AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Life Cycle Assessment

A brief introduction

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Life Cycle Assessment

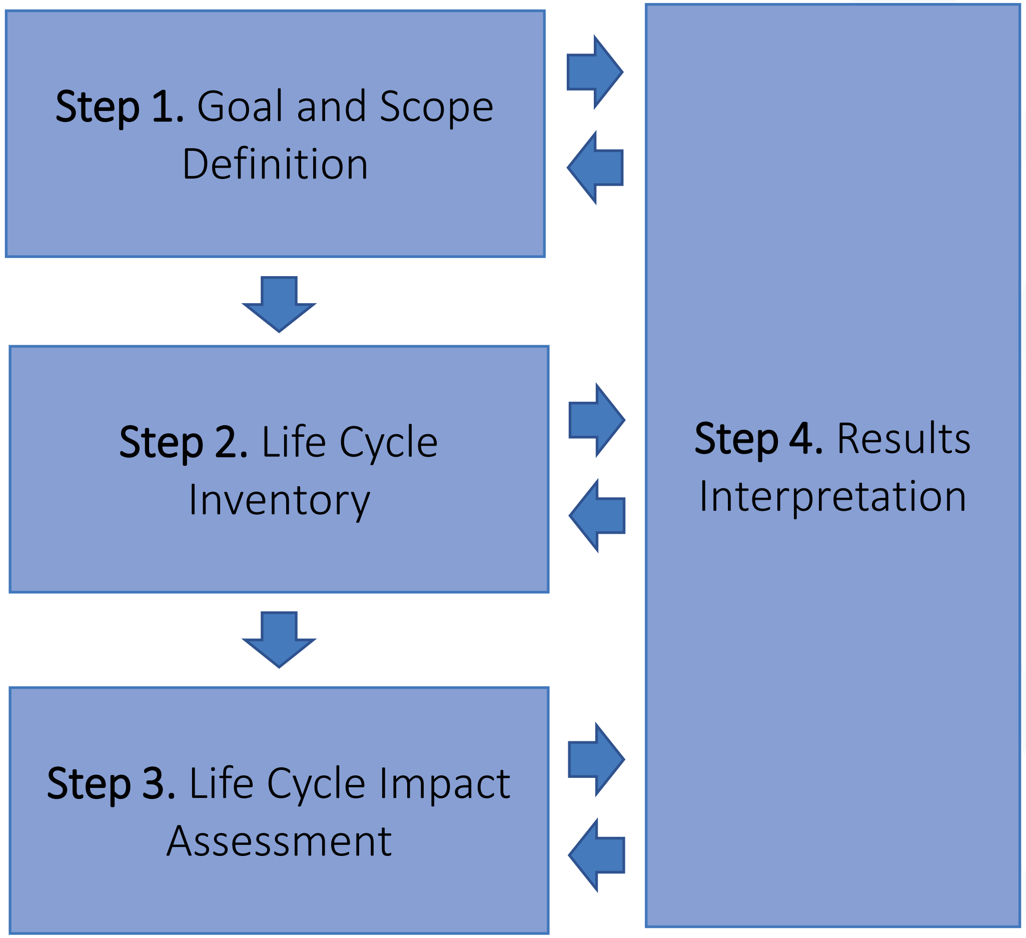
A Brief Definition

- Systematic monitoring and accounting of the flows and stocks of materials and energy in physical units within a system defined in space and time throughout its entire life cycle, and assessment of the associated environmental impact.
- From raw material extraction through production, distribution, use, end-of-life treatment, recycling to final disposal

Steps of a Life Cycle Assessment

According to ISO 14040:2006 - Environmental management

- What is the purpose of the study and the reference flow of the analysis?
- What are the boundaries of the system?



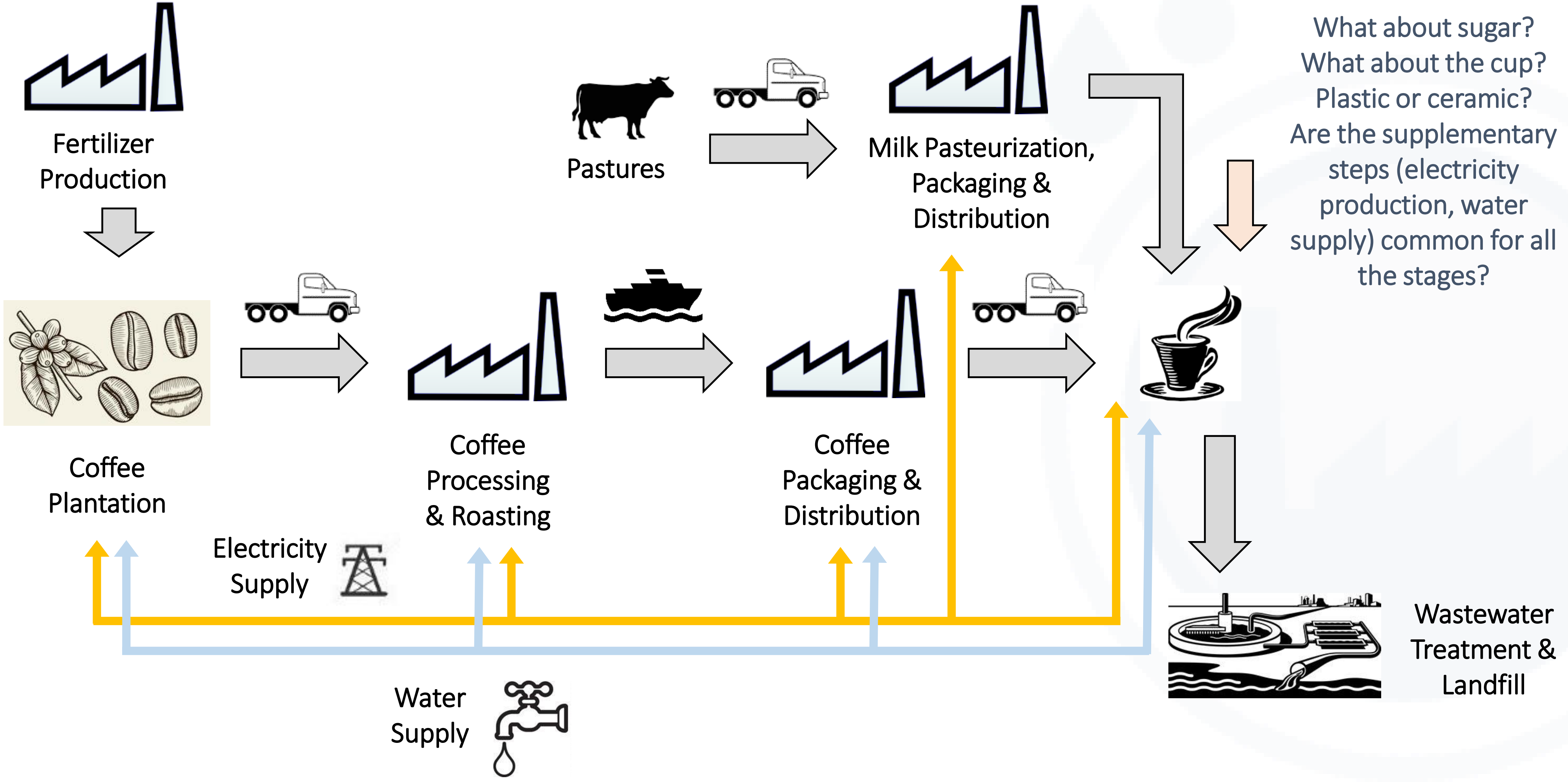
- What are the materials involved in the system
- What are the values of the corresponding flows?

- Which flows correspond to each environmental impact?
- What are the main environmental impacts?

- What do the results indicate?
- What should be the next actions?

Life Cycle Assessment of a cup of coffee

Where do we set the boundaries?



What about sugar?
What about the cup?
Plastic or ceramic?
Are the supplementary steps (electricity production, water supply) common for all the stages?

Step 1. Goal And Scope Definition

- What is the purpose of the study?
  - Who will use the results?
  - Identification of hot spots? Comparison of alternative products? Comparison of alternative procedures? Assess the consequences?
- What are the boundaries of the system?
- What will be the reference flow of the analysis?
  - Reference Flow: The flow to which all other input and output flows quantitatively relate
  - Functional Unit: The numeric value of the reference flow, a reference to which results are normalized and compared

Life Cycle Boundaries

Common variants that can be used

- Cradle-to-grave
  - From resource extraction ('cradle') to the disposal stage ('grave')
- Cradle-to-gate
  - From resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer). The use and disposal stages are not included
- Cradle-to-cradle or closed loop production
  - Specific type of cradle-to-grave assessment, where the disposal stage for the product is a recycling process.
- Gate-to-gate
  - Specific type of LCA focusing on one value-added process in the entire production chain
- Well-to-wheel
  - Specific LCA used for transport fuels and vehicles

Life Cycle Boundaries

Foreground vs Background System

- An important element in the life cycle approach is the distinction between “foreground” and “background” systems
  - Foreground System: The set of processes whose selection or mode of operation is affected directly by decisions based on the study
  - Background System: Includes all other activities, which deliver energy and materials to the foreground system, usually via a homogeneous market

Functional Unit

- The functional unit provides a reference to which results are normalized and compared
- Appropriate definition of functional unit to allow comparisons
- For a beverage bottling company possible functional units can include:
  - 1 bottle of beverage
  - 1 litre of beverage
  - 1 day/year of operation
  - …

What about multiple products?

- System Expansion
  - Co-products are considered alternatives to other products on the global market
- Impact Allocation based on:
  - Economic factors/Value allocation
  - Mass ratio between products
  - Other methods depending on the product/sector

Step 2. Life Cycle Inventory

- Life cycle inventory (LCI) analysis involves creating an inventory of flows entering and leaving every process in the foreground system, i.e. the system within the defined system boundaries
- In a typical LCA methodology, the inventory of flows must be related to the functional unit defined in the goal and scope definition

Step 3. Life Cycle Impact Assessment

Three mandatory elements

- Selection of relevant impact categories and the corresponding indicators
- Classification and characterization
  - Inventory flows are assigned to specific impact categories and are characterized into common equivalence units
- Impact calculation
  - Inventory flows are used to provide an overall environmental impact score per category

Step 3. Life Cycle Impact Assessment

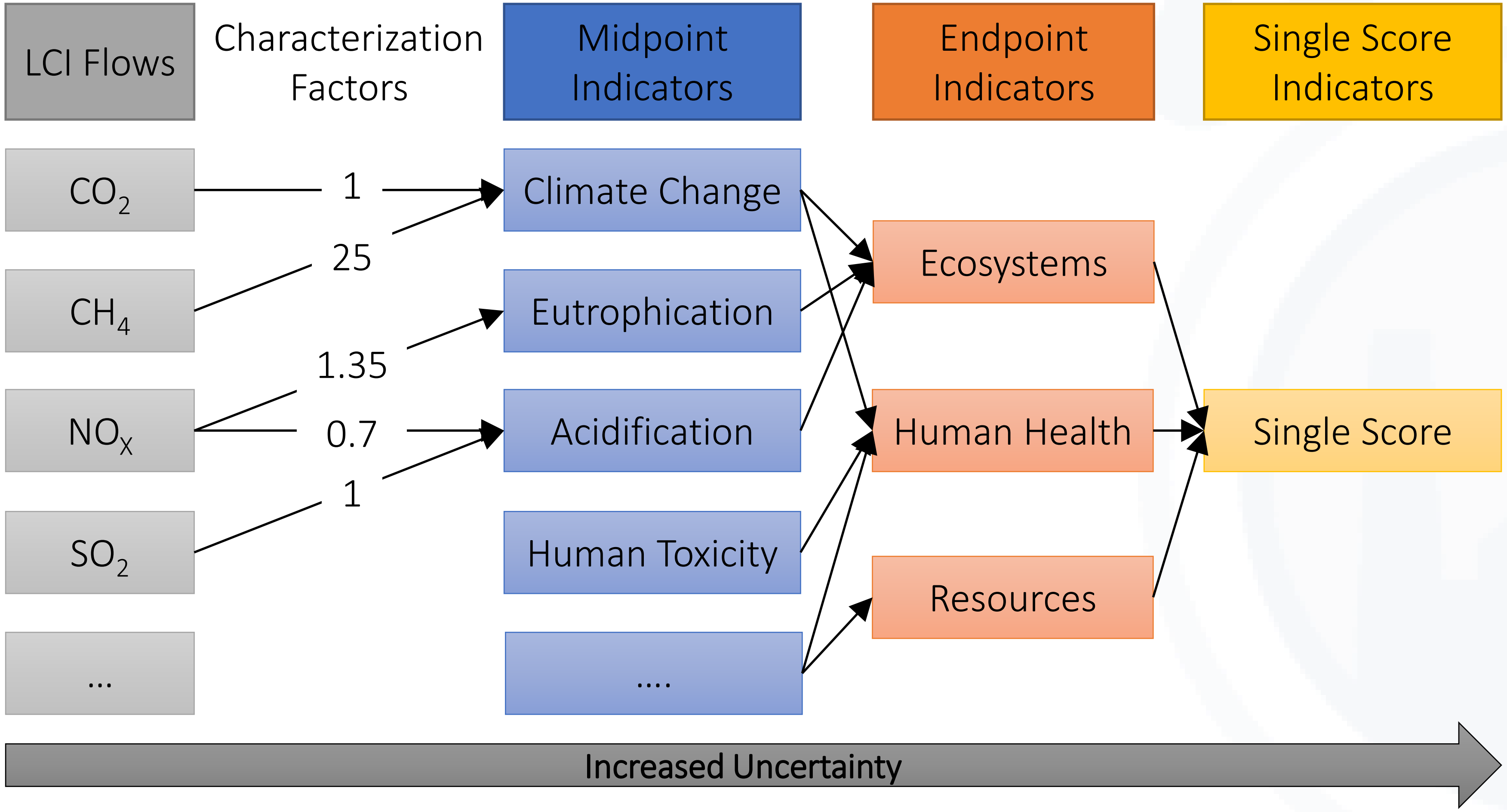
Two optional elements

- Normalisation of different characterised impact scores using a common reference
  - Facilitate comparisons across impact categories
- Weighting among the environmental impact categories
  - Reflect the relative importance of the impacts considered in the study
  - May also lead to a single score indicator, which would make easier the comparison between different studies (but with increased uncertainty and subjectivity)

Selecting Impact Categories

- An impact category represents a certain environmental issue of concern, to which the life-cycle inventory flow can contribute and thus a value may be assigned
- The selection of the most appropriate ones is case specific and is directly related to the information required to make concrete proposals for specific policies
- Distinction between midpoint and endpoint categories
  - Midpoint impact categories refer to specific environmental issues (such as climate change, acidification, eutrophication, human toxicity, etc.)
  - Endpoint categories refer to the three generally recognized issues of concerns (degradation of ecosystems, negative impact in human health and depletion of natural resources)

Midpoint vs Endpoint



Classification and characterization

- Quantify the impact of the elementary flows by aggregating the inventory flows into a limited number of midpoint or endpoint indicators
  - Classification: Organize and, if possible, combine the life cycle inventory flows into impact categories
  - Characterization: Quantify the extent to which each resource/emission contributes to different environmental impact categories
- The environmental impact for a given category (c) is expressed as a score (ESc) in the common unit for all contributions within the category

Characterisation Factors

- Factors for Foreground Systems
  - Retrieved from LCA databases
    - A widely used one (CML-IA) can be retrieved from the University of Leiden Department of Industrial Ecology webpage
  - Vary based on the method used
- Factors for Foreground Systems
  - More difficult to retrieve
  - The background system is usually considered as a homogeneous market, so that individual plants and operations normally cannot be identified
  - Environmental impact factors are usually retrieved from databases, mainly provided with commercial and publicly available LCA software
  - Selection of which ones to include

Climate Change

Climate Change	
Description	Climate change is defined as the impact of human emissions on the radiative forcing (heat radiation absorption) of the atmosphere, which results in the rise of the earth's surface temperature (greenhouse effect).
Indicator	Radiative forcing expressed as Global Warming Potential (GWP): Reflects the relative effect of the emissions of greenhouse gases into the air, considering a fixed time period (i.e. 100 years).
Unit of Measure	$kgCO_{2,eq}$
Characterization factors of relevant supplementary resources / emissions	Carbon Dioxide (CO_2): 1 t $CO_{2,eq}/tCO_2$ Methane (CH_4): 25 $tCO_{2,eq}/tCH_4$ Nitrous Oxide (N_2O): 298 $tCO_{2,eq}/tN_2O$ Methylene Chloride (CH_2Cl_2): 8.7 $tCO_{2,eq}/tCH_2Cl_2$ Hydrofluorocarbons; e.g. HFC-134a: 1430 $tCO_{2,eq}$/tHFC-134a Perfluorocarbons; e.g. CF_4: 7390 $tCO_{2,eq}/tCF_4$ Sulphur hexafluoride (SF_6): 22800 $tCO_{2,eq}/tSF_6$

Eutrophication

Eutrophication	
Description	Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients, which may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems.
Indicator	Eutrophication Potential (EP): Measures the fraction of nutrients, which cause over-fertilization of water.
Unit of Measure	$kgPO_{4,eq}$ or $kgNO_{x,eq}$
Characterization factors of relevant supplementary resources / emissions	Ammonia (NH_3): 0.35 $kgPO_4^{3-}{}_{,eq}/kgNH_3$ Nitric Acid (HNO_3): 0.1 $kgPO_4^{3-}{}_{,eq}/kgHNO_3$ Nitrogen Total (N): 0.42 $kgPO_4^{3-}{}_{,eq}/kgN$ Nitrogen Oxides (NO_x): 0.13 $kgPO_4^{3-}{}_{,eq}/kgNO_x$ Nitrous Oxide (N_2O): 0.27 $kgPO_4^{3-}{}_{,eq}/kgN_2O$ Phosphoric Acid (H_3PO_4): 0.97 $kgPO_4^{3-}{}_{,eq}/kgH_3PO_4$ Total Phosphorus (P): 3.06 $kgPO_4^{3-}{}_{,eq}/kgP$ Phosphorus Oxide (P_2O_5): 1.34 $kgPO_4^{3-}{}_{,eq}/kgP_2O_5$ Chemical Oxygen Demand (COD): 0.022 $kgPO_4^{3-}{}_{,eq}/kgCOD$

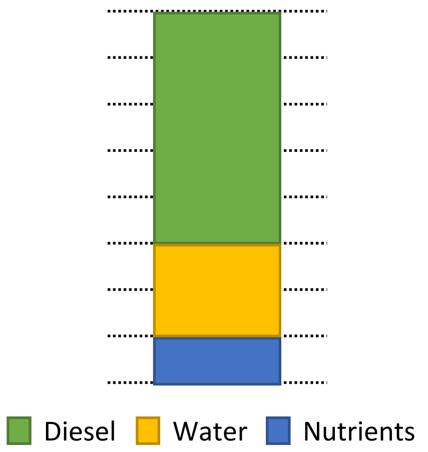
Step 4 – Results Interpretation

- Many numbers/tables/charts!
- Identify the most significant issues based on the results of the environmental assessment
- Identify the stages/processes/flows that mainly contribute to the environmental impact
- Formulate conclusions and recommendations, according to the goal and scope of the study
- Explain the limitations of the analysis
- Provide recommendations for progressively improving the performance of the system

What can LCA offer?

Identify Hot Spots

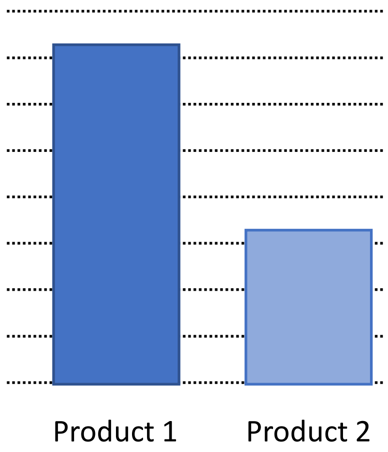
Identify the stage or the flow that is responsible for the higher share of environmental impact



Breakdown of the environmental performance of process X

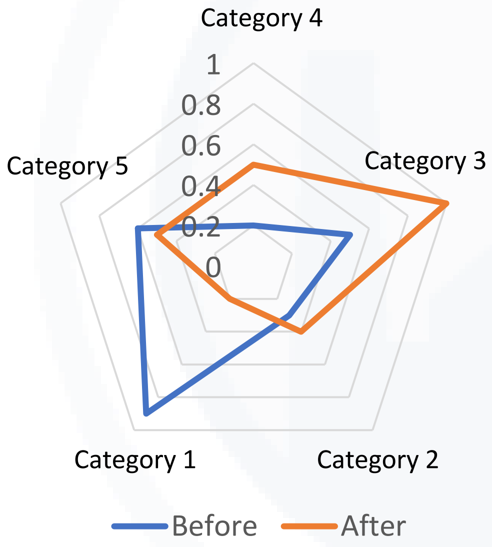
Compare Alternative Processes/Products

Compare the environmental performance of two similar products, with different production methods



Estimate the Consequences

Assess the environmental performance of a process before and after certain interventions



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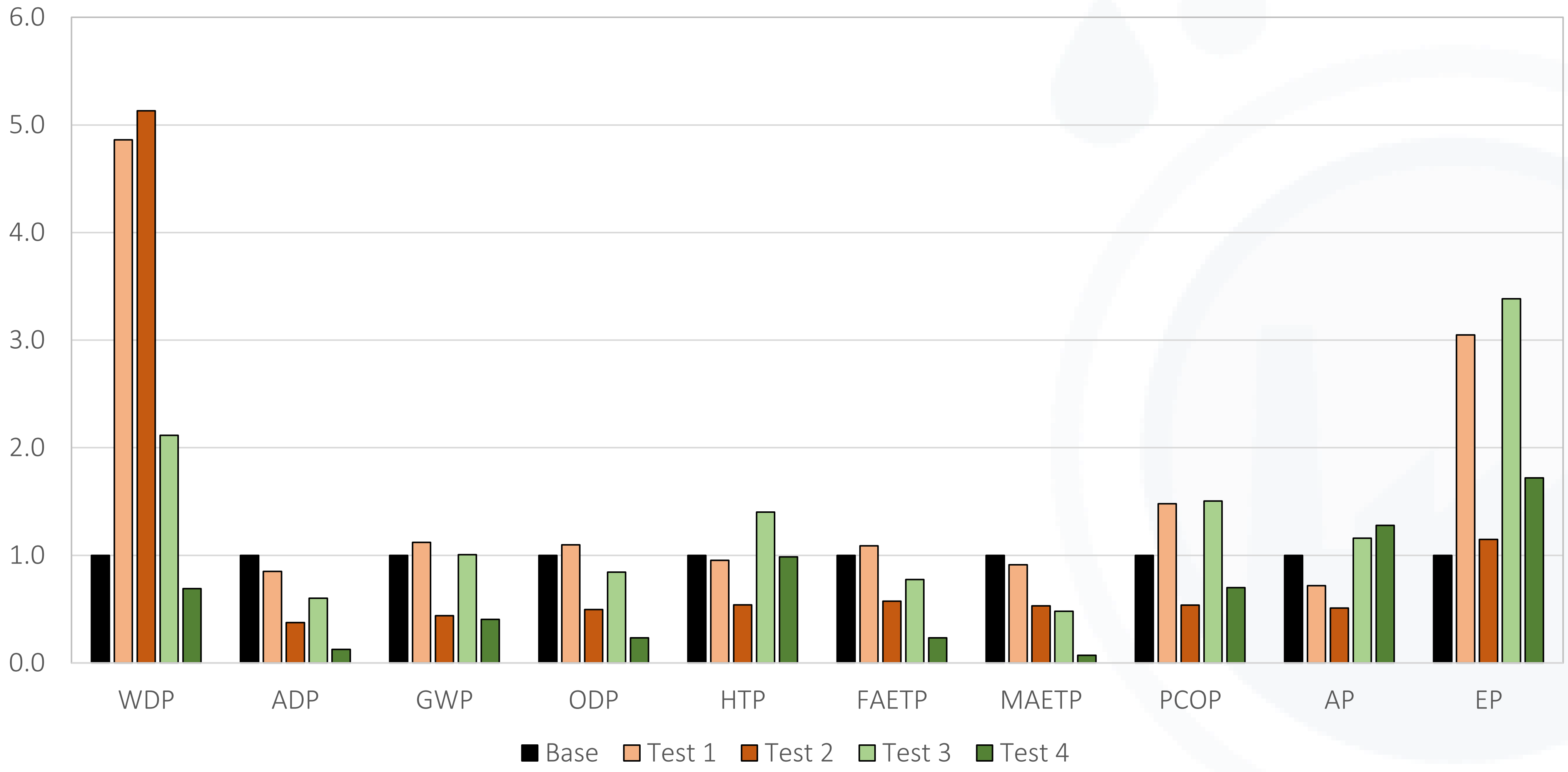
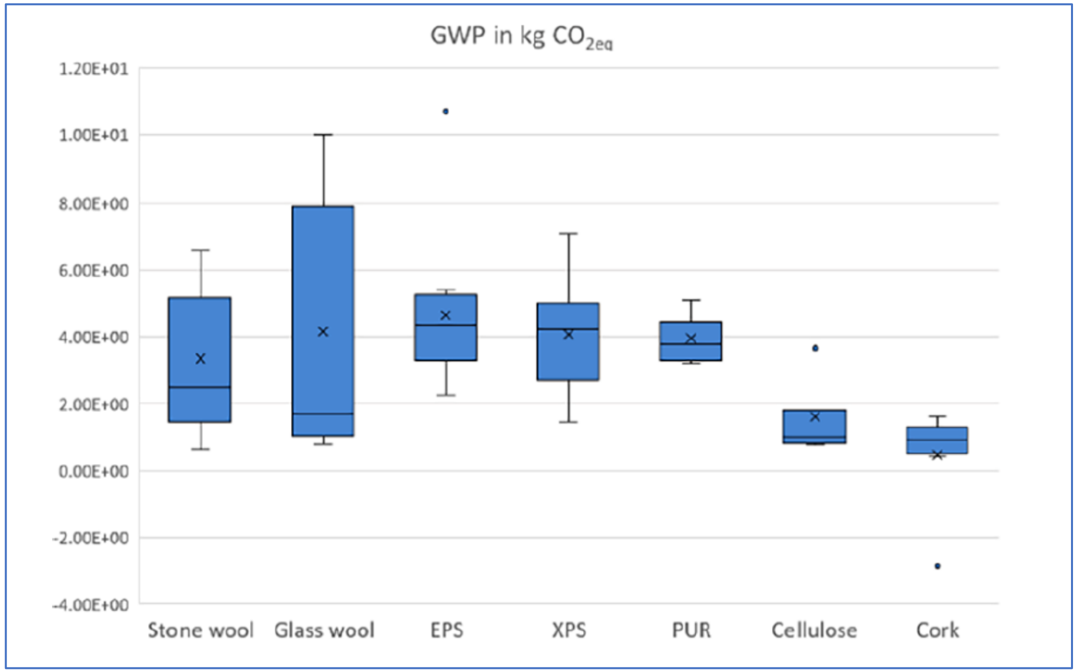
Marketing Tool

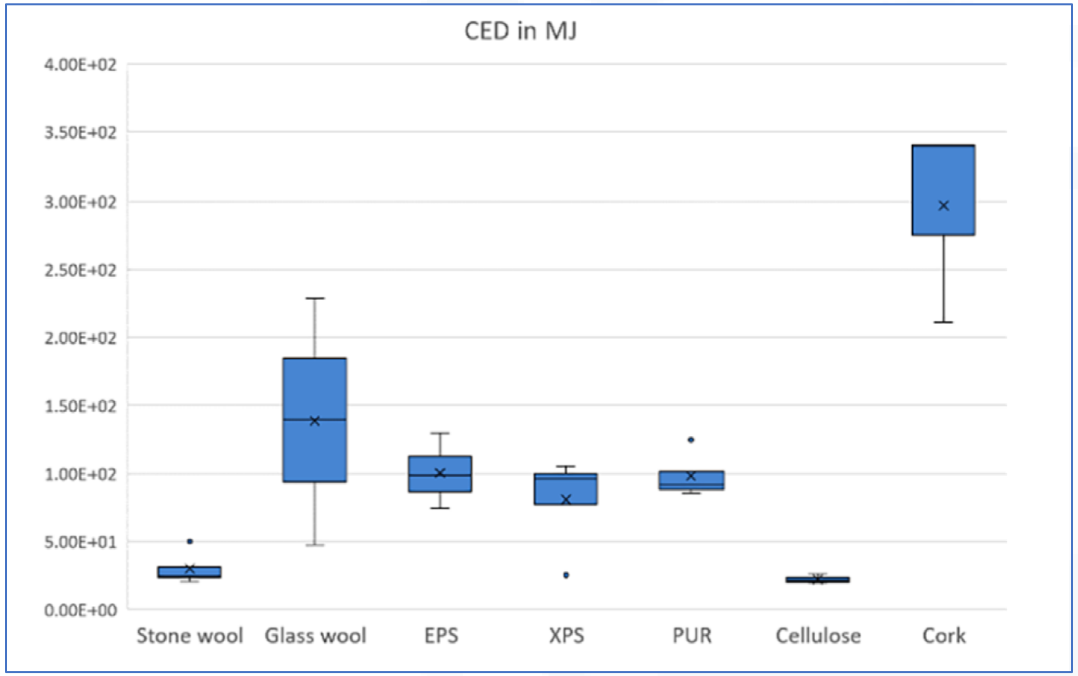
Source: The Life Cycle of a Jean – Understanding the environmental impact of a pair of Levi's 501 jeans
https://www.levistrauss.com/wp-content/uploads/2015/03/Full-LCA-Results-Deck-FINAL.pdf

Product Development



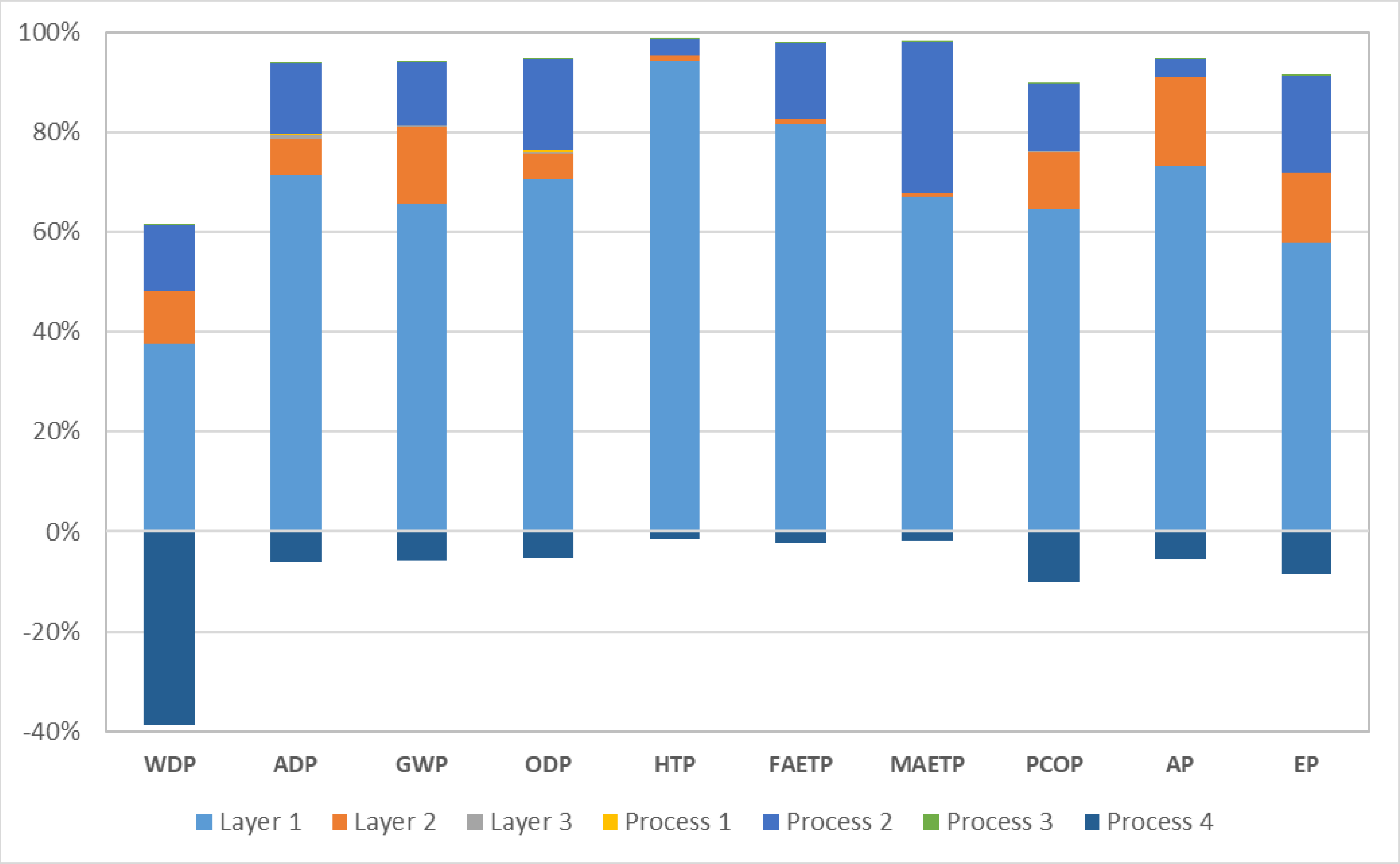
Benchmarking Products





Source: Füchs, S., Rheude, F., Roder, H. Life cycle assessment (LCA) of thermal insulation materials: A critical review, *Cleaner Materials*, 5 (2022) 100119

Identify the hot spots



Compare alternative products

		Product with Recycled Raw Material	Product with Virgin Raw Material	
	Carbon Footprint	8.2 $kgCO_{2,\ eq}/kg$	10.5 $kgCO_{2,\ eq}/kg$	-21.9%
	Water Footprint	0.67 m^3/kg	0.71 m^3/kg	-4.5%
	Eutrophication Potential	0.014 $kgPO_4/kg$	0.014 $kgPO_4/kg$	-0.8%
	Resource Depletion	102.4 MJ/kg	162.7 MJ/kg	-37.1%