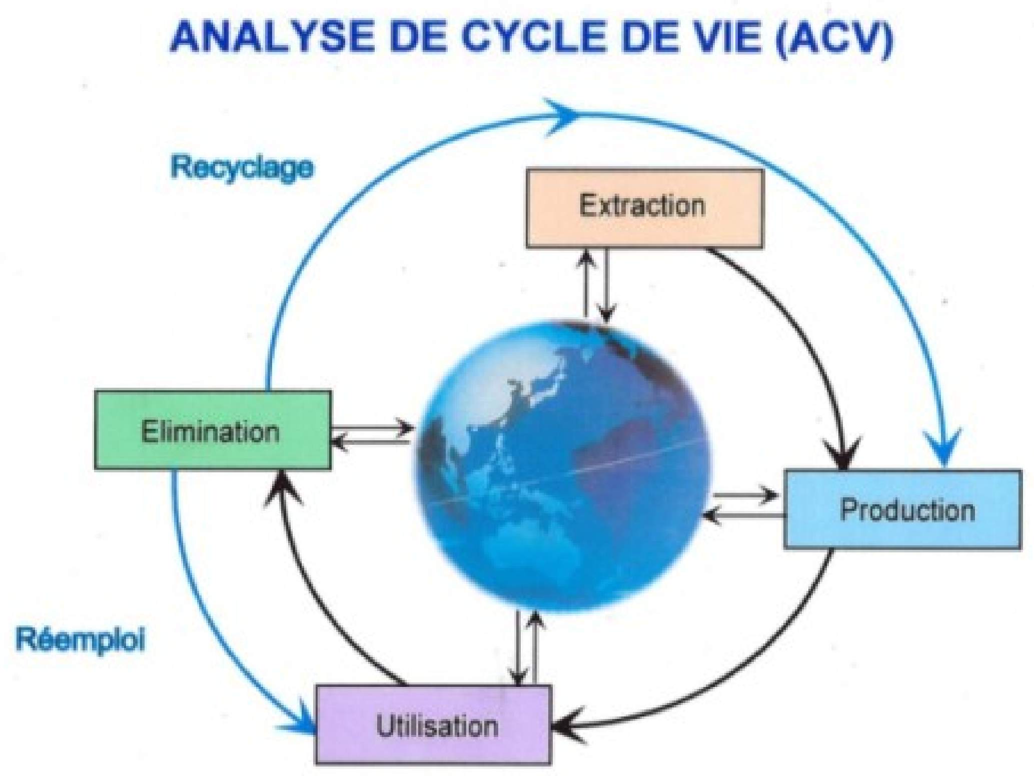
Life Cycle Analysis (LCA)

Definition

- Life Cycle Analysis (LCA) = eco-balance = **decision-making tool**
- Goal: **to quantify and reduce the environmental impact of products, services or production systems "from cradle to grave "**



The 4 major iterative steps

1. the **definition of the objectives and scope of the study** ,
2. **inventory** analysis ,
3. **impact assessment** ,
4. **interpretation** of the results.

Limitations of LCA

An LCA takes into account **measurable and summable aspects** through databases.

The ACV cannot take into account :

- **the impact on landscapes,**
- **the noise,**
- **the smells,**
- **the time,**
- **the toxicity of the products emitted (significant uncertainties)**
- ….

Some great principles

In the context of eco-design some principles have been defined *:*

- **dematerialize**
- design stage : design a **product**
  - **reusable,**
  - **removable (easy maintenance)**
  - **recyclable (end of life stage**).
- manufacturing stage: **reduce materials with the same function as much as possible**
  - minimize their diversity
  - minimize waste,
  - use recycled materials
  - remove toxins.
- Usage step : **reduce energy consumption**

The challenges of Life Cycle Analysis

- **Energy issues** (depletion of natural resources)

- **climate issues (or environmental impacts) :**

  1 the **scarcity of natural resources, mainly matter** (mineral , biological) **and energy**

  2 pollution **inherent to human activity** visible and/or measurable in the three environments that surround us (**water, air and soil**).

  3 toxicity and risks to human health (accidents but also through production activity)

Contradictions in the LCA ?

We often ask ourselves this kind of question:

- ✓ What is the use of an LCA if we don't know how to make a final decision ?
- ✓ Is it better to improve this or that criterion ?
- ✓ Between the greenhouse effect and nuclear waste, what to choose ?
- ✓ Should I pollute water by cleaning my packaging to promote its recycling ?
- ✓ Or more pragmatically an example that raises more questions than answers :

- ➢ Should I continue to use my old car that "pollutes" but uses 4.5L/100Km or order an SUV with a DPF but uses 10L/100Km ??? Here, two issues are in conflict : energy and climate!
- ➢ But if we look at the full life cycle…. The old car has the merit of already being manufactured. Will recycling the old car compensate for the effort of manufacturing the SUV ? and what do we do with the DPF when recycling the SUV at the end of its life?
- ➢ All this should be quantified by an LCA….

Objectives and scope of the study

1. Methodology

It is requested to clearly indicate :

- **the intended application,**
- **the reasons** for carrying out the study
- **the people** who will have access to the results
- **the nature of the use** of the results

So we need to define :

- **product system** to be studied
- **functional unit** ;
- product system **boundary ;**
- **assignment rules** ;
- **impact assessment methodology and types of impact** ;
- further **interpretation to be used;**
- **requirements regarding data and assumptions made;**
- **limitations;**
- **initial data quality requirements;**
- **type of critical review;**
- **type and format of the report specified for the study** .

Objectives and scope of the study

2. Function, Functional Unit and Reference Flow

Definitions : Functional Unit :

- precise, measurable, additive and clearly defined concept **which quantifies the service provided by the product**
- **allows to compare solutions**
- **reference flow** = quantity of products required to fulfill the function specified by the functional unit

Example

- For a paint, key parameters may be the lifespan of a coat of paint and the amount of paint needed to **adequately cover a surface.**
- In the case of wall protection, **the reference flow** could be :

✓ For a good quality A paint (requires only 2 coats in 20 years): **5 kg.**
✓ For a lower quality B paint (requires 3 coats in 20 years): **7 kg** .
✓ For wall wallpaper (to be changed once in 20 years): **$2m^2$ + 100g of glue…**

Objectives and scope of the study

3. System boundaries

To define the boundaries of a system, we **consider the main stages of its life cycle, the elementary processes and the flows** :

- **extraction of raw materials, production and consumption of fuels, electricity and heat,**
- **inputs and outputs in manufacturing and processes** (raw materials, natural resources and energy),
- **transport** that may occur during the product life cycle **,**
- **the use (and also maintenance)** of the products,
- **the end-of-life scenario:** disposal of waste (related to processes and/or product waste) and their recovery after use (reuse, recycling, energy recovery),
- **the manufacture of auxiliary materials and equipment (as well as maintenance and its decommissioning),**
- **additional energy consumption** (lighting and heating).

Objectives and scope of the study

4. Systems of elementary products and processes

In an LCA study, the life cycle of a product is **modeled by a system of products** which are subdivided into elementary processes which include

- transformation processes,
- of transport
- storage
- ….

Incoming and outgoing flows can take the form

- of materials
- energy in particular
- of products
- of services
- of waste
- of environmental flows (natural resources extracted, polluants emitted…)

Inventory, flow collection and data analysis
1. Inventory

- The inventory = description of **the different crossing flows studied are quantified.**
- **Inventory data is made up of**

  - ✓ **of material flows** (natural resources in particular)
  - ✓ **of energies** entering the system studied
  - ✓ **corresponding outgoing flows** (waste, gaseous emissions, liquids, etc.).

- **Two methods** for calculating inventory :

✓ **the process approach**

Production inventory = intermediate flows corresponding to the unit processes of the system + reference flows.

Emission and extraction factors are taken from the databases and express the quantity of each substance emitted/extracted per unit of input taken into account.

✓ **the input-output approach** = quantitative description of the flows of matter, energy and pollutants that cross the system boundaries

Inventory, flow collection and data analysis
2. Data collection

1. data types : qualitative and quantitative can be understood by measurement, calculation and/or estimation .

In the inventory there are several categories :

- Energy inputs, raw materials, auxiliaries, other physical inputs.
- Products, co-products and waste.
- Emissions to air, water and soil.
- Other environmental aspects.

2. Methodology :

1 validate the collected data .
2 Establish relationships between data and elementary processes or with the Functional Unit.
3 analyze sensitivity
4 refine the system boundary based on sensitivity.

Inventory, flow collection and data analysis
3. Inventory analysis

1.Nature **inventoried flows** taken into account for the study

- **economic flows** exchanged between elementary processes and with external systems:
  - ✓ material flows,
  - ✓ energy flows,
  - ✓ services ,
- **elementary flows** which are flows exchanged with the ecosphere
  - ✓ raw materials,
  - ✓ waste
  - ✓ emissions (into air, water and soil)

2. the analysis is done in 4 stages :

1. **Quantification flows** (economic and elementary) associated with each elementary process.
2. **Scaling these flows** based on a reference value.
3. **Quantification of emissions and extractions for each** elementary process,
   goal : **to identify all the elements that have an environmental impact at each stage** .
4. **Aggregation of elementary flows** :
   - CO_2 emissions from all elementary processes are added together into a single value.

Inventory, flow collection and data analysis
4. The assignment

1. Principle

it is **necessary to allocate the share of incoming and outgoing flows to each function studied only** .
the sum of the inputs and outputs of an elementary process that are assigned must be equal to the inputs and outputs of the elementary process before assignment

2. Methodology

1. **Avoiding questionable assignment** :
- By dividing the elementary process to be affected into sub-processes
- By extending the product system to include the additional functions of co-products
1. **allocate the inputs and outputs** of the system among its various components or functions in a way that reflects **how the inputs and outputs change with quantitative changes** in the products or functions that the system provides **.**
2. **Agree on an assignment between products and functions by another relationship**
   - (example : proportionally to the economic value of the products).

Life cycle impact assessment

Mandatory elements in the impact assessment phase :

1. Select

- ✓ impact categories,
- ✓ category indicators
- ✓ and characterization models.

2. Assign flow inventory results to selected impact categories

3. Calculate category indicators.

Life cycle impact assessment (to follow)

Mandatory elements :

- **Selection of impact categories, category indicators and characterization models**
- **Allocation of Inventory results to selected impact categories**
- **Characterization = calculation of category indicator results`**

Inventory	Climate change (100 years) IPCC 2007	Acidification CML 2001
2000g of $_{CO2}$	x 1 = 2000	
20g of CH_4	x 25 = 500	
20g of SO_2		x 1 = 20
5g of NO_x		x 0.5 = 2.5
Total	2500g eq . $_{CO2}$	22.5g eq . $_{SO2}$

Results Interpretation
Description, methodology

Method : in 3 steps :

- identify significant issues .
- Check the
  - completeness,
  - sensitivity
  - and consistency .
- Conclude , express limitations and recommendations .

Verification :

Dual objective: **establish and improve**

- **confidence in the results of the LCA study**
- **their reliability,** based on the three control techniques :

- completeness,
- sensitivity
- and consistency

LCA tools :
Introduction to database characteristics

Databases **are spreadsheet files composed of three** main parts to perform an LCA **:**

- **Materials, which represent the raw material for manufacturing processes** (chemicals , metals, mineral and plastic raw materials, paper, biomass, biological materials).

- **processes which generate impacts through the energy consumption required for the transformation of raw materials or for the treatment of waste (** incineration, deposition, sanitation).

- **Transport of provision** (road, rail, air, sea traffic).

This also concerns :

✓ Energy transport (infrastructure)

✓ The routing of products requiring additional transport steps must be quantified
  - Transport of materials to the production site
  - Transport between different production stages (customer factory / supplier)
  - Transportation to the sales site (take into account the various modes of transportation).

Example : Designing Interior Furniture for a Sailing Yacht

Definitions of Objectives and Scope of the Study :

✓ Composites made from plant fibers, particularly those reinforced with flax or hemp fibers, possess competitive specific properties and are biodegradable if the chosen resin is a biopolymer. However, the fact that they are biodegradable and partially or wholly derived from renewable resources does not guarantee environmental harmlessness. The use of Life Cycle Assessment (LCA) is necessary for the development of biocomposites to ensure that they are not a factor of greenwashing.

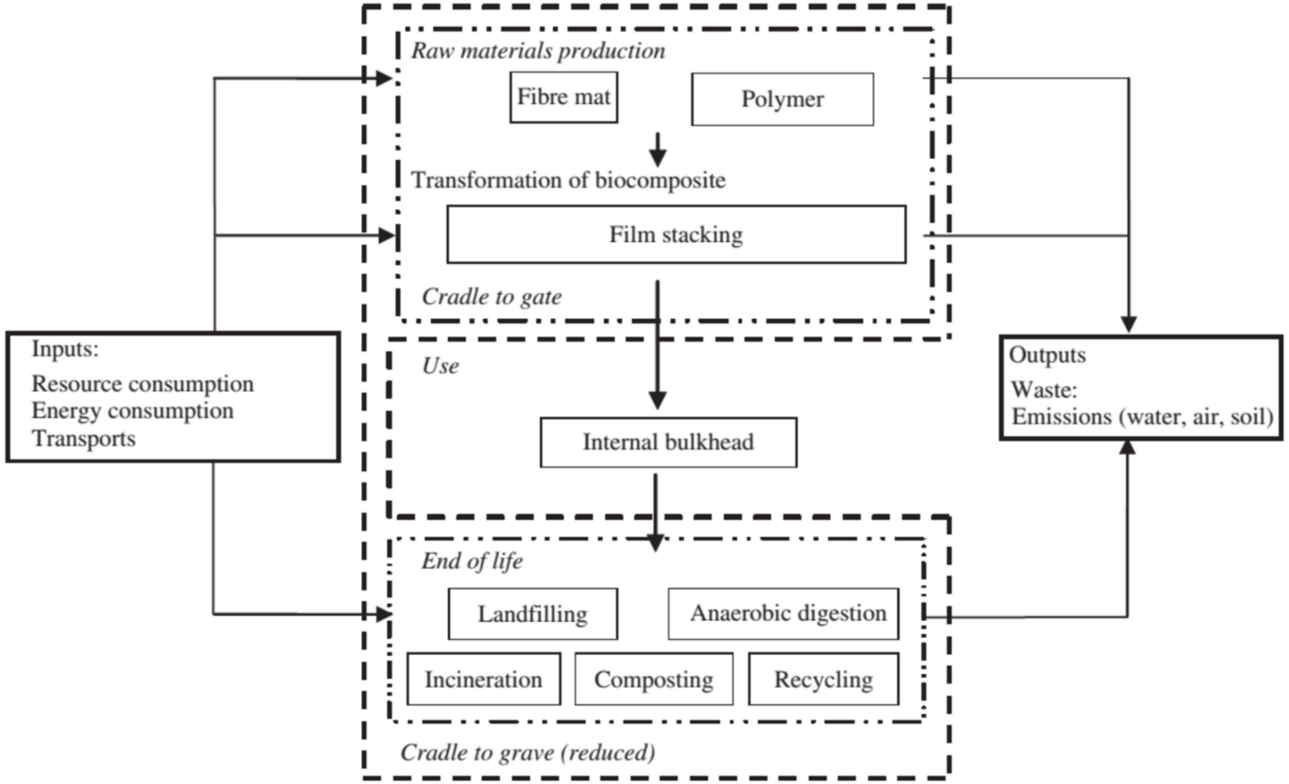
✓ The functional unit applied in this case is: "a flax/Poly(lactic acid) (PLA) mat biocomposite with tensile mechanical properties identical to those of glass mat/Polyester composites."

✓ System Boundaries: the system boundaries extend over the entire life cycle of the two parts, from raw material extraction to end-of-life. The use phase is excluded from the modeling because it appears to be relatively insignificant for the life cycle of a sailing yacht. Two end-of-life scenarios are considered: one by landfilling and the other by incineration.

Inventory Analysis :

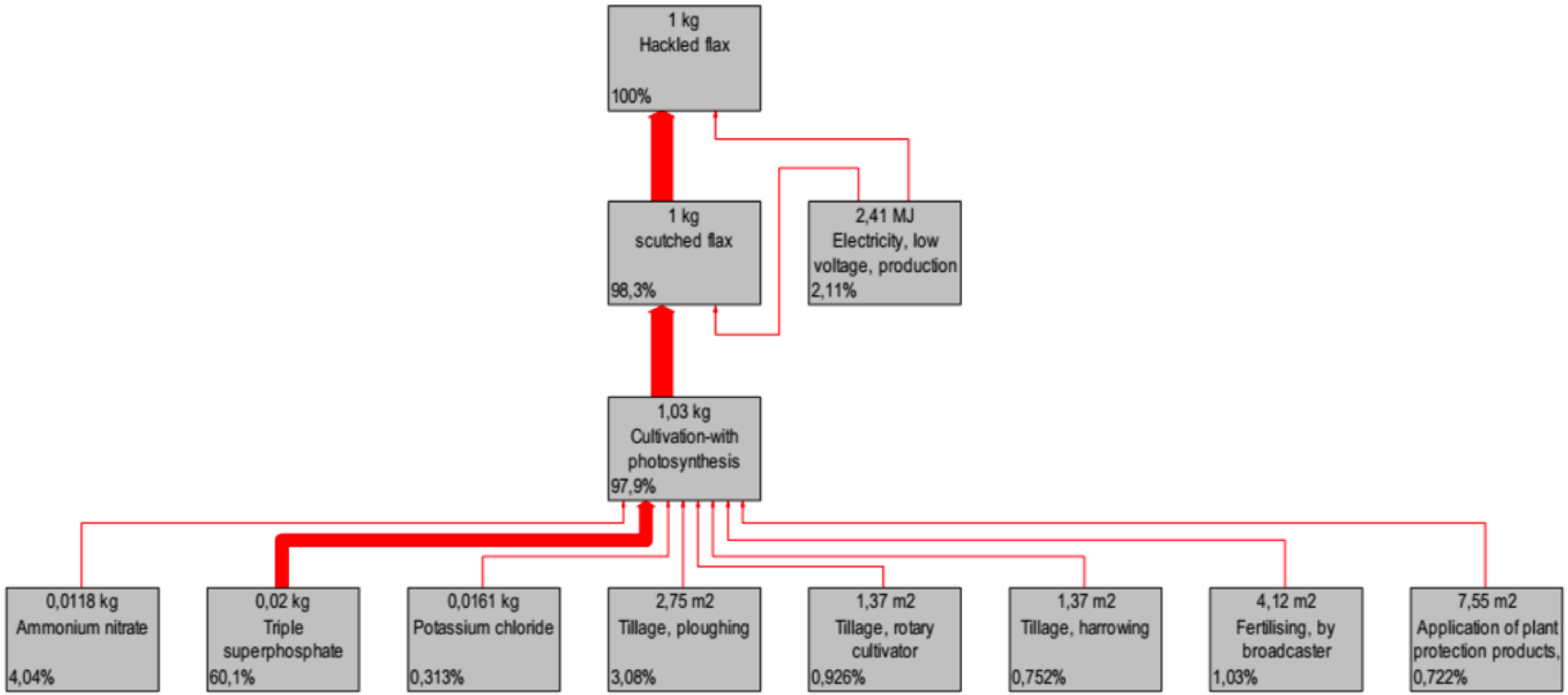
✓ Inputs: the inputs include the resources used for manufacturing the parts (for cultivation, extraction, retting, scutching, hackling of flax, as well as for transportation and material production) and the energy used for this manufacturing process.

- ✓ Outputs: the scenarios for landfilling and incineration are evaluated for both materials. However, other end-of-life scenarios have been evaluated for the biocomposites. One of these is aerobic composting (in the presence of oxygen), which involves the treatment of organic waste through aerobic fermentation to produce compost, CO_2, and water. Anaerobic fermentation composting also adds value to organic waste, particularly by producing methane, CO_2, and water.



Inventory Analysis :

Each step of the processes performed during the life cycle of a part will be subject to an analysis of the input and output flows. For example, this includes evaluating the contribution of all input and output flows to non-renewable energy consumption during the production of 1 kg of flax fibers. The production of "Triple Superphosphate" fertilizer appears to be the most impactful.



Environmental Impact Evaluation :

✓ We are interested in mid-point impacts such as ocean acidification, eutrophication (accumulation of nutrients in soil and water, such as nitrogen), ozone layer depletion, human toxicity, freshwater toxicity, photochemical oxidation, land use/artificialization, terrestrial eco-toxicity, non-renewable energy consumption, and end-point damages such as the depletion of natural resources (abiotic depletion) and global warming.

- ✓ Example of impact comparison for both types of materials under the two end-of-life scenarios :

Impact category	Units	incineration flax /PLLA	landfill flax/PLLA	incineration glass/ UPE	landfill glass/UPE
Abiotic depletion	kg Sb eq	2.3 10^{-2}	2.7 10^{-2}	4.0 10^{-2}	4.3 10^{-2}
Acidification	kg SO_2 eq	1.2 10^{-2}	1.5 10^{-2}	1.85 10^{-2}	2.1 10^{-2}
Eutrophication	kg PO_4^{3-} eq	7.7 10^{-3}	1.25 10^{-2}	3.2 10^{-3}	53.9 10^{-3}
Global warming (GWP100)	kg CO_2 eq	4,3	1,66	6,9	6,0
Ozone layer depletion (ODP)	kg CFC eq	3,1 10^{-7}	3,4 10^{-7}	7,3 10^{-7}	7,5 10^{-7}
Human toxicity	kg 1,4-DB eq	1,3	1,46	8,2	8,3
Fresh water aquatic ecotox.	kg 1,4-DB eq	1,1	1,6	8.1 10^{-1}	1,14
Photochemical oxidation	kg C_2H_4	4.1 10^{-4}	5.4 10^{-4}	1.4 10^{-3}	1.5 10^{-3}
Land use	m^2/Year	5.0 10^{-1}	5.1 10^{-1}	1.4 10^{-2}	1.6 10^{-2}
Terrestrial ecotoxicity	kg 1,4-DB eq	2.15 10^{-2}	3.1 10^{-2}	3.4 10^{-2}	4.0 10^{-2}
Non renewable energy consumption	(MJ/FU)	3.4	77	89.8	144.3

Environmental Impact Assessment :

✓ The compared solutions can enable specific design choices based on indicators of contribution to climate change. For example, the fiber content in the composite material is evaluated concerning its impact on greenhouse gas emissions.

	Flax/PLLA		Glass/polyester
Fibre content	*K* (Quantity of greenhouse gas/kg of material)	Fibre content	*K* (Quantity of greenhouse gas/kg of material)
0	1,55	0	7,7
16.5	1,33	17.3	6,5
26.5	1,29	26.1	5,9
40.1	1,15	37.1	5,4
		48	4,9