Fundamentals in
Life Cycle Assessment

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Erasmus Mundus

SMACCs

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Industrial Ecology | Historical Background

Adoption of the term "Industrial Ecology"

Industrial Ecology

*"….the analogy between the industrial ecosystem concept and the biological ecosystem is not perfect but much could be gained if the **industrial system were to mimic the best features of the biological analogue**"*

(Frosch and Gallopoulos, 1989)

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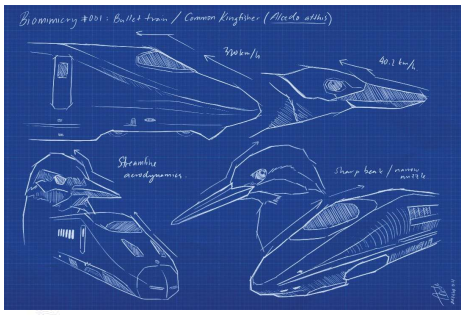
Defining Industrial Ecology | Biomimicry design

Dragonfly inspired design

Beetle inspired design



Japanese "Bullet Trains"

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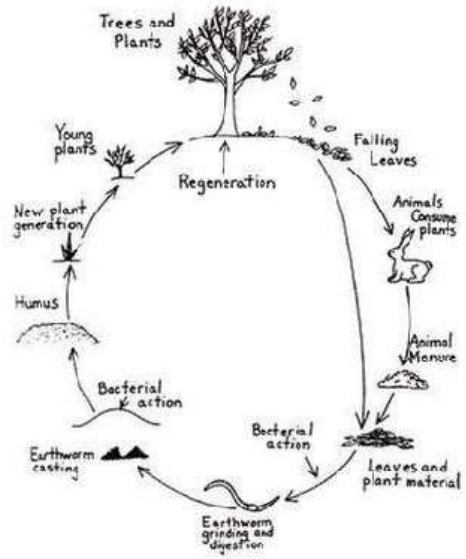
Defining Industrial Ecology | Waste as a resource



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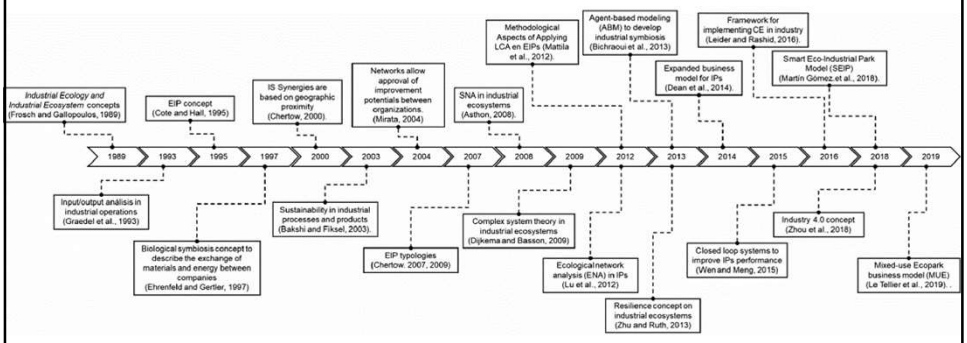
Evolution of Industrial Ecology



Source: Barrera G.A.F., Gabarrell i Durany X., Rieradevall Pons J., Erazo J.G.G. (2021) Trends in global research on industrial parks: A bibliometric analysis from 1996–2019. Heliyon 7, e07778

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Defining Industrial Ecology

There is no any universally accepted definition of the term "industrial ecology"

However, most definitions include similar features

Industrial Ecology

Specifically:

- A **systemic approach** for the **interactions** between industrial and ecological systems
- Analysis of the material and energy **transformations**
- Conversion **from linear** (open) processes **to circular (closed-loop)** processes so that waste from one industry is used as an input for another
- Attempt to **reduce the environmental impact** of industrial systems on the environment
- Advancing the idea that industrial systems can more effectively and sustainably **mimic** natural systems

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Key targets of Industrial Ecology

- The primary goal of industrial ecology is to promote **sustainable development** at **global**, **regional** and **local levels**

Industrial Ecology

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Key targets of Industrial Ecology

- Three basic principles of industrial ecology:
  1. The **preservation of health** of the natural environment and the human capital
  2. The promotion of **environmental justice**, both between generations and also between societies
  3. The **sustainable use** of natural **resources**

Industrial Ecology

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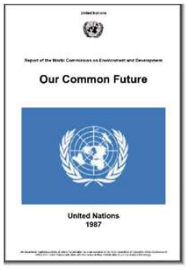
Key targets of Industrial Ecology

It is important that industrial activities do not cause catastrophic disruption to ecosystems or slowly degrade their structure and function, endangering the planet's life support system



ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Industrial Ecology

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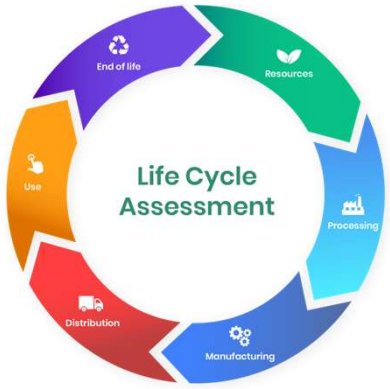
Tools to support Industrial Ecology

Industrial Ecology



Carbon Footprint

Water Footprint

Tools for measuring environmental performance

ENVIRONMENTAL MANAGEMENT SYSTEM ISO 14001

eco label

EPD®

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KYKLOS 4.0

Circular Manufacturing Framework

www.kyklos40project.eu

Industrial Ecology

01 Decentralized Interoperable Agent-Based B2B Marketplace Platform

02 Virtual Production Line Orchestration Module & Interoperative Fog Architecture Framework

03 Continuous Deep Learning Toolkit for Operational Metrics

04 Tailored Circular Manufacturing and Mass Customization Services

05 Big Data Aggregation and Integrated DSS for Optimizing Production Capacity

06 KYKLOS 4.0 Auditing Mechanisms

Kyklos 4.0 key objectives

07 Product Data Management

08 Product Life Cycle Monitoring / Customer Feedback

09 KYKLOS 4.0 Production Line "Smartification" System

10 Additive Manufacturing Simulation Modules

11 KYKLOS 4.0 Automated Refurbishment Certification

KYKLOS 4.0 aims at providing a Technology Ecosystem which creates and supports the configurations, methodologies, production techniques, decisions and actions at all different levels and stages of the manufacturing value chain to achieve:

- Increased energy efficiency
- Decreased use of raw materials
- Customer-centricity
- On-demand manufacture

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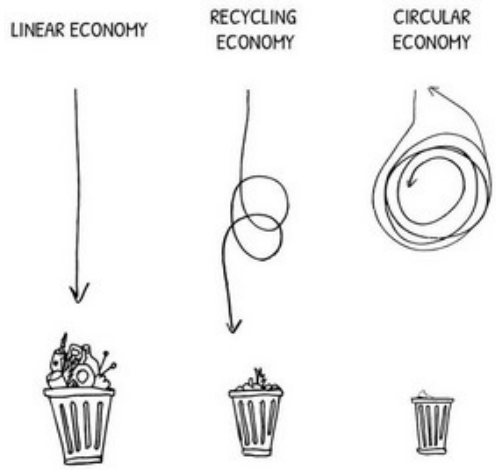
From linear to circular



Κυκλική Οικονομία

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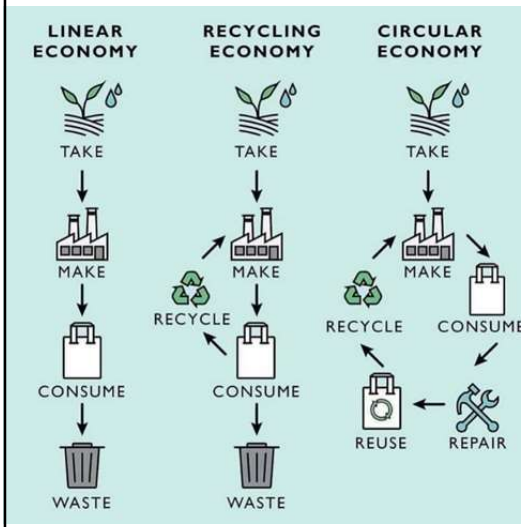
From linear to circular



Recycling vs Circular Economy

- Business Model vs Business Need
- Recycling begins only at the disposal lifecycle phase
- Products are built to last several life cycles
- Design Thinking & Life Cycle Thinking
  - Design for Environment
  - Design for Disassembly
  - Design for Reuse
  - Life Cycle Assessment
- Sharing economy

waste reducing strategy ≠ business model

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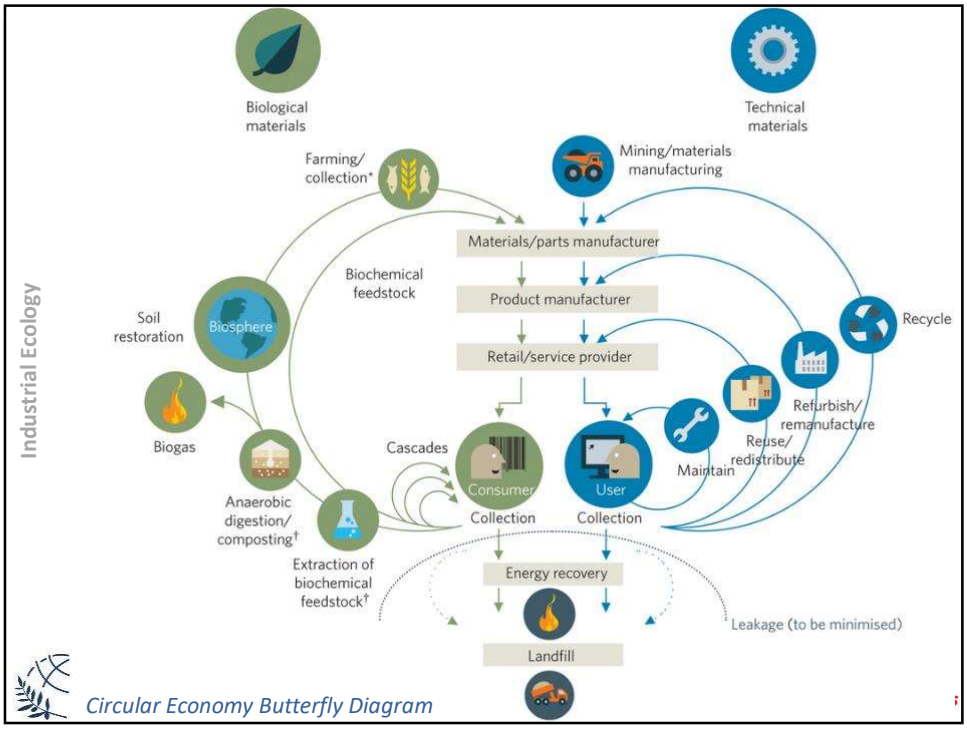

Circular Economy Butterfly Diagram

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Life Cycle Assessment

Is this an eco-friendly industrial product?

What does eco-friendliness depend on?

We need a structured methodology for quantification

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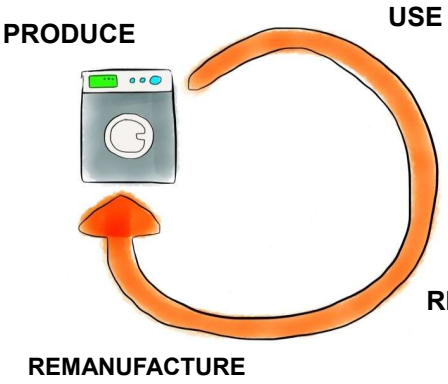
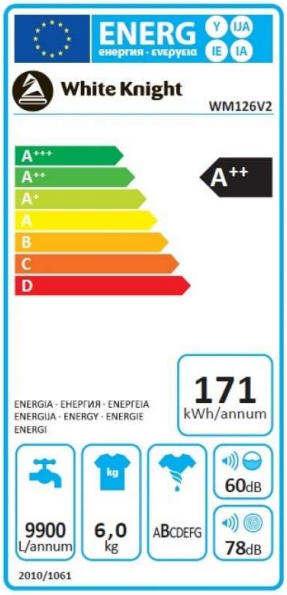
Life Cycle Assessment

Industrial Ecology





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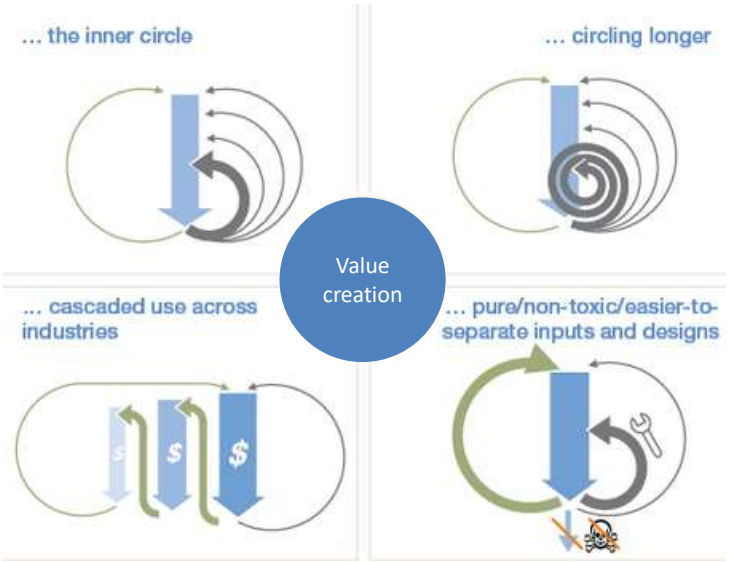
From linear to circular

Industrial Ecology



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Life Cycle Assessment

- Life Cycle Assessment is a **structured methodology** of assessing the environmental impacts of a product, service or a process throughout their lifetime *(Cradle to Grave)*

Life Cycle Assessment

Phases of Human Life: Cradle to Grave


Infant


Adolescent


Adult


Old

…

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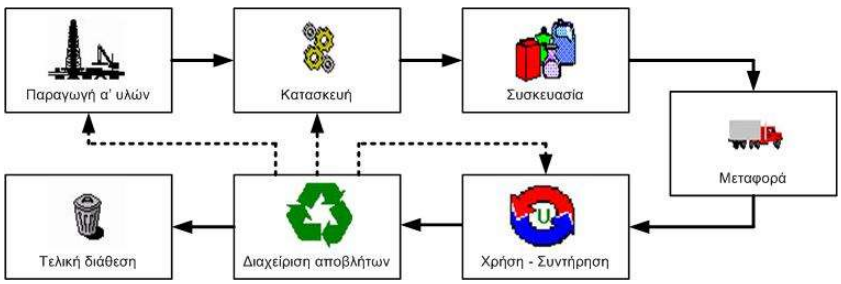
Life Cycle Assessment

- Life Cycle Assessment is a **structured methodology** of assessing the environmental impacts of a product, servuce or a process throughout their lifetime *(Cradle to Grave)*

Life Cycle Assessment

Phases of **Industrial Products**: Cradle to Grave



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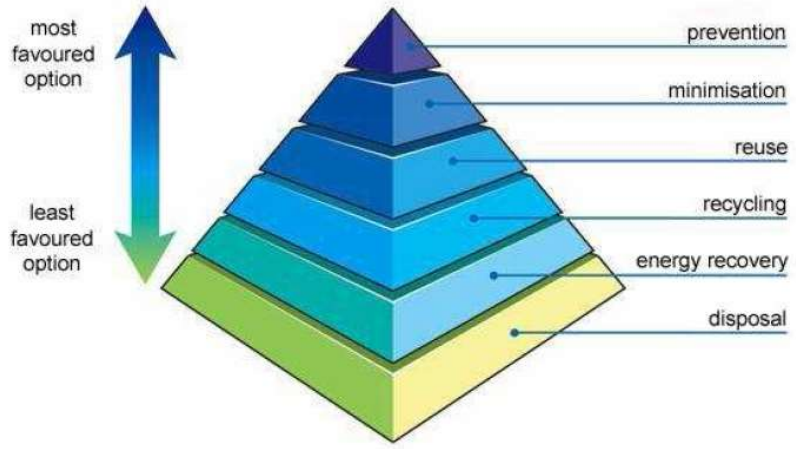
Life Cycle Assessment

Product Life Cycle

In the E.U. the hierarchy of final disposition options is institutionalized

- **End of life alternatives**

Life Cycle Assessment



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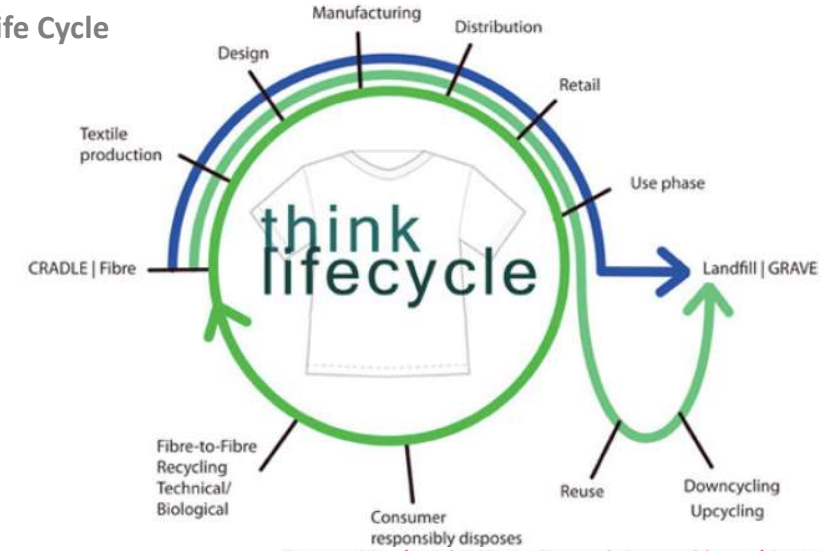
Life Cycle Assessment

Garments' Life Cycle

Life Cycle Assessment



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Life Cycle Assessment

Garments' Life Cycle

Fibre-to-fibre recycling

Life Cycle Assessment

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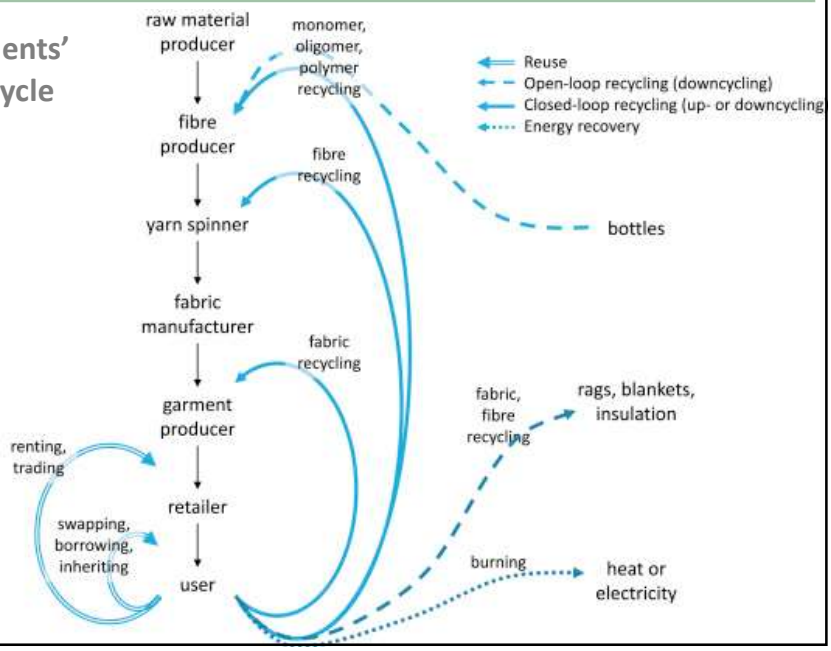
Life Cycle Assessment

Garments' Life Cycle



Life Cycle Assessment

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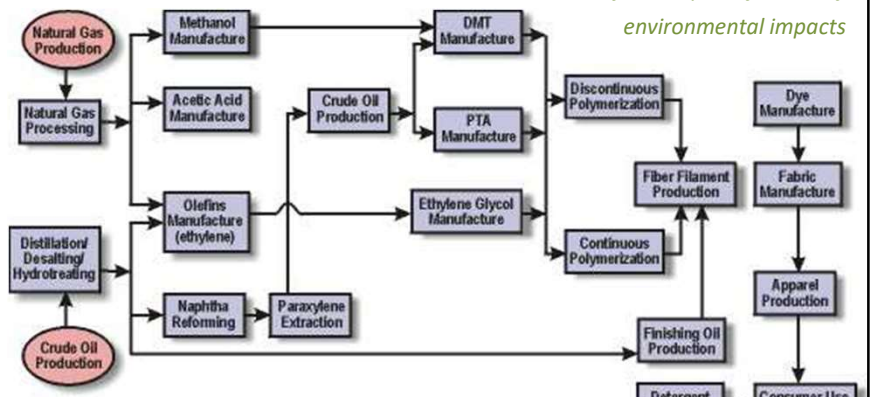
Life Cycle Assessment

Garments' Life Cycle

The mapping of the process is considered as a basic requirement for the quantification of environmental impacts

Life Cycle Assessment



Mapping of garments' life cycle

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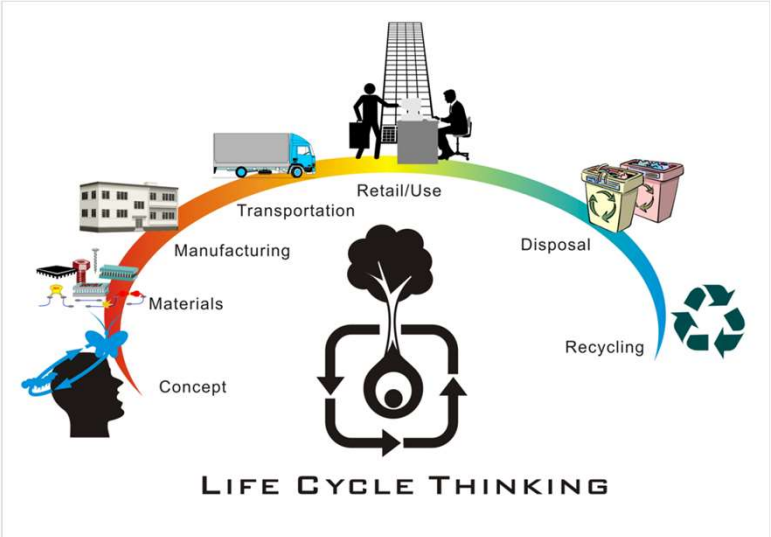
Life Cycle Assessment

Life Cycle Assessment is based on the concept of Life Cycle Thinking

Life Cycle Assessment



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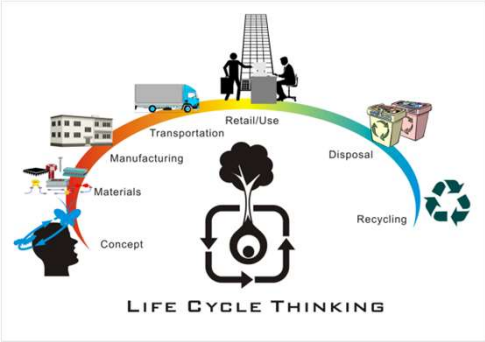
Life Cycle Assessment

Life Cycle Thinking is a way of thinking that includes the economic, environmental and social consequences of a product or process ***throughout its life cycle***

Life Cycle Thinking supports businesses to ***understand*** *and* ***improve*** *their environmental and social* ***performance*** *while maintaining or improving profits*



Life Cycle Assessment

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Life Cycle Assessment

Definition of Life Cycle Assessment

Life Cycle Assessment (LCA) is a **process of evaluating the effects** that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities

LCA's key elements are: (i) **identify and quantify the environmental loads** involved; e.g. the energy and raw materials consumed, the emissions and wastes generated; (ii) **evaluate the potential environmental impacts** of these loads; and (iii) assess the options available for **reducing these environmental impacts**

European Environmental Agency

Life Cycle Assessment

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Life Cycle Assessment

Life Cycle Assessment

In a nutshell, Life Cycle Assessment …

- is a **comprehensive approach** to the life cycle of a product or process that **quantifies** the impacts on ecosystem health and human health throughout its life cycle;
- uses **reliable** and **standardized** scientific **methods** to calculate impacts;
- assists **decision-makers understand** the scale of many environmental and human health impacts of competing products, services, policies or actions

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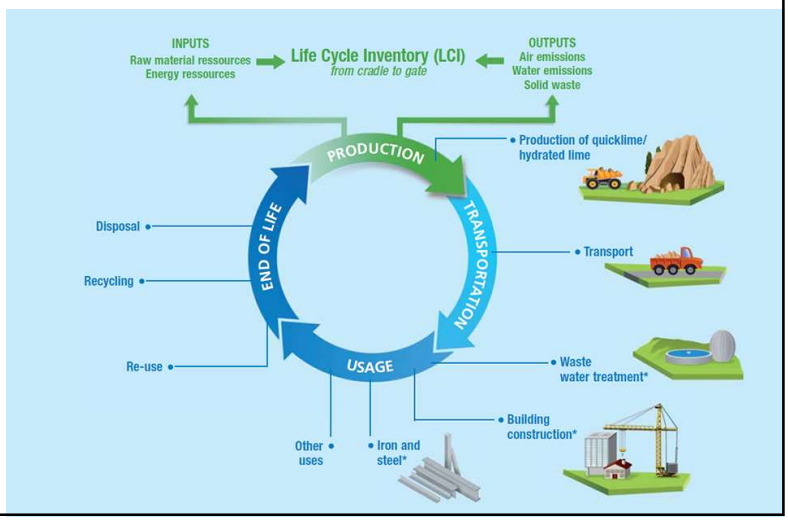
Life Cycle Assessment

Life Cycle Assessment

Quantification Assessment

Environment Life Cycle

Improvement Systemic Approach



LCA focuces on …

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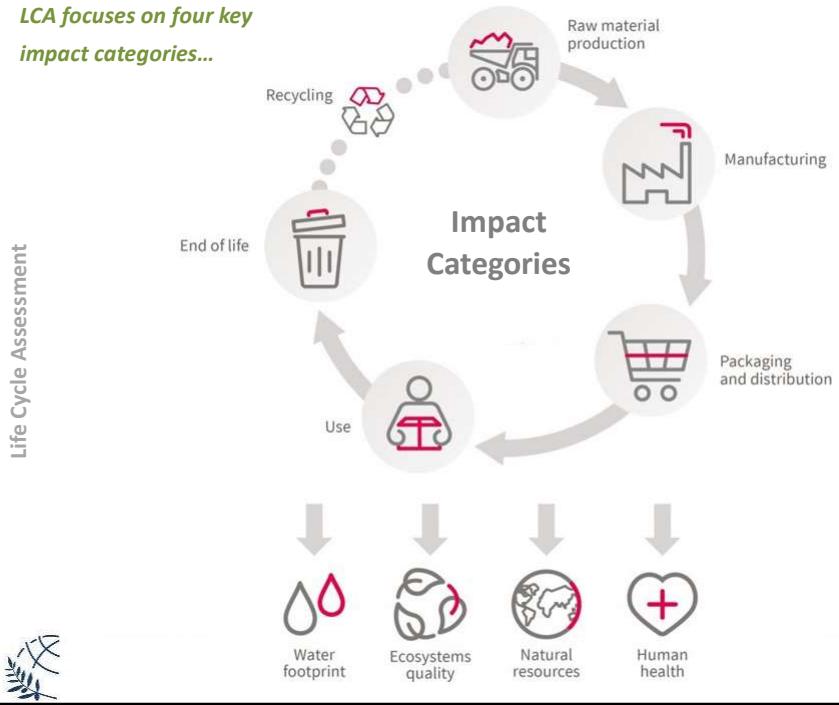
LCA focuses on four key impact categories…



Life Cycle Assessment

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Life Cycle Assessment | Decision support

- **Who does LCA support?**
  - Product Design
  - Purchasing
  - Marketing

  } Businesses to improve their products and image

  - Regional or national policy makers
  - Consumers, customers and product users

Life Cycle Assessment

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Life Cycle Assessment | Environmental labelling

Eco-labels:

An important area of application of LCA is environmental labelling, which is based on environmental information

Life Cycle Assessment

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Life Cycle Assessment | Decision support

- **Expectations of LCA use:**
  - Study of the environmental performance of products and services
  - Minimization of production costs
  - Compliance with legislation and regulations
  - Minimization of the impact on the environment and human health

Life Cycle Assessment

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Life Cycle Assessment | Environmental information

Life Cycle Assessment

Indicative topics for decision-making

- Strategic planning and capital investments
  (e.g."green" building/warehouse, waste management strategy, etc.)
- Eco-design – Product development
- Operations management with an emphasis on impact reduction
- Green procurement
- Marketing (eco-labeling, EPD)

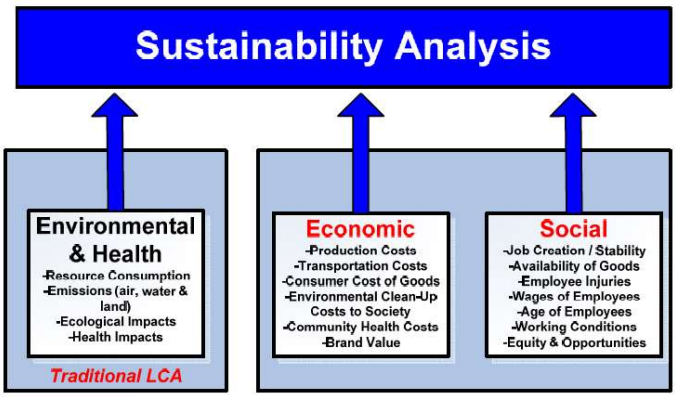
Indicative types of decision-making

- Materials to be used
- Product or service design
- Industrial process design
- Technology to be used

LCA is used for operational, tactical and strategic decisions

Sustainability Assessment

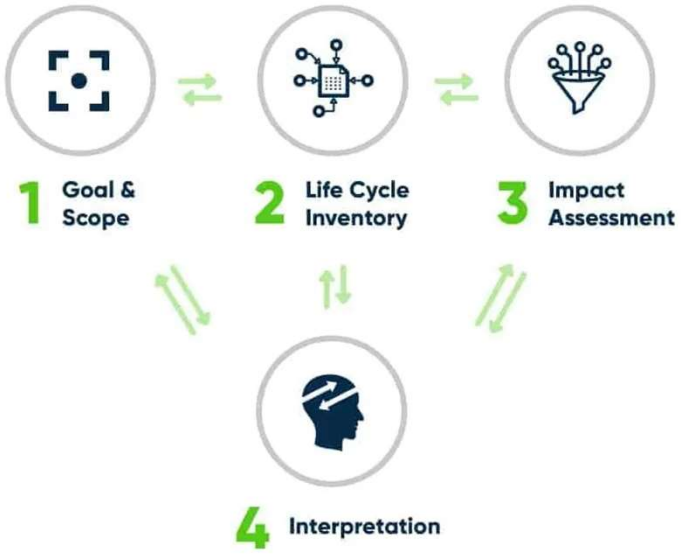
Life Cycle Assessment



In recent years there has been a shift towards sustainability assessment (e.g. Social LCA)

Life Cycle Assessment | Methodology

Life Cycle Assessment



LCA comprises of four discrete steps (phases)

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Life Cycle Assessment | Methodology

Life Cycle Assessment

1. Determination of the objective and scope of the study
2. Detailed data inventory
3. Impact assessment
4. Assessment of improvements

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Life Cycle Assessment | Methodology

Phase 1

Determination of the objective and scope of the study

- The scope and the aim of the study is defined
- The procedure for quality assurance of the study is defined
- The limits of the system to be studied are determined
- The functional unit is set

Life Cycle Assessment

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Life Cycle Assessment | Methodology

- **Functional unit of LCA study**
  - Example of functional unit determination: Milk products

Life Cycle Assessment

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Life Cycle Assessment | Methodology

Functional unit of LCA study

x (e.g. 10,000) hours AND y (e.g. 1,000) lumen

Life Cycle Assessment

Incandescent lamp - 15 Lumen/Watt
Fluorescent lamp - 50 Lumen/Watt (x3)
Led lamp - 90 Lumen/Watt (x6)

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Life Cycle Assessment | Methodology

- **Definition of system's boundaries**

Life Cycle Assessment

What information is required to assess the life cycle of a television?

upstream:
TV --> Transformer --> Copper wire --> Copper --> Copper ore
upstream:
TV --> Electricity --> High voltage electricity --> Lignite / Natural Gas / RES
downstream:
TV --> WEEE --> Removal of valuable and recyclable materials --> Landfill

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Life Cycle Assessment | Methodology

Phase 2

Detailed data inventory

Life Cycle Assessment

Based on the defined system's boundaries, Phase 2 includes:

- Design of process flow charts
- Compilation of a registry / inventory list

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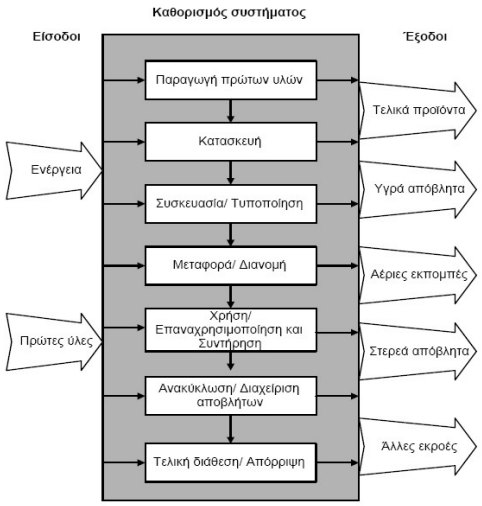
Life Cycle Assessment | Methodology

- **Definition of system's boundaries**

Life Cycle Assessment



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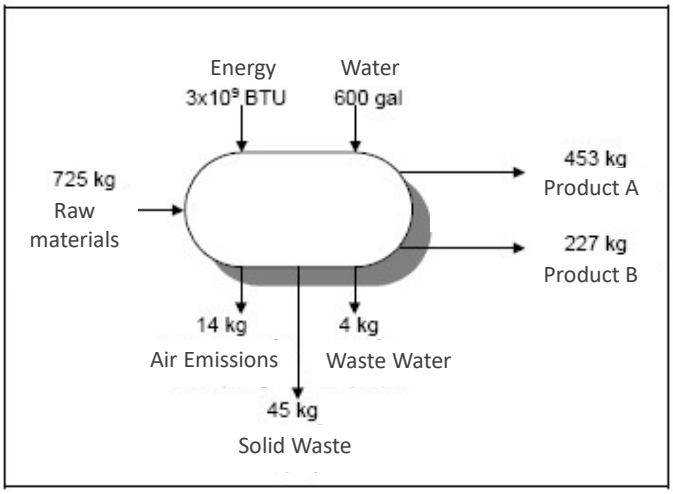
Life Cycle Assessment | Methodology

- **Indicative data inventory**



Life Cycle Assessment

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Life Cycle Assessment | Methodology

Phase 3

Impact Assessment

- It is a quantitative and/or qualitative process used to characterize and assess the environmental impacts identified during the data inventory phase

Life Cycle Assessment

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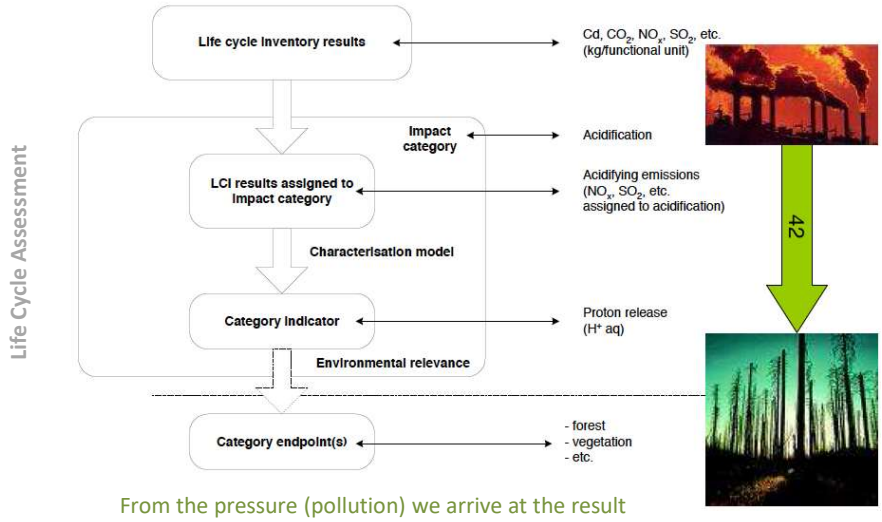
Life Cycle Assessment | Methodology



From the pressure (pollution) we arrive at the result
(destroyed forests, reduced agricultural production, etc.)

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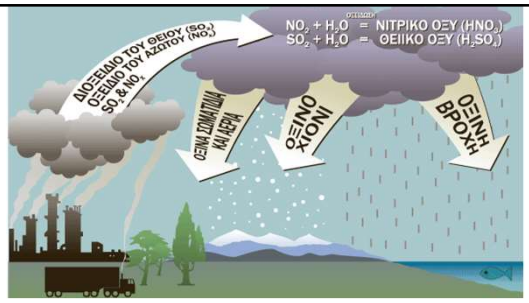
Impacts of
acid rain



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Life Cycle Assessment | Methodology

- **Impact Assessment**
  - Impacts on climate change
  - Effects on ecosystem quality
  - Effects of depletion of natural resources
  - Effects on human health
  - Other impacts that are not easily quantifiable in the analytical inventory such as:
    - ✓ Land use
    - ✓ Temperature rise
    - ✓ Noise pollution

Life Cycle Assessment

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Life Cycle Assessment | Methodology

- **Impact Assessment**

Which lamp is eco-friendlier?

Impact category	Incandescent lamp	Fluorescent lamp
Climate change	1.2×10^{-11} yr	4×10^{-12} yr
Ecotoxicity	1.6×10^{-10} yr	2.2×10^{-10} yr
Acidification	9×10^{-11} yr	4.2×10^{-11} yr
Depletion of resources	24×10^{-12} yr	9×10^{-13} yr
etc	...	...

Life Cycle Assessment

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Life Cycle Assessment | Methodology

- **Impact Assessment**

We need a normalization methodology to arrive at a number

Example of a weighted environmental index

Weighed index	Incandescent lamp	Fluorescent lamp
Weighted index	8.5×10^{-10} yr	1.4×10^{-10} yr

Life Cycle Assessment

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Life Cycle Assessment | Methodology

Phase 4

Assessment of improvements

*«The improvement assessment is a **systematic approach** of defining the needs and possibilities for **reducing the environmental burden** associated with the use of energy and raw materials and environmental emissions throughout the life cycle of products, processes and services. It is possible to provide **qualitative and quantitative improvement measures** such as changes in the product, in the process and design, in the use of raw materials, etc.»*

SETAC

Life Cycle Assessment

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Life Cycle Assessment | Barriers

In practice, LCA is limited by methodological inconsistencies:

- Key issues related to data inventory:
  - System boundaries
  - Data requirements and data quality
- Key issues related to impact assessment
  - Complex (often incomprehensible) procedures
  - Different methodological approaches (e.g. CML, eco-indicator 95, eco-indicator 99)

Life Cycle Assessment

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Life Cycle Assessment | Barriers

Data requirements:

- Data is often obtained from a secondary source, in many cases it may not be representative of the actual emissions of a particular material or process
- Data may be old and may not represent emissions from current processes and materials
- Available from limited geographic areas (industrialized countries)
- Many different data formats are used which are often not compatible with each other

Need for ISO standardization

Life Cycle Assessment

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Life Cycle Assessment | ISO 14000 family

Life Cycle Assessment

ISO 14040 family: Includes instructions that reinforce the role of LCA as a fundamental process of thorough environmental data recording

- ISO 14040: LCA – Principles and framework of methodology
- ISO 14041: LCA – Analytical inventory
- ISO 14042: LCA – Life cycle impact assessment
- ISO 14043: LCA – Interpretation
- ISO 14048: LCA – Data documentation format

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Life Cycle Assessment | Conclusions

Life Cycle Assessment

- **LCA is a very well-developed and acknowledged tool**
  - The practice of LCA is becoming more and more accepted worldwide
  - LCA has a wide range of applications
- **LCA has clear limitations**
  - There is a strong need for additional tools within the Life Cycle Thinking approach
  - When supported by tools that monitor economic and social performance, LCA is a powerful tool towards sustainability assessement
- **LCA and products' / services' certification are mutually supportive activities**

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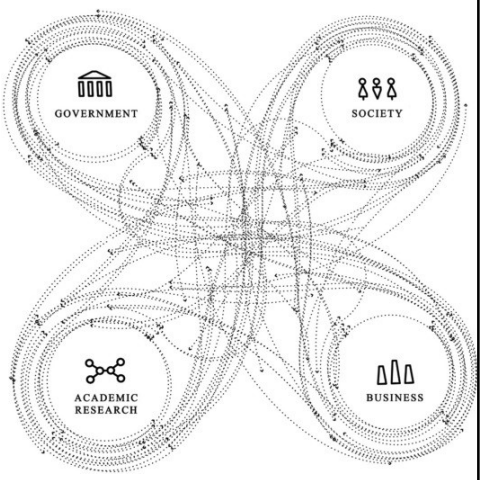
Industrial ecology | Synergies are required

Quadruple Helix

Promoting circular economy models requires a harmonious “quadruple helix” synergy between:

i. business sector
ii. public sector
iii. research and academia
iv. civil society

The digital revolution represents a significant opportunity for the transformation of the business model



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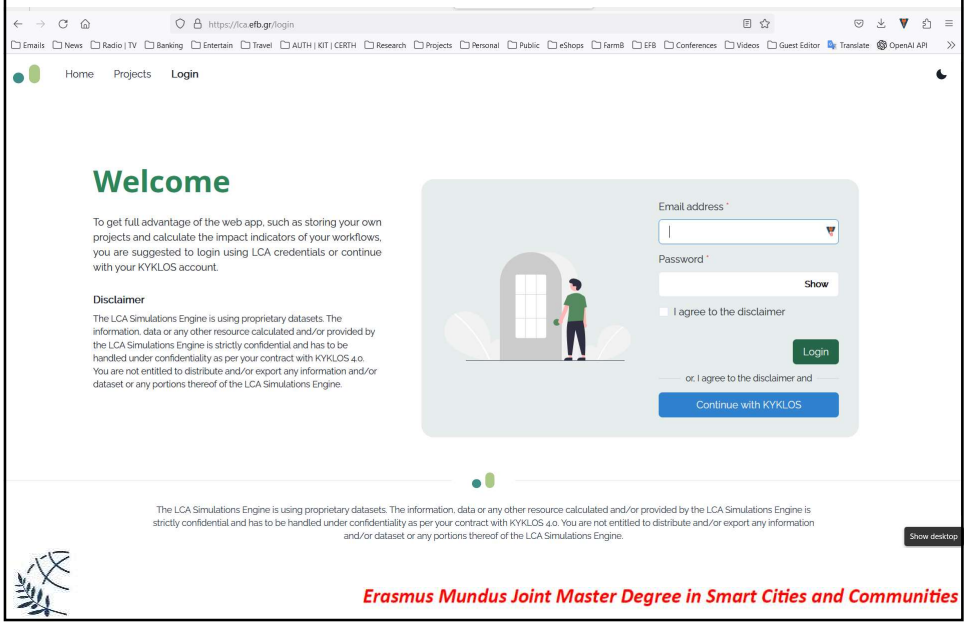
Kyklos 4.0 | Live Demonstration



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Thank you!

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