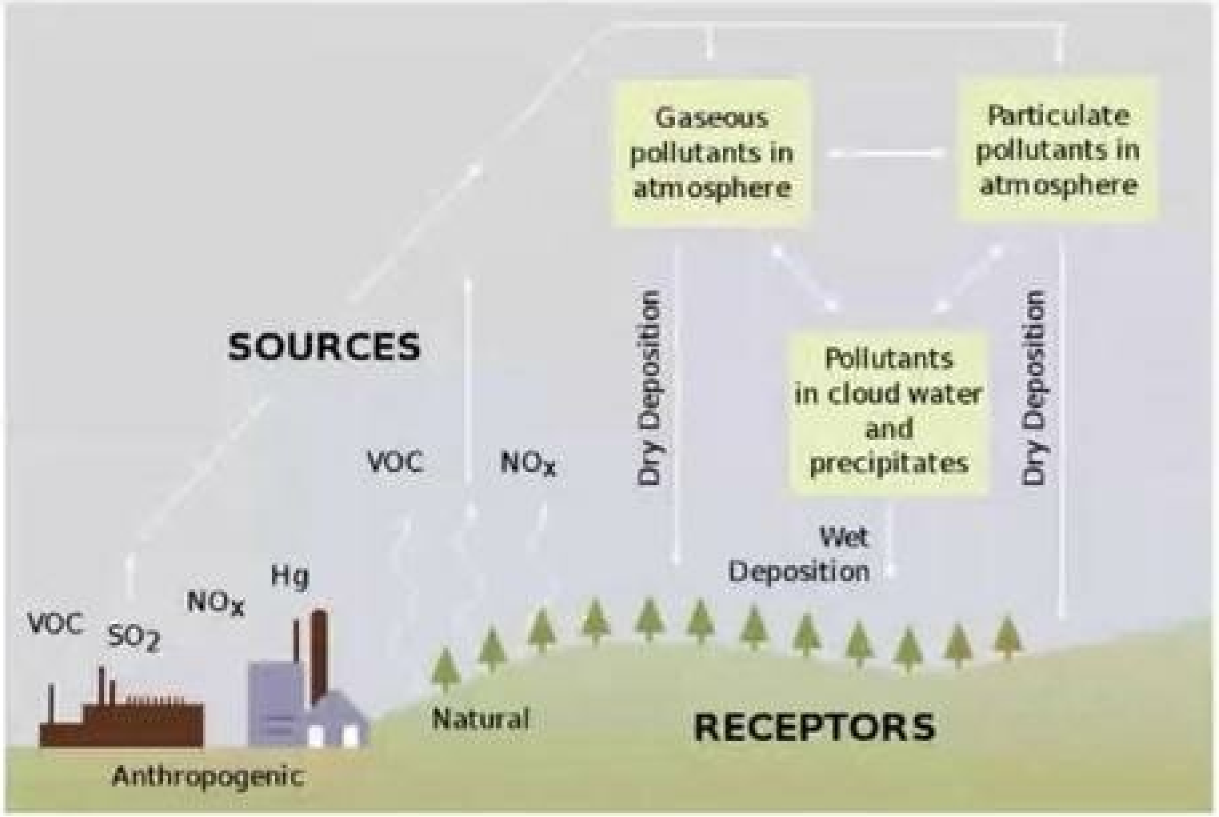
Energy in = Energy out (balance) | Energy in ≠ Energy out (imbalance)

- Based on the radiative forcing of various substances (e.g. CO_2, CH_4)
- Burning fossil fuels and deforestation causes energy imbalance
- A metric based on human contributions to climate change

Commonly used Environmental Indicators

Acidification Potential

- Air emissions which **lower the pH** of water, soils and clouds (regional scale)
- Sulphur oxides (SO_2, SO_x), nitrogen oxides (NO_2, NO_x), ammonia (NH_3)
- **Acid rain** is the most common effect
- Excludes natural emissions sources (e.g. volcanoes)



Commonly used Environmental Indicators

Eutrophication Potential

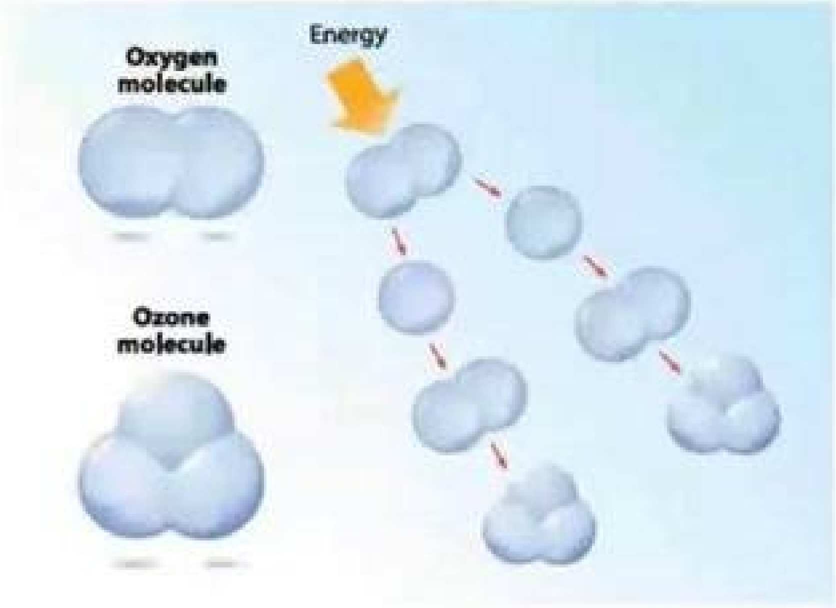
- An indicator of the **nutrient enrichment** of water bodies (marine) or soil (terrestrial) due to nitrogen and phosphorus containing compounds (e.g. fertilizer)

- Nutrients accelerate the growth of algae and other vegetation in water which deplete oxygen

Commonly used Environmental Indicators

Photochemical Ozone Formation

- Photochemical ozone is formed by the reaction of a VOC and NOx catalyzed by sun



- Primarily found in urban regions under hot anticyclonic weather conditions

Environmental Indicators with Greatest Uncertainty

Land Use

Land use includes the following:

- Land occupation: type and location of land use
- Land transformation: change in type, e.g. forest to agricultural land

Two types of land use change:

- Direct (dLUC) and indirect (iLUC)
- dLUC can be measured and/or forecast while iLUC is more difficult to quantify

Summary

- Classification tells you what indicators your inventory results contribute to; characterisation tells you by how much they contribute
- Midpoint and endpoint indicators are considered complementary
- Some environmental indicators are used more than others

Sources & Further reading

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Useful resources

- **GaBi database library:** http://www.gabi-software.com/databases/gabi-databases/

- **European Commission, European Platform on LCA:** http://eplca.jrc.ec.europa.eu/?page_id=86

- **United Nations, Global LCA Data network (GLAD):** https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad/

- **USDA data catalogue:** https://data.nal.usda.gov/life-cycle-assessment

- **ReCipe Model:** https://www.rivm.nl/en/life-cycle-assessment-lca/downloads

- **European Commission report:** Fazio, S., Castellani, V., Sala, et al., 2018. Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods.

- **Water footprint methods:** http://www.wulca-waterlca.org/pdf/Water_Footprint_class_LCAXIII_2013.pdf

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Useful resources

- **GaBi database library:** http://www.gabi-software.com/databases/gabi-databases/

- **European Commission, European Platform on LCA:**
http://eplca.jrc.ec.europa.eu/?page_id=86

- **United Nations, Global LCA Data network (GLAD):**
https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad/

- **USDA data catalogue:** https://data.nal.usda.gov/life-cycle-assessment

- **ReCipe Model:** https://www.rivm.nl/en/life-cycle-assessment-lca/downloads

- **European Commission report:** Fazio, S., Castellani, V., Sala, et al., 2018.
Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods.

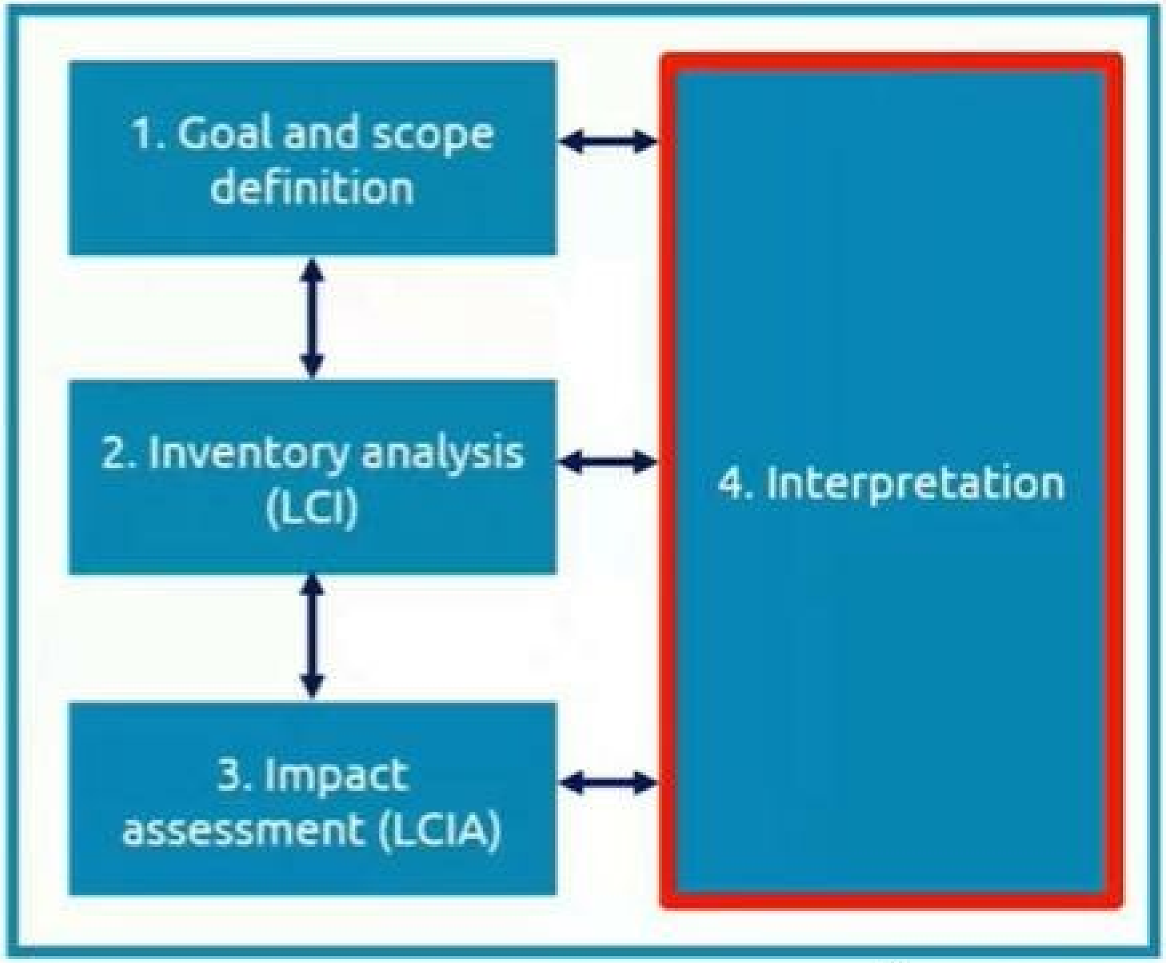
- **Water footprint methods:**
http://www.wulca-waterlca.org/pdf/Water_Footprint_class_LCAXIII_2013.pdf

Module 4. Conducting an LCA:

Interpreting and Communicating results

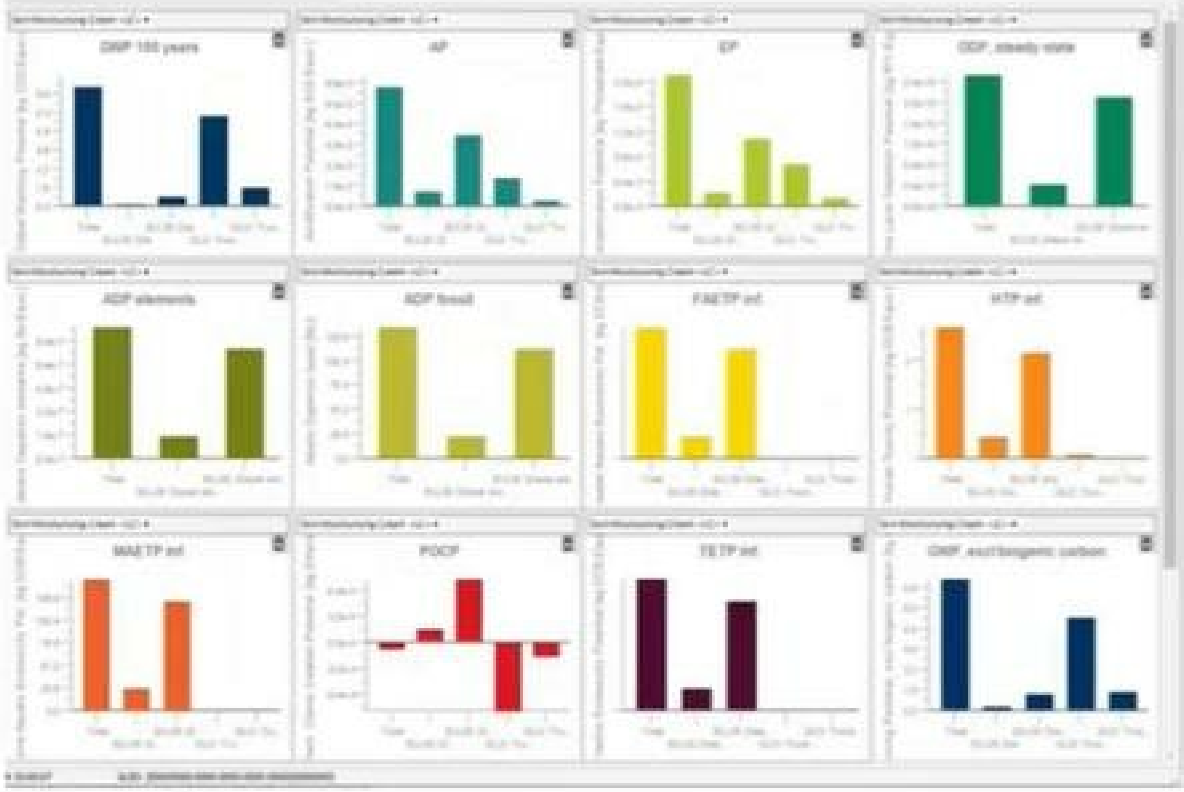
- Basics of interpretation/reporting
  - Hotspot analysis
  - Environmental communication

- Uncertainty
  - Sources of uncertainty
  - analytical methods
  - communicating uncertainty



Basics of LCA Interpretation and Reporting

Overview of Interpretation Stage



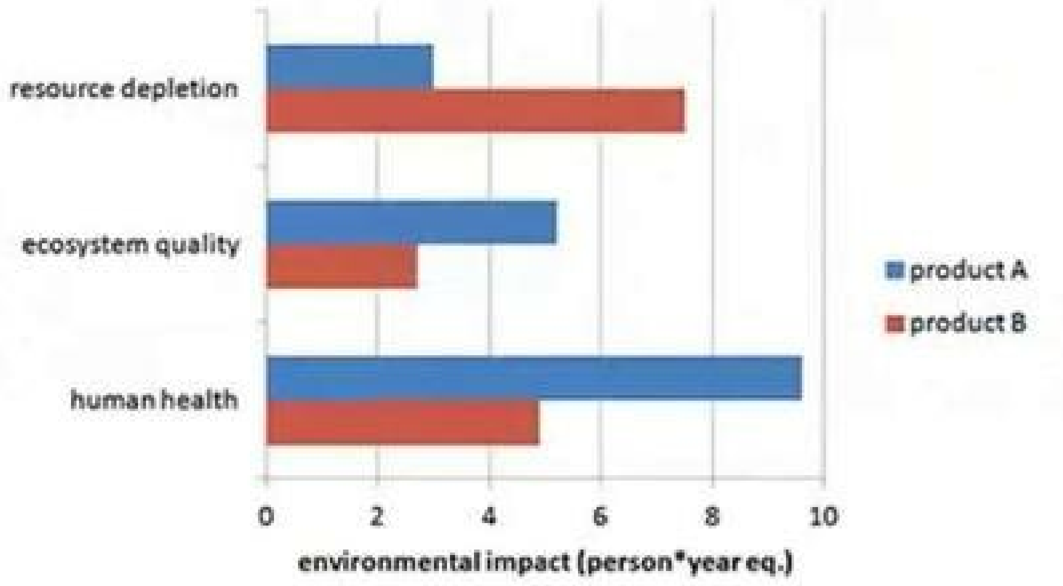
- Present results
- Evaluate results and determine data sensitivity and uncertainty
- Draw conclusion and make recommendations

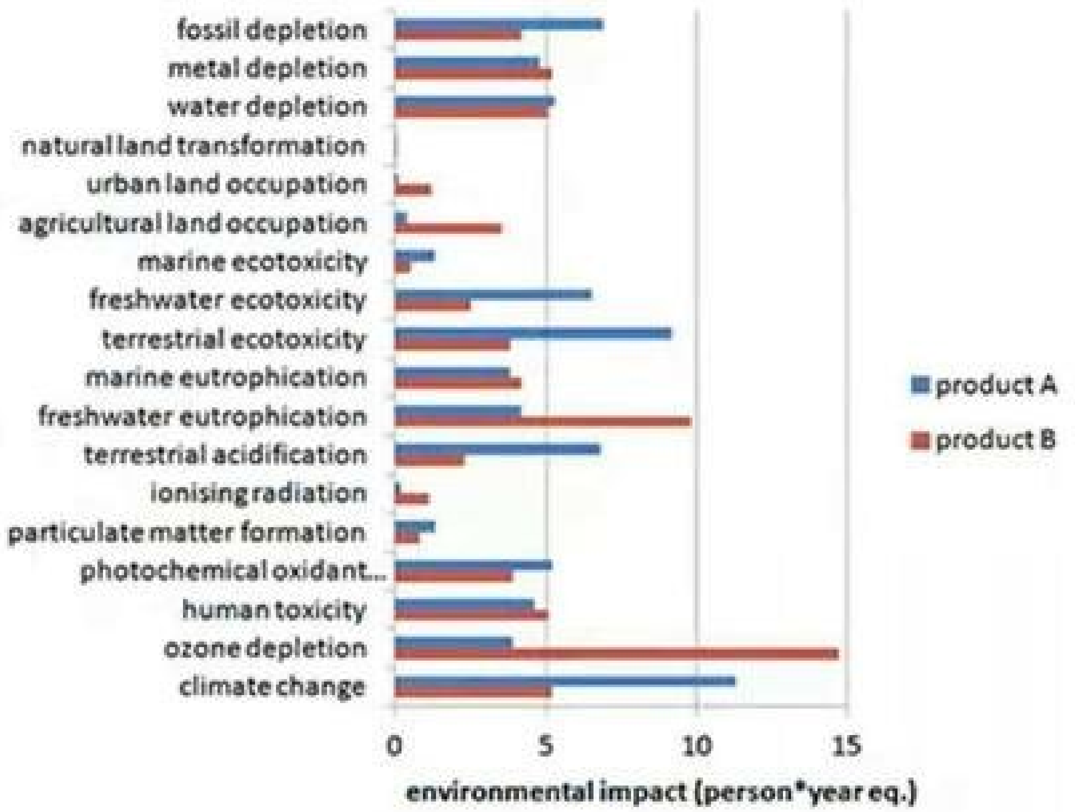
Basics of LCA Interpretation and Reporting

Common elements of LCA reports

A good LCA will

- Not arrive at a single answer
- Provide a specific recommendations
- Disclose all assumptions and uncertainties





Basics of LCA Interpretation and Reporting

Hotspots analysis

Provide focus for action by identifying where your impacts are greatest

Differents levels:

- Impact category (e.g. GWP)
- Life cycle stage
- Unit process
- Elementary flows

Unit Process	Contribution (%)
Process A	18%
Process B	35%
Process C	25%
Process D	15%
Process E	7%

Life Cycle Stage	Contribution (%)
Resource extraction	48%
Product Manufacture	35%
Product distribution	8%
Product use	3%
End of life	6%

Environmental communication

ISO 14063(2020) principles:

- Transparency
- Appropriateness
- Credibility
- Responsiveness
- Clarity

Basics of LCA Interpretation and Reporting

Greenwashing

The act of misleading the public regarding the environmental benefits of a product

95% of consumer products fall foul to at least one of the seven forms of greenwashing

Basics of LCA Interpretation and Reporting

Sin of irrelevance

An environmental claim that is unhelpful for consumers seeking environmentally preferable products (e.g. CFC free)

Misleading - CFCs are already banned by law

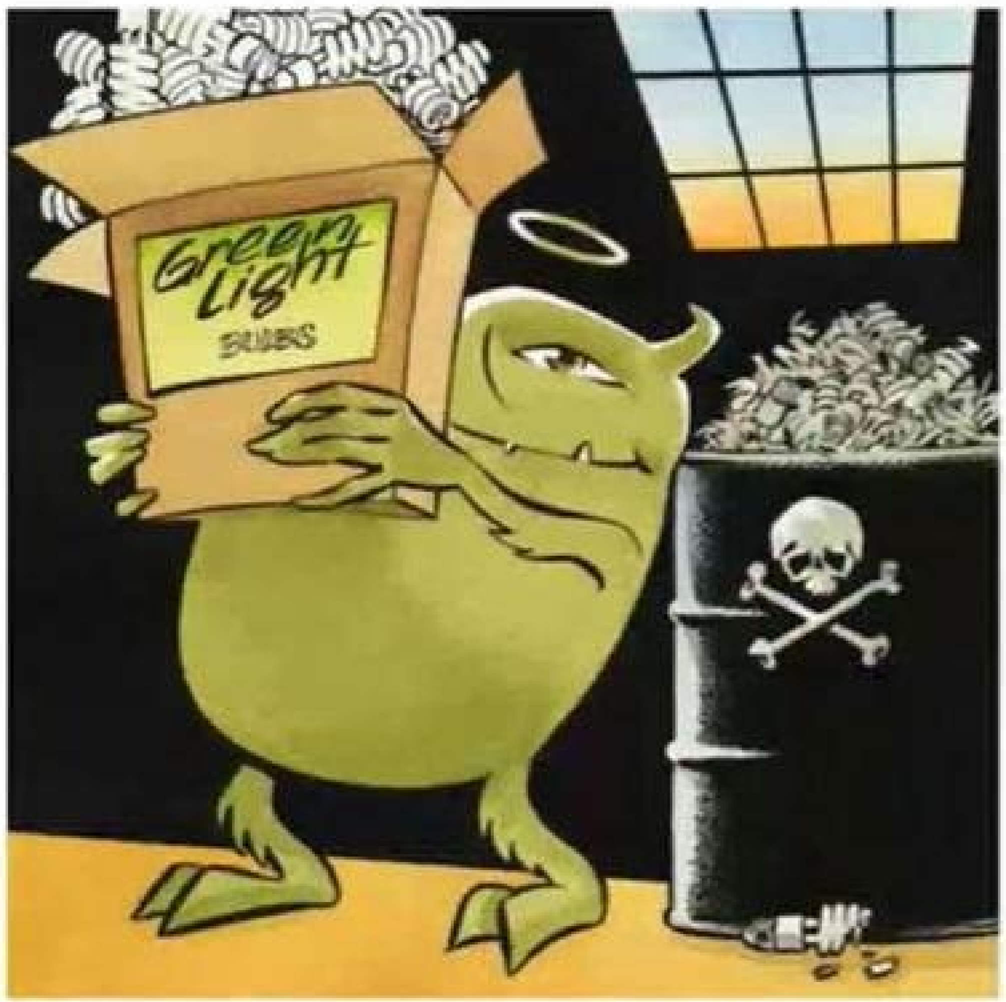
Basics of LCA Interpretation and Reporting

Sin of lesser of two evils

Claims that risk distracting the customer from the greater environmental impacts

Basics of LCA Interpretation and Reporting

Sin of hidden trade-off



Claims that a product is “green” based on a narrow set of attributes

Basics of LCA Interpretation and Reporting

Sin of vagueness

Claims that are so poorly defined or broad that it's real meaning is likely misunderstood by the costumer

Buzz words, e.g.

- Earth friendly
- All natural
- Chemical free
- 100% sustainable
- Non-toxic

Basics of LCA Interpretation and Reporting

Sin of no proof

Claims made without supporting information or a reliable third-party certification

Feds warn plastic bag makers over misleading biodegradable claim

The FTC has warned 15 'bio-friendly' plastic bag companies over deceptive advertising – but will it have any impact on the dubious disposable plastics industry?

MATERIAL 100% RECYCLED

Preventing greenwashing

Most cases of greenwashing is due to ignorance or sloppiness rather than malicious intent

Disseminating results accurately and transparently is key to preventing greenwashing (**LCA is therefore a useful tool**)

Uncertainty and Results presentation

Sources of Uncertainty in LCA projects

Parameters (or data related) uncertainty

- Intrinsic data uncertainty (e.g. equipment precision)
- Reliability of data sources (e.g. primary/secondary, peer-reviewed or not)
- Representativeness of input data (e.g. energy mix

Scenario-related uncertainty

- Modeller choices (e.g. allocation methods, aLCA vs cLCA)

Model-related uncertainty

- Environmental indicators – Midpoint vs. endpoint, (e.g. ReCipe)
- Consequential LCA is associated with market-based uncertainties

Uncertainty and Results presentation

Sensitivity analysis

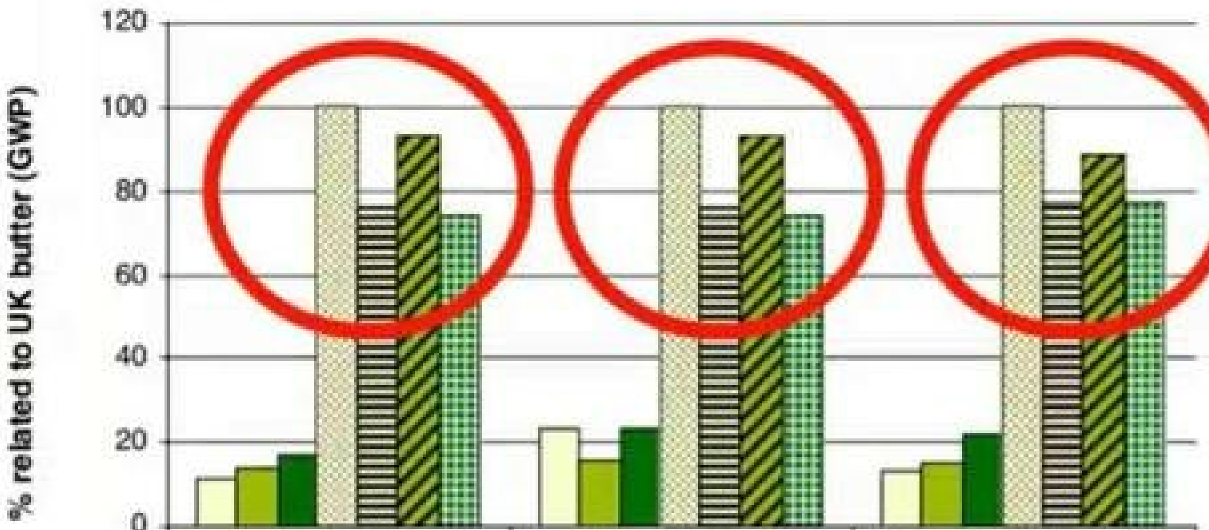
- A method for determining how **robust** your results are by testing their **sensitivity to uncertainty factors**

- To perform a sensitivity analysis, **change one variable at a time** and see **how much the results change** in response, for example:
  - Use a different market value for recycled materials
  - Use different EoL allocation methods
  - Use a different set of characterisation factor

- You need to show that input data, methodological and value choices do not **significantly influence** your LCA results

Uncertainty and Results presentation

Example 1 - Sensitivity analysis



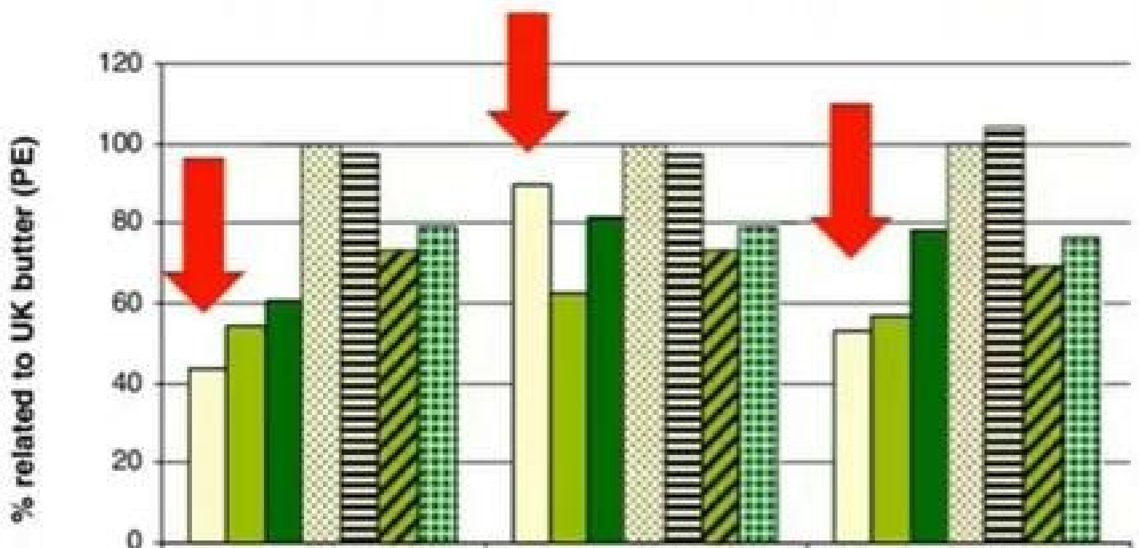
	Base case	Alternative FU	Alternative allocation
UK margarine	11	23	13
DE margarine	14	16	15
FR margarine	17	23	22
UK butter	100	100	100
UK spreadable	76	76	77
DE butter	93	93	89
FR butter	74	74	77

Global warming potential base case compared to results produced with alternative functional unit and allocation method

Nilsson et al., 2010

Uncertainty and Results presentation

Example 2 - Sensitivity analysis



	Base case	Alternative FU	Alternative allocation
UK margarine	44	90	53
DE margarine	54	62	57
FR margarine	61	82	78
UK butter	100	100	100
UK spreadable	97	97	104
DE butter	73	73	69
FR butter	79	79	77

Energy consumption potential base case compared to results produced with alternative functional unit and allocation method

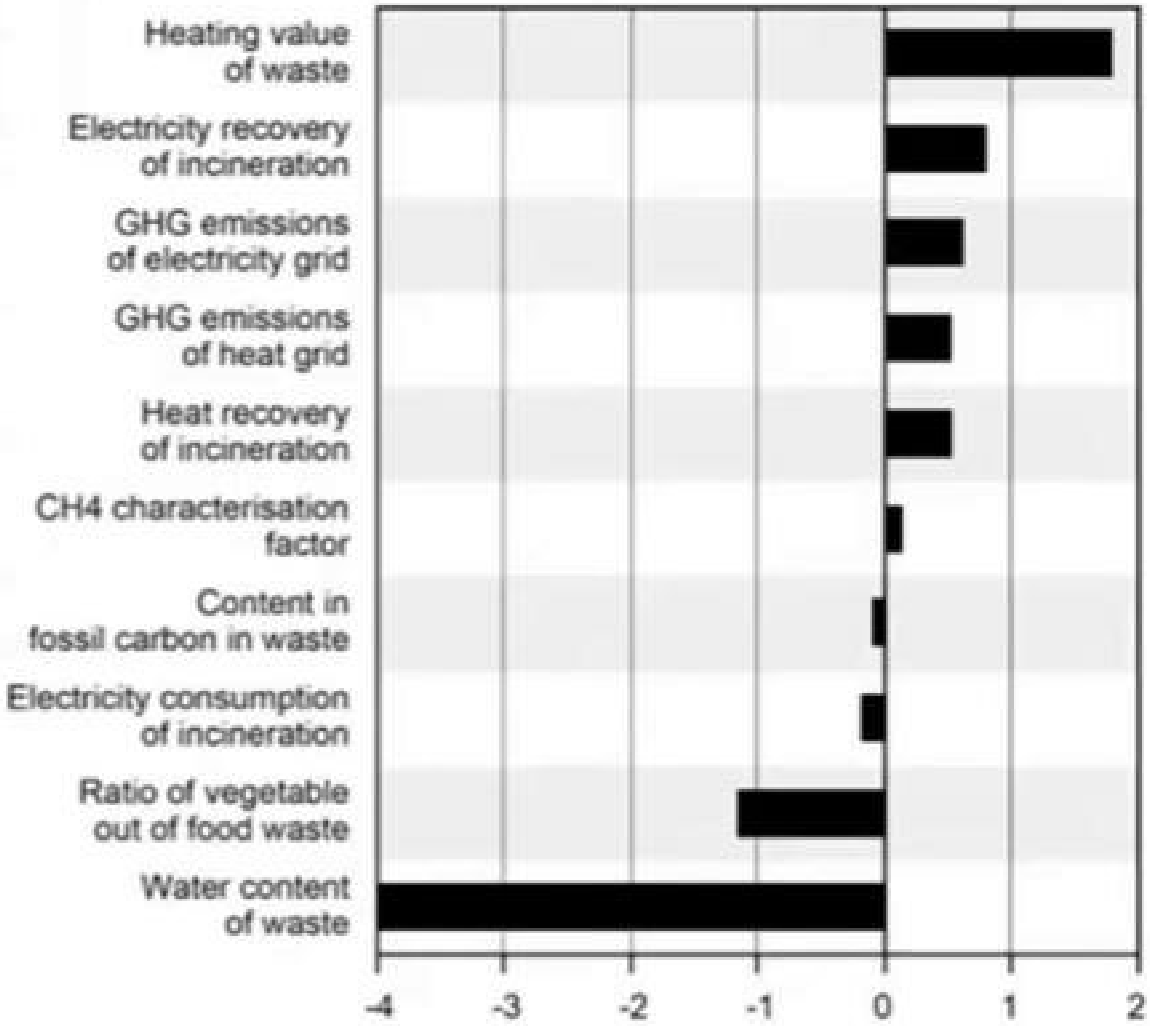
Nilsson et al., 2010

Uncertainty and Results presentation

Use of Sensitivity ratios

Sensitivity ratio (SR) represents the ratio between the relative change in the result vs. the relative change in the input

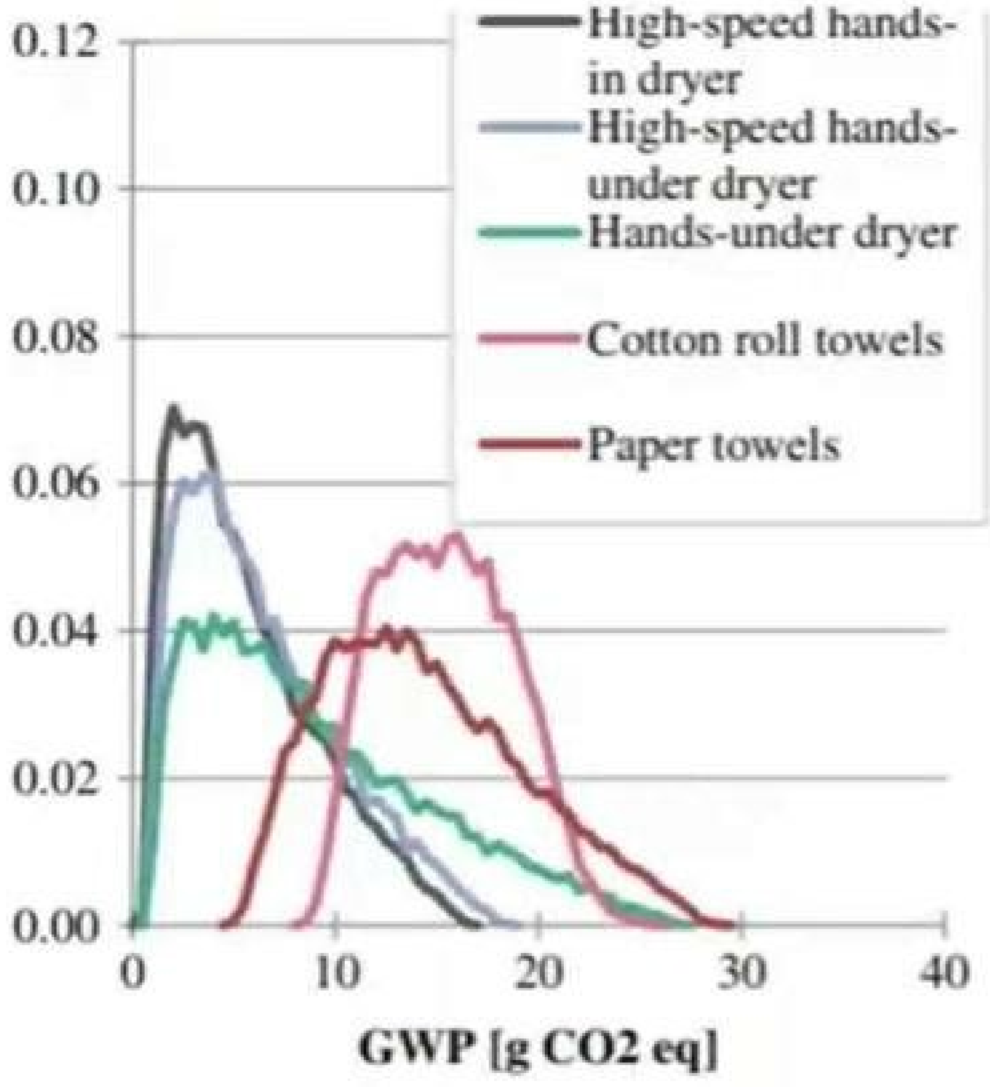
$$SR = \frac{\frac{\Delta result}{initial\_result}}{\frac{\Delta parameter}{initial\_parameter}}$$



SR for incineration scenarios

Uncertainty and Results presentation

Monte-Carlo analysis



Time-driven usage patterns

- Uncertainty analysis describes the set of possible outcomes together their associated probabilities of occurence

- Monte-Carlo numerical approach is often used to vary multiple parameters at once

- 80% probability that paper towels have a higher GWP than high-speed HID

Uncertainty and Results presentation

Communicating uncertainty

Deterministic statements

Gives a single value, no uncertainty given

- Simply A < B

Example :

- Product A: 17.5 kg CO_2e / FU
- Product B: 30 kg CO_2e / FU

How confident are the LCA results?

How do we communicate confidence?

Uncertainty and Results presentation

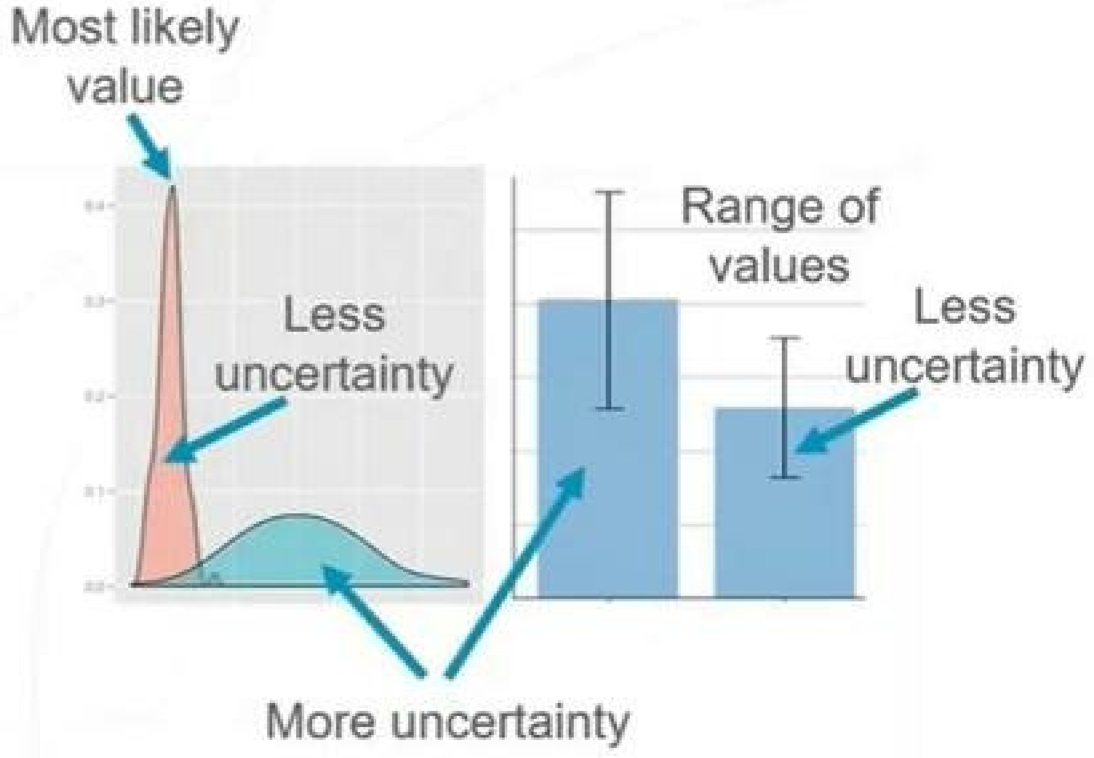
Communicating uncertainty

Probabilistic statements

Gives a range of values, accounts for uncertainty

e.g. Product A contributes 17.5±2.5 kg CO_2e / FU

There is 95% probability that GWP of product A is between 15 and 20 kg CO_2e / FU



Uncertainty and Results presentation

Final thoughts on uncertainty

"A decision made without taking uncertainty into account is barely worth calling decision."

(Wilson et al., 1985)

"Uncertainty analysis and sensitivity analysis shall be done for comparative studies intended for public release."

(ISO 14040)

Summary

- Use hotspot analysis to highlight the most significant areas of concern
- Evaluate and report uncertainty to support interpretation
- Arrive at sensible conclusions and recommendations that link to the study goal
- Transparently report findings to prevent misinterpretation and/or greenwashing accusations.

Sources & Further reading

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