

# Industrial Ecology – LCA module

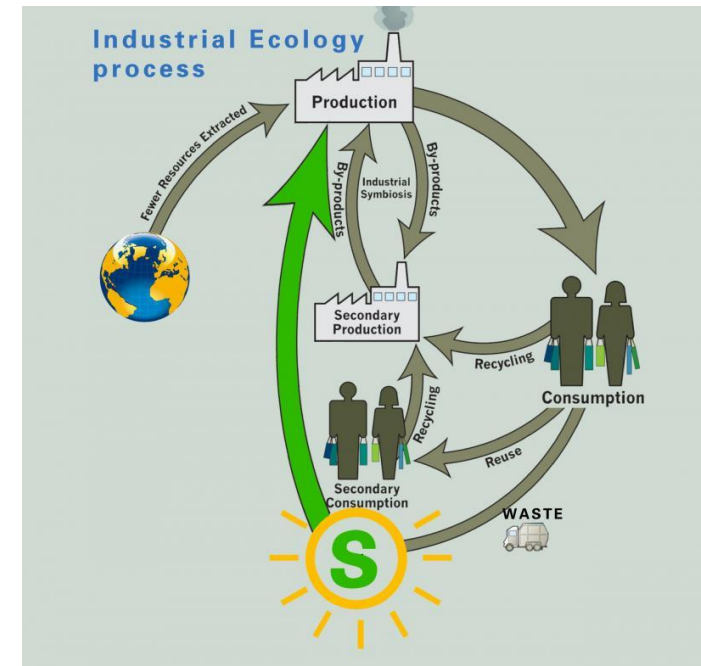
## 1<sup>st</sup> semester 2013/2014

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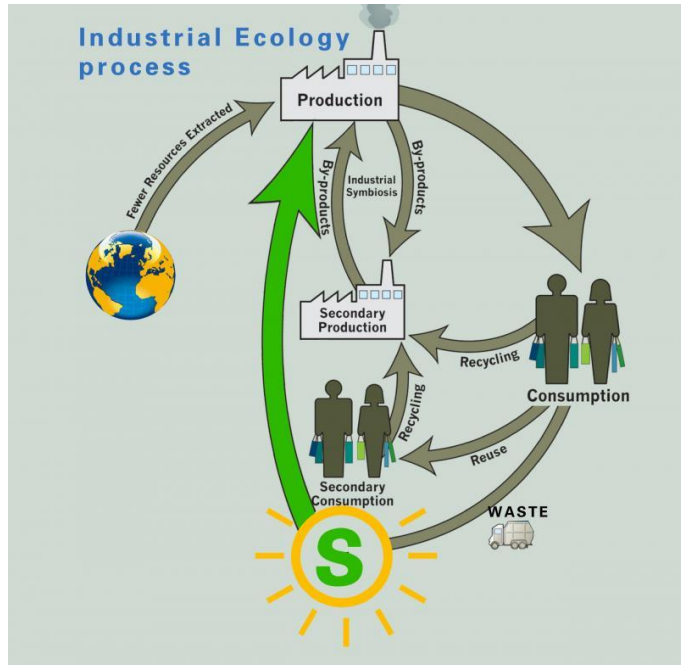
Researcher ID: A-4724-2012



## OUTLINE

- Industrial ecology and LCA
- Life cycle notion
- ISO norms steps
- Goal, boundaries, allocation, functional unit?
- What assessments to choose?
- Impact assessment calculation
- Softwares/databases
- Examples

“Industrial metabolism” study of material and energy flows through industrial systems.



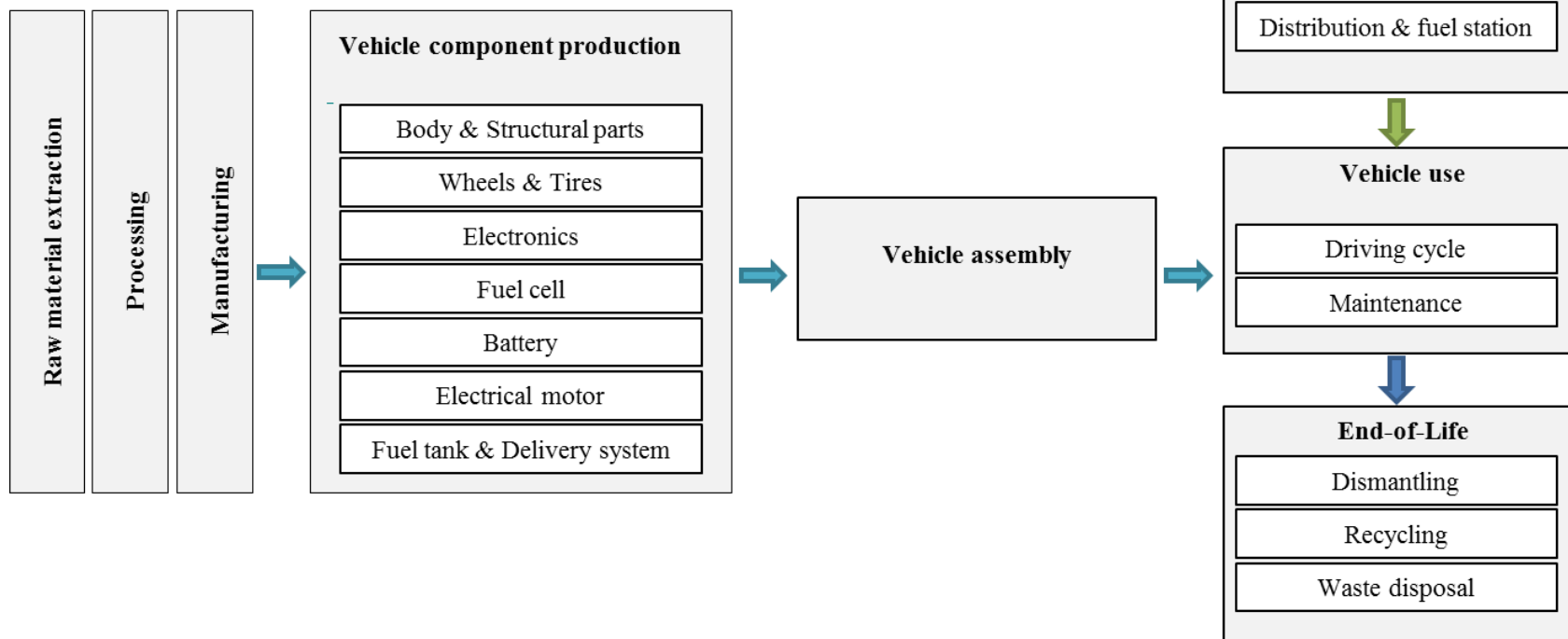
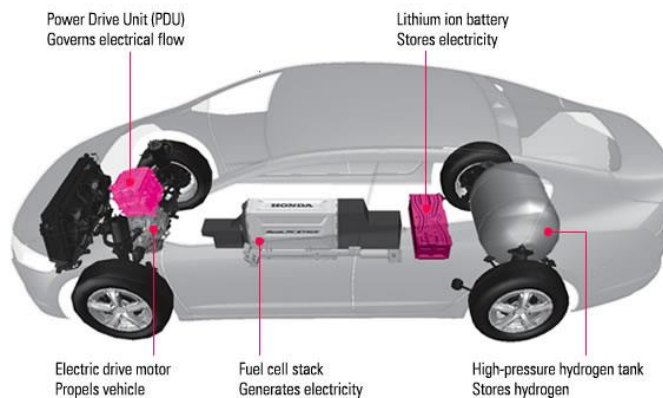
Inputs/Outputs

Sustainability  Energy  
 Emissions  
 Impact

“closed loop system where wastes can become inputs for new processes”

 Zero waste

## Life cycle notion

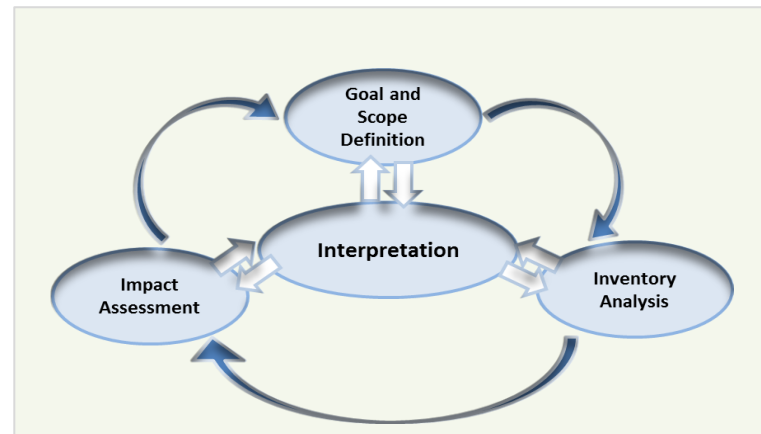


## LCA – Life Cycle Analysis

**Methodology** to assess environmental impacts associated with all the stages of a product's life from cradle-to-grave

- Raw material extraction
- Materials processing
- Manufacture
- Distribution
- Use
- Maintenance
- Disposal or recycling

**Steps** as in ISO 14040:2006 and 14044:2006



## Life Cycle – Goal and scope definition

- **Functional unit\***
- **System boundaries;**
- **Assumptions and limitations;**
- **Allocation methods\*\*; and**
- **Impact categories**

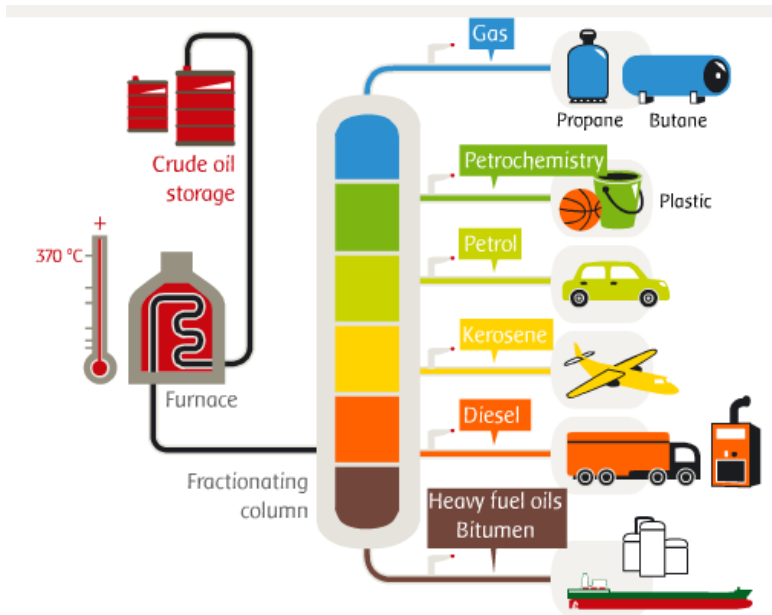


**Cradle-to-Grave (CTG)**  
**Cradle-to-Gate (CTG)**  
**Cradle-to-Cradle (CTC)**  
**Gate-to-Gate (GTG)**  
**Well-to-Wheel (WTW)**

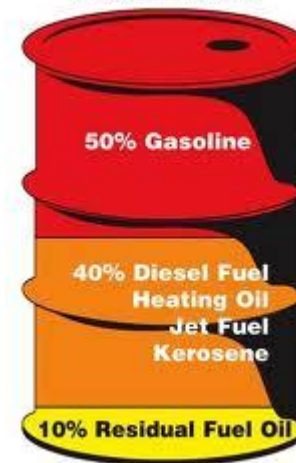
\*defines what precisely is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related; important basis that enables the product to be compared and analyzed

\*\*used to partition the environmental load of a process when several products or functions share the same process **mass and economic**

## Life Cycle – Goal and scope definition



Typical U.S. Refinery Yield from a Barrel of Crude Oil

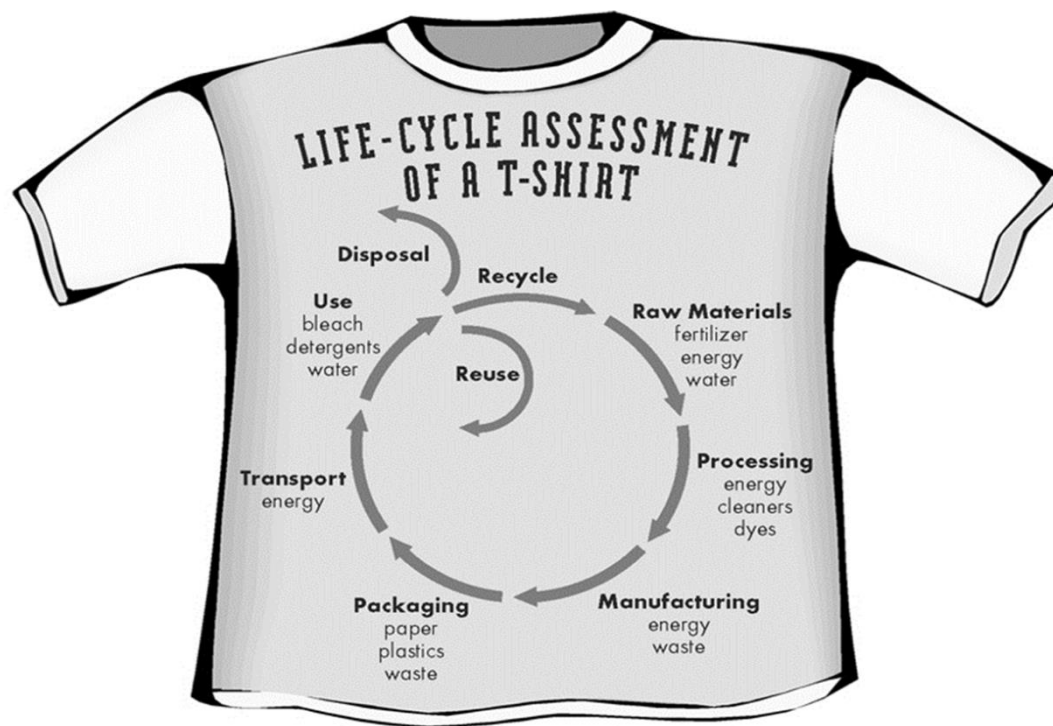


## Life Cycle – Goal and scope definition





## Life Cycle – Goal and scope definition



## Life Cycle - Inventory

### Inputs-Outputs balance

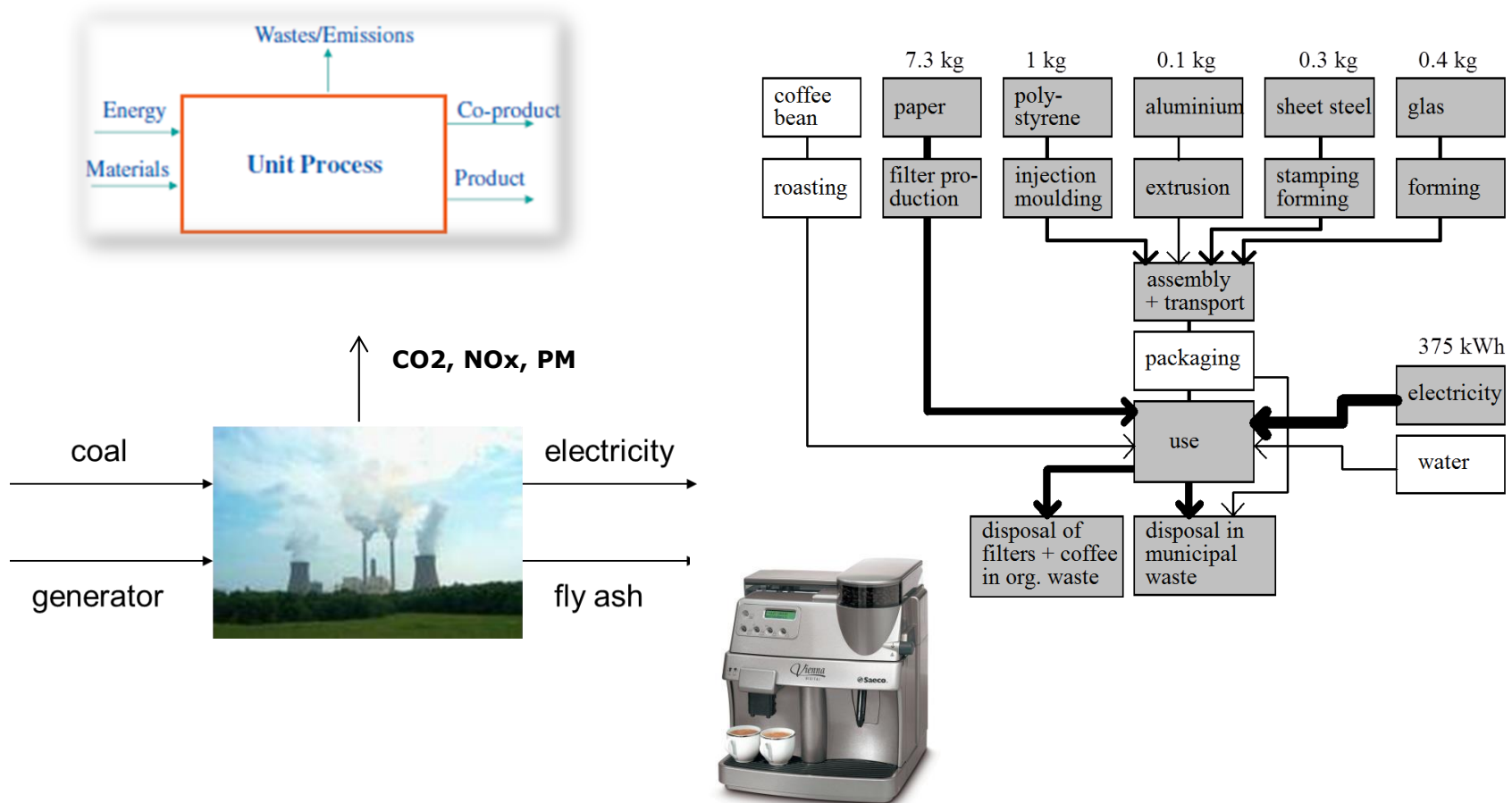


$$Energy = \sum Energy_{eachprocess} / FU$$

$$CO_2 = \sum CO_{2eachprocess} / FU$$

FU – Functional Unit    e.g. MJ of final product  
    kg of final product  
    passenger.km  
    km

## Life Cycle - Inventory



## Life Cycle - Inventory

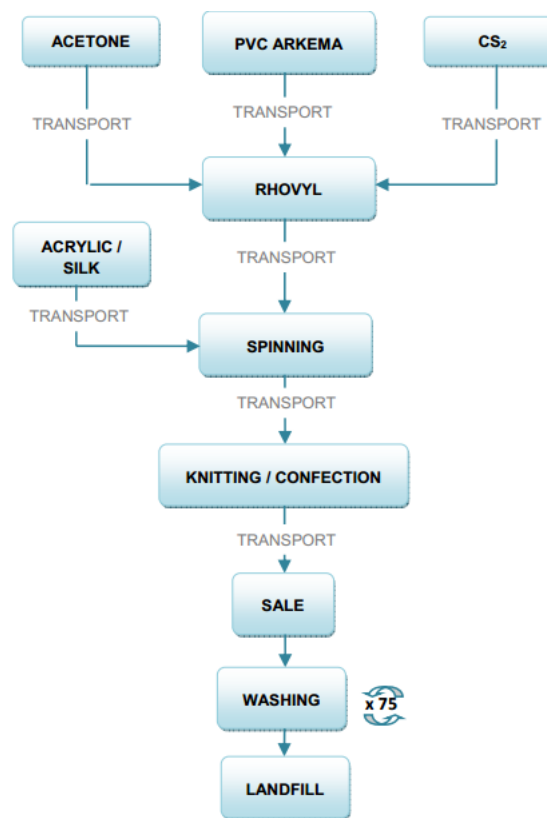
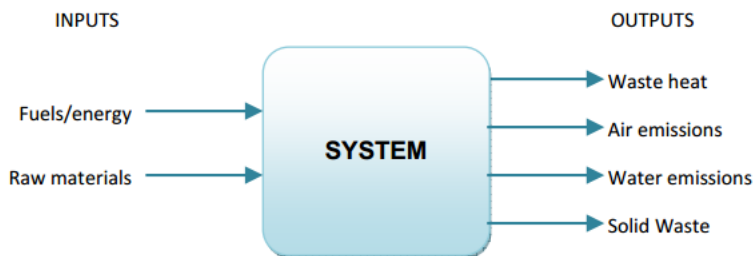
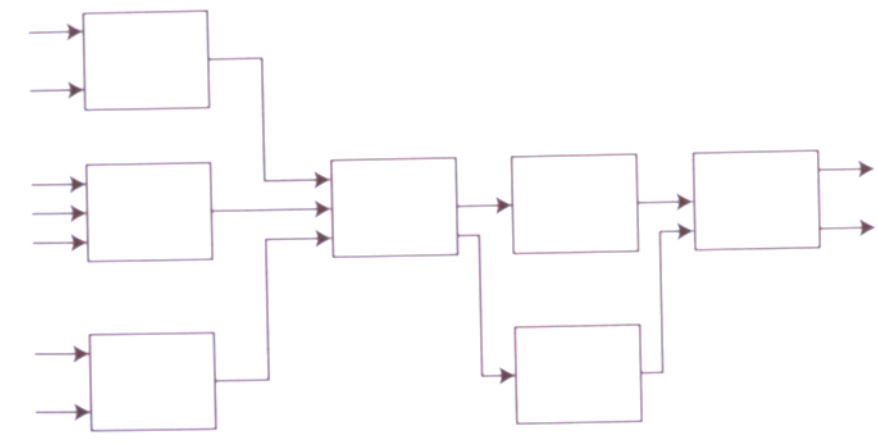


Figure 1. Flow diagram of the t-shirt

**1 wash/day**  
**75 day**  
**g/day**

## Life Cycle - Inventory



Inventory Table	per FU
CO2	915 g
CH4	1.08 g
N2O	6.37 mg
Halon-1301	53.93 microg
CO	1.74 g
NO2	4.95 g
SO2	2.86 g
NO	3.23 mg
Hydrochloric acid (HCL)	64.63 mg
HF	14.66 mg
Amonia (NH3)	34.86 mg
Ni	808.34 mg
Benzene (C6H6)	7.43 mg
Chromium (Cr)	1.8 microg
PAH	5.95 microg
Cd	12.37 microg
Pb	40.57 mg
Mn	29.62 microg
Hg	2.7 microg
Aldehydes	273.46 microg
NMVOC	2.58 g
dust	1.28 g
Cu	3.72 microg
Zn	615.49 microg
Cr	1.8 microg

## Life Cycle – Interpretation/level of confidence in the final results

$$SD_{g95} = \sigma_g^2 = \exp \sqrt{[\ln(U_1)]^2 + [\ln(U_2)]^2 + [\ln(U_3)]^2 + [\ln(U_4)]^2 + [\ln(U_5)]^2 + [\ln(U_6)]^2}$$

The factors U1 till U6 referring to the scores in the following table; the factor Ub refers to the basic uncertainty factor. So if you want to assess the impact of reliability (U1), and you have verified, measured data, the value of U1 is equal to 1.00, if you have obtained data from an expert that has done a theoretical calculation and some estimations, you cut give U2 a value of 1.2, etc.

Score:	1	2	3	4	5
U1 Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	Non-qualified estimate
	<b>1.00</b>	<b>1.05</b>	<b>1.10</b>	<b>1.20</b>	<b>1.50</b>
U2 Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods
	<b>1.00</b>	<b>1.02</b>	<b>1.05</b>	<b>1.10</b>	<b>1.20</b>
U3 Temporal correlation	Less than 3 years of difference to our reference year (2000)	Less than 6 years of difference to our reference year (2000)	Less than 10 years of difference to our reference year (2000)	Less than 15 years of difference to our reference year (2000)	Age of data unknown or more than 15 years of difference to our reference year (2000)
	<b>1.00</b>	<b>1.03</b>	<b>1.10</b>	<b>1.20</b>	<b>1.50</b>
U4 Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than area under study, or from similar area		Data from unknown OR distinctly different area (north america instead of middle east, OECD-Europe instead of Russia)
	<b>1.00</b>	<b>1.01</b>	<b>1.02</b>		<b>1.10</b>
U5 Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)		Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology
	<b>1.00</b>		<b>1.20</b>	<b>1.50</b>	<b>2.00</b>
U6 Sample size	>100, continuous measurement, balance of purchased products	>20	> 10, aggregated figure in env. report	>=3	unknown
	<b>1.00</b>	<b>1.02</b>	<b>1.05</b>	<b>1.10</b>	<b>1.20</b>

The basic uncertainty factor Ub can be derived from the table below. This basic uncertainty factor is based on expert judgement. For instance, experts often find that CO<sub>2</sub> emission data can be quite precise, and can be easily checked against the fuel input. As you can see the basic uncertainty is assumed to be very high for poly aromatic hydrocarbons (PAH), Fine dust (PM10 and PM2.5) and heavy metal emissions, as well as radionuclides and CO from combustion.

input / output group	Ub	input / output group	Ub
<b>demand of:</b>		<b>emission to air of:</b>	
thermal energy	1.05	CO2	1.05
electricity	1.05	SO2	1.05
semi-finished products	1.05	combustion: NOX, NMVOC total, methane, N2O and NH3	1.50
working materials	1.05	Combustion: CO	5.00
transport services	2.00	Combustion: individual hydrocarbons, TSM	1.50
waste treatment services	1.05	Combustion: PM10	2.00
Infrastructure	3.00	Combustion: PM2.5	3.00
<b>resources:</b>		combustion: polycyclic aromatic hydrocarbons (PAH)	3.00
primary energy carriers	1.05	Combustion: heavy metals	5.00
metals, salts	1.05	process emissions: individual VOCs	2.00
land use, occupation	1.50	process emissions: CO2	1.05
land use, transformation	2.00	process emissions: TSM	1.50
<b>waste heat:</b>		process emissions: PM10	2.00
emission to air, water, and soil	1.05	process emissions: PM2.5	3.00
<b>emission to water of:</b>		from agriculture: CH4, NH3	1.20
BOD, COD, DOC, TOC	1.50	from agriculture: N2O, NOX	1.40
inorganic compounds (NH4, PO4, NO3, Cl, Na etc.)	1.50	radionuclides (e.g., Radon-222)	3.00
individual hydrocarbons, PAH	3.00	process emissions: other inorganic emissions	1.50
heavy metals	5.00	<b>Emission to soil of:</b>	
from agriculture: NO3, PO4	1.50	oil, hydrocarbon total	1.50
from agriculture: heavy metals	1.80	Pesticides	1.20
from agriculture: pesticides	1.50	heavy metals	1.50
radionuclides	3.00	radionuclides	3.00

(taken from: Ecoinvent report number 1: Overview and methodology)

## Life Cycle – Impact Assessment

- **Selection of impact categories, category indicators, and characterization models;**
- **Classification stage, where the inventory parameters are sorted and assigned to specific impact categories;**
- **Impact measurement, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total.**

## Life Cycle – Impact Assessment

### LCIA methodologies

<http://lct.jrc.ec.europa.eu/pdf-directory/Recommendation-of-methods-for-LCIA-def.pdf>

**climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related), respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion**

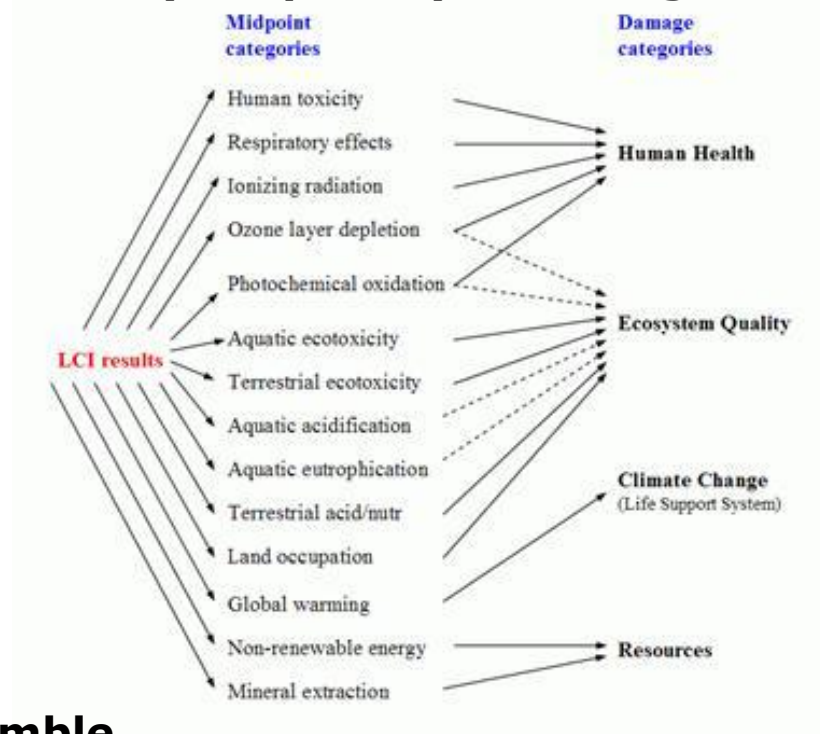
- **human health**
- **natural environment**
- **natural resource use**



## Life Cycle - Impact Assessment

**problem-oriented (mid points)**

**damage-oriented (end points)**



**e.g. Procter & Gamble ....**

“It is important to understand both the advantages and limitations of the conversion in order to interpret the indicators properly and reach sound conclusions.”

## Life Cycle – Impact Assessment

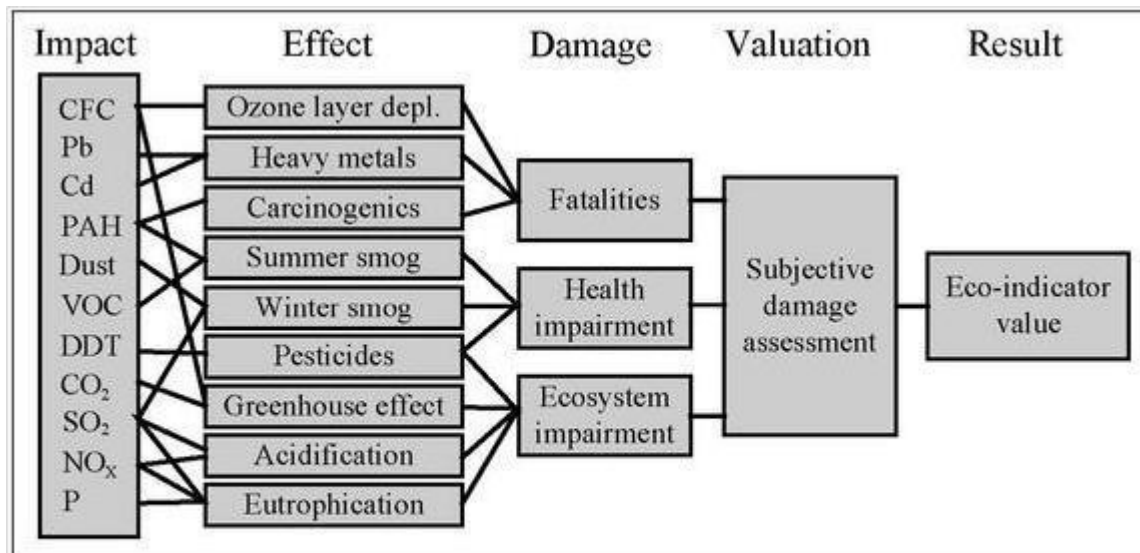
### LCIA methodologies

- ReCiPe
- BEES
- Eco-indicator 99
- Eco-indicator 95
- CML 92
- CML 2001
- Ecosystem Damage Potential
- EDIP/UMIP
- EDIP 2003
- EPS 2000
- EPD2007
- Ecopoints 97
- Impact 2002+
- TRACI
- EPD method
- Cumulative Energy Demand
- Cumulative Exergy Demand
- IPCC Greenhouse gas emissions
- IPCC2007
- Ecological Footprint
- Eco Scarcity 2006
- Selected LCI's

**Eco-Indicator 99**  
**Eco-Indicator 95**  
**CML 2001**  
**Impact 2002**

## Life Cycle – Impact Assessment

### Eco-Indicator



Bertoluci, G., & Millet, D. (2008). Functional product enrichment and supply chain disorganisation: two barriers for sustainable design [Figure 5]. *International Journal of Product Development*, 7, 149-169. Publisher: Inderscience Publishers Ltd.

## Life Cycle – Impact Assessment

Climate change (global warming potential 20/100/500 years)

$$\text{CO}_2 \text{ eq [kg]} = \sum_i^n (\text{GWP}_{100} * \text{Emission}_i \text{ [kg]})$$

*Intergovernmental Panel on Climate Change (IPCC)*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m <sup>-2</sup> ppb <sup>-1</sup> )	Global Warming Potential for Given Time Horizon			
				SAR <sup>†</sup> (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO <sub>2</sub>	See below <sup>a</sup>	<sup>b</sup> 1.4x10 <sup>-5</sup>	1	1	1	1
Methane <sup>c</sup>	CH <sub>4</sub>	12 <sup>c</sup>	3.7x10 <sup>-4</sup>	21	72	25	7.6
Nitrous oxide	N <sub>2</sub> O	114	3.03x10 <sup>-3</sup>	310	289	298	153
<b>Substances controlled by the Montreal Protocol</b>							
CFC-11	CCl <sub>3</sub> F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl <sub>2</sub> F <sub>2</sub>	100	0.32	8,100	11,000	10,900	5,200
CFC-13	CClF <sub>3</sub>	640	0.25		10,800	14,400	16,400
CFC-113	CCl <sub>2</sub> FCF <sub>2</sub>	85	0.3	4,800	6,540	6,130	2,700
CFC-114	CClF <sub>2</sub> CClF <sub>2</sub>	300	0.31		8,040	10,000	8,730
CFC-115	CClF <sub>2</sub> CF <sub>3</sub>	1,700	0.18		5,310	7,370	9,990
Halon-1301	CBrF <sub>3</sub>	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	CBrClF <sub>2</sub>	16	0.3		4,750	1,890	575
Halon-2402	CBrF <sub>2</sub> CBrF <sub>2</sub>	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl <sub>4</sub>	26	0.13	1,400	2,700	1,400	435

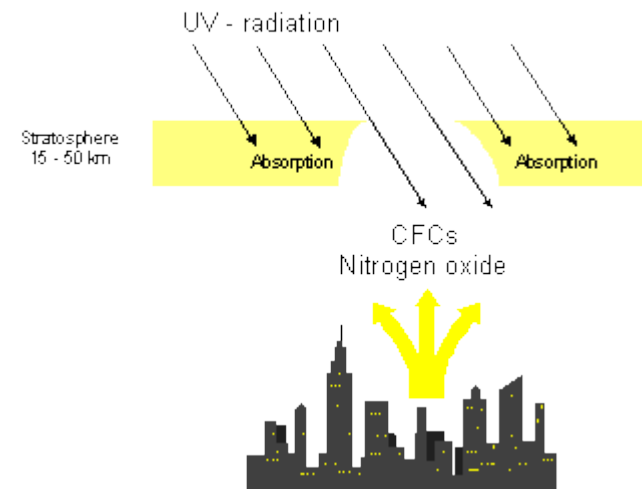
## Life Cycle - Impact Assessment

Ozone depletion *ref CFC-11*

ozone depletion potential (ODP)

$$\text{CFC-11}_{\text{eq}}[\text{kg}] = \sum_i^n (\text{ODP} * \text{Emissioni} [\text{kg}])$$

Stratospheric Ozone Depletion			
Ethane, 1-chloro-1,1-difluoro-, HCFC-142	000075-68-3	0.043	kg CFC-11 eq / kg
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	001717-00-6	0.086	kg CFC-11 eq / kg
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	0.11	kg CFC-11 eq / kg
Ethane, 1,1,1-trifluoro-2,2-chlorobromo-, Halon 2311	000151-67-7	0.14	kg CFC-11 eq / kg
Ethane, 1,1,1,2-tetrafluoro-2-bromo-, Halon 2401	000124-72-1	0.25	kg CFC-11 eq / kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	000076-13-1	0.9	kg CFC-11 eq / kg
Ethane, 1,2-dibromotetrafluoro-, Halon 2402	000124-73-2	7	kg CFC-11 eq / kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	000076-14-2	0.85	kg CFC-11 eq / kg
Ethane, 2-chloro-1,1,1,2-tetra-fluoro-, HCFC-124	002837-89-0	0.026	kg CFC-11 eq / kg
Ethane, 2,2-dichloro-1,1,1-tri-fluoro-, HCFC-123	000306-83-2	0.012	kg CFC-11 eq / kg
Ethane, chloropentafluoro-, CFC-115	000076-15-3	0.4	kg CFC-11 eq / kg
Methane, bromo-, Halon 1001	000074-83-9	0.37	kg CFC-11 eq / kg
Methane, bromochlorodifluoro-, Halon 1211	000353-59-3	5.1	kg CFC-11 eq / kg
Methane, bromodifluoro-, Halon 1201	001511-62-2	1.4	kg CFC-11 eq / kg
Methane, bromotrifluoro-, Halon 1301	000075-63-8	12	kg CFC-11 eq / kg
Methane, chlorodifluoro-, HCFC-22	000075-45-6	0.034	kg CFC-11 eq / kg
Methane, dibromodifluoro-, Halon 1202	000075-61-6	1.25	kg CFC-11 eq / kg
Methane, dichlorodifluoro-, CFC-12	000075-71-8	0.82	kg CFC-11 eq / kg
Methane, monochloro-, R-40	000074-87-3	0.02	kg CFC-11 eq / kg
Methane, tetrachloro-, CFC-10	000056-23-5	1.2	kg CFC-11 eq / kg
Methane, trichlorofluoro-, CFC-11	000075-69-4	1	kg CFC-11 eq / kg
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	000507-55-1	0.017	kg CFC-11 eq / kg
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	000422-56-0	0.017	kg CFC-11 eq / kg



## Life Cycle – Impact Assessment

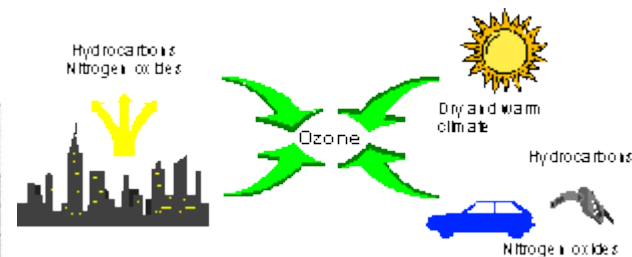
### Summer Smog

*ref C<sub>2</sub>H<sub>4</sub>*

**photochemical ozone creation potential (POCP) indicates the potential capacity of a volatile organic substance to produce ozone**

$$\text{Smog (kg)} = (\text{POCP} \times \text{airborne emission (kg)})$$

Pollutant species (MELCHIOR compound)	Corresponding item in life cycle inventory	POCP <sub>mean</sub>	POCP <sub>AOT40</sub>	POCP <sub>AOT60</sub>	POCP <sub>AOT90</sub>	POCP <sub>peak</sub>
CO	Carbon monoxide	2.0	1.9	2.3	2.2	1.8
C <sub>2</sub> H <sub>6</sub>	Ethane	2.1	3.3	4.8	5.9	3.1
NC <sub>6</sub> H <sub>10</sub>	Other alkanes	10	15	19	22	14
C <sub>2</sub> H <sub>4</sub>	Ethene (ethylene)	100	100	100	100	100
C <sub>3</sub> H <sub>6</sub>	Other alkenes	67	75	82	91	76
C <sub>5</sub> H <sub>8</sub>	Isoprene	23	33	39	30	29
APINEN	Terpenes	2.2	11	15	16	9
Oxyl	Aromatics HC, phenols	44	53	59	68	54
HCHO	Formaldehyde	41	43	40	45	43
CH <sub>3</sub> CHO	Other aldehydes	6.3	11	20	23	11
CH <sub>3</sub> COE	Ketones	6.7	14	17	21	14
TOTVOC	Total VOC	21	27	32	34	26
NO <sub>x</sub>	Nitrogen oxides	95	59	66	27	50



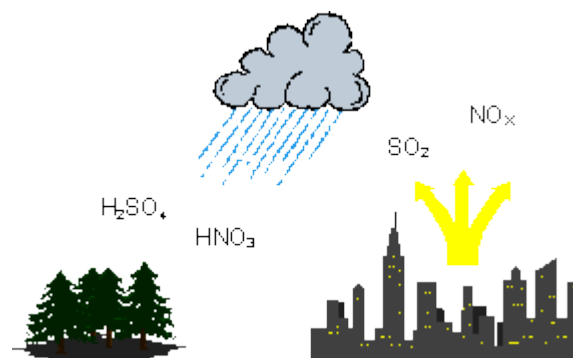
## Life Cycle – Impact Assessment

### Acidification

$$\text{Acidification (kg)} = (\text{AP} \times \text{airborne emission (kg)})$$

Substance	Acidification potential (AP <sub>i</sub> in kg SO <sub>2</sub> -equiv./kg)
SO <sub>2</sub>	1.00
NO	1.07
N <sub>2</sub> O	0.70
NO <sub>x</sub>	0.70
NH <sub>3</sub>	1.88
HCl	0.88
HF	1.60

*ref SO<sub>2</sub>*



## Life Cycle – Impact Assessment

**Human toxicity** The degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of human exposed to the substance over a designated time period.

$$\text{Human toxicity (kg)} = (\text{HCA (kg.kg}^{-1}) \times \text{emission to air (kg)} + \text{HCW (kg.kg}^{-1}) \times \text{emission to water (kg)})^5$$

Burden	Human Toxicity Potential
CO (carbon monoxide)	0.012
NO <sub>x</sub> (oxides of nitrogen)	0.78
SO <sub>2</sub> (sulphur dioxide)	1.2
Hydrocarbons (excluding methane)	1.7
Chlorinated hydrocarbons	0.98
Chlorofluorocarbons	0.022
As (arsenic vapour)	4700
Hg (mercury vapour)	120
F <sub>2</sub> (fluorine)	0.48
HF (hydrogen fluoride)	0.48
NH <sub>3</sub> (ammonia)	0.0017-0.020
As (arsenic as solids)	1.4
Cr (chromium)	0.57
Cu (copper)	0.02
Fe (iron)	0.0036
Hg (mercury as liquid)	4.7
Ni (nickel)	0.057
Pb (lead)	0.79
Zn (zinc)	0.0029
Fluorides	0.041
Nitrates	0.00078
Phosphates	0.00004



## Life Cycle – Impact Assessment

### Carcinogenic

The 'Air Quality Guidelines' do not specify acceptable levels, but calculate the probability of cancer at a level of  $1 \mu\text{g}/\text{m}^3$ . In the table below this probability is expressed as the number of people from a group of 1 million who will develop cancer with the stated exposure. (Polycyclic aromatic hydrocarbons (PAHs))

	Probability of cancer at $1 \mu\text{g}/\text{m}^3$	Weighting factor for PAH equivalent	Type of cancer
Arsenic	0.004	0.044	General, also mutagenic effects
Benzene	0.000001	$1.1 \cdot 10^{-5}$	Leukaemia
Nickel	0.04	0.44	Lung and larynx
Chromium (VI)	0.04	0.44	Lung, among others, and mutagenic effects
PAHs (benzo(a)pyrene)	0.09	1	Lung cancer but also other types of cancer

$$\text{Carcinogenic eq [kg]} = \sum_i^n (\text{WF} \cdot \text{Emission}_i \text{ [kg]})$$

## Life Cycle – Impact Assessment

**Heavy Metals**      high atomic weight

WF

Heavy metal to air (kg lead eq.) = (AQG (lead)/AQG (substance) \* emission)

Heavy metal to water (kg lead eq.) = (GDWQ (lead)/GDWQ (substance)\* emission)



### Air Quality Guidelines

	Maximum concentration (µg/m³)	Weighting factor	Main health effect
Cadmium	0.02	50	Kidneys
Lead	1	1	Blood biosynthesis, nervous system and blood pressure
Manganese	7	0.14	Lungs and nervous system (shortage cause skin complaints)
Mercury	1	1	Brain: sensory and co-ordination functions

### Water Quality Guidelines

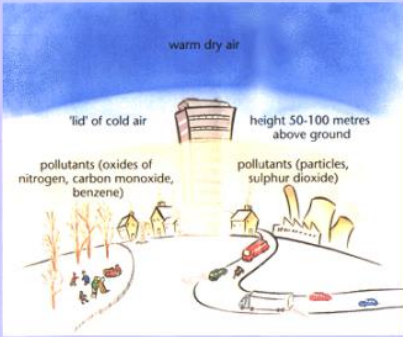
Substance	Norm (mg/litre)	Weighting factor	Effect
Antimony	0.005	2	Glucose and cholesterol content of blood
Arsenic	0.01	1	Probability of skin cancer $6 \cdot 10^{-4}$
Barium	0.07	0.14	Blood pressure and blood vessels
Boron	0.3	0.03	Fertility
Cadmium	0.003	3	Kidneys
Chromium (all)	0.05	0.2	Hereditry (carcinogenity only applicable in event of inhalation)
Copper	2	0.005	Generally no problems, sometimes liver abnormalities
Lead	0.01	1	Blood biosynthesis, nervous system and blood pressure
Manganese	0.5	0.02	Nervous system
Mercury	0.001	10	Kidneys, nervous system (methyl mercury)
Molybdenum	0.07	0.14	No clear description
Nickel	0.02	0.5	Weight loss, great uncertainty

## Life Cycle – Impact Assessment

### Winter Smog

Only dust (SPM) and SO<sub>2</sub> are factors in this problem. For both substances the 'Air Quality Guidelines' specify a level of 50 µg/m<sup>3</sup>. The weighting factors are thus both 1.

$$\text{Winter smog (SO}_2 \text{ or SPM eq.)} = \text{SO}_2 \text{ emission} + \text{SPM emission}$$



The diagram illustrates the formation of winter smog. It shows a cross-section of the atmosphere. At the top, there is 'warm dry air'. Below it, a layer of 'lid of cold air' is shown at a 'height 50-100 metres above ground'. This lid traps pollutants below. On the left, pollutants from homes and buildings are listed as 'pollutants (oxides of nitrogen, carbon monoxide, benzene)'. On the right, pollutants from road vehicles and factories are listed as 'pollutants (particles, sulphur dioxide)'. The ground level shows a residential area with houses and trees, and a road with cars. The trapped pollutants create a thick layer of smog near the ground.

**Caused by mixture of pollutants from:**

- road vehicles
- fuels used to provide electricity and heating in offices, factories and homes

**Formed by:**  
 Pollutants building up at ground level in urban areas. The 'lid' of cold air above the warm air traps the pollutants

**When:**  
 On cold, calm days, often after a clear, cloudless night and an early-morning frost or mist close to the ground

## Life Cycle – Impact Assessment

### Eutrophication

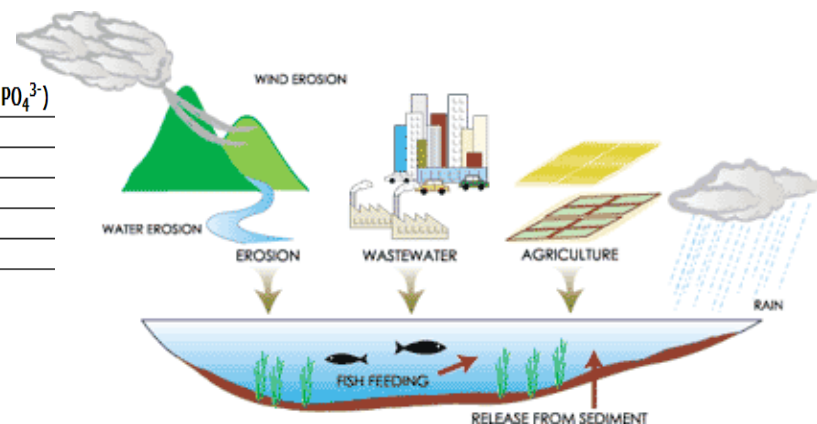
enrichment of aquatic systems with nutrients

The Nutriphication Potential (NP) is set at 1 for phosphate ( $PO_4$ ). Other emissions also influence eutrophication, notably nitrogen oxides and ammonium.

The eutrophication effect score is calculated as follows:

$$\text{Eutrophication (kg)} = (\text{NP} \times \text{airborne emission (kg)})$$

Burden	Eutrophication Potential (vs $PO_4^{3-}$ )
Phosphates	1
Nitrates	0.42
Ammonia	0.33
Oxides of nitrogen	0.13
Chemical Oxygen Demand (COD)	0.022



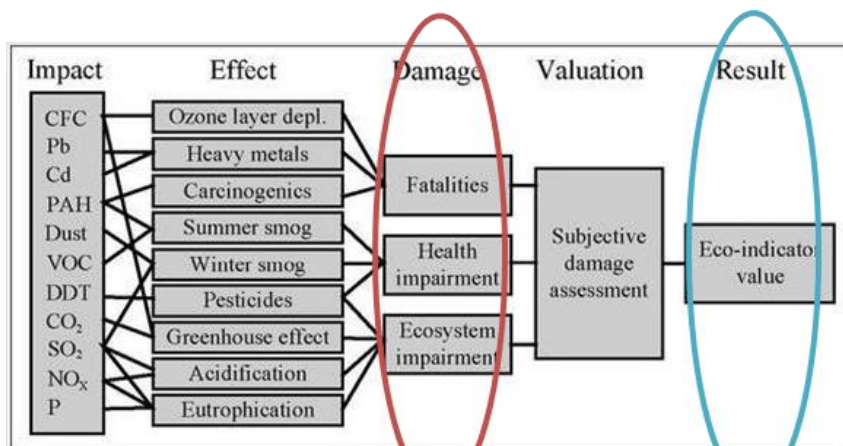
## Life Cycle – Impact Assessment

### Resource depletion

Exhaustion = (amount consumed (kg) × {1/resources (kg)})



## Life Cycle - Impact Assessment



Bertoluci, G., & Millet, D. (2008). Functional product enrichment and supply chain disorganisation: two barriers for sustainable design [Figure 5]. *International Journal of Product Development*, 7, 149-169. Publisher: Inderscience Publishers Ltd.

## Weighting

Normalisation is strongly recommended by CML, suggesting also choosing the whole world or an average world citizen for one year as reference system for all impact categories.

Impact categories	Netherlands, 1997	West-Europe, 1995	World, 1995
Depletion of abiotic resources, kg antimony.yr <sup>-1</sup> .cap <sup>-1</sup>	110	32.6	27.7
Climate change, kg CO <sub>2eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	16 100	14 600	6 830
Stratospheric ozone depletion, kg CFC <sub>11eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	0,0626	0,256	0,0911
Human toxicity, kg 1,4-DCB <sub>eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	12 100	23 300	8 800
Fresh water aquatic ecotoxicity, kg 1,4-DCB <sub>eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	483	1550	359
Marine ecotoxicity, kg 1,4-DCB <sub>eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	2,73E+05	3,49E+05	9,05E+05
Terrestrial ecotoxicity, kg 1,4-DCB <sub>eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	61,5	146	47,4
Photo-oxidant formation, kg C <sub>2</sub> H <sub>4eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	11,7	25,4	8,04
Acidification, kg SO <sub>2eq</sub> .yr <sup>-1</sup> .cap <sup>-1</sup>	42,9	84,2	52,9
Eutrophication, kg PO <sub>4</sub> <sup>3-</sup> .yr <sup>-1</sup> .cap <sup>-1</sup>	32,1	38,4	22,8

	Unit	Western Europe	Eastern Europe	Total	Per head of the population	Uncertainty
Greenhouse effect	GWP kg	4.8E+12	1.7E+12	6.5E+12	1.31E+04	small
Ozone layer depletion	ODP kg	3.7E+08	9.4E+07	4.6E+08	9.26E-01	large
Acidification	AP kg	3.5E+10	2.1E+10	5.6E+10	1.13E+02	small
Eutrophication	NP kg	1.4E+10	5.1E+09	1.9E+10	3.82E+01	mod.
Heavy metals	Pb equiv. kg	2.1E+07	5.9E+06	2.7E+07	5.43E-02	large
Carcinogens	PAH equiv. kg	4.3E+06	1.1E+06	5.4E+06	1.09E-02	large
Winter smog	SO <sub>2</sub> equiv. kg	2.3E+10	2.3E+10	4.7E+10	9.46E+01	small
Summer smog	POCP kg	7.0E+09	1.9E+09	8.9E+09	1.79E+01	large
Pesticides	active ingr. kg	3.8E+08	9.8E+07	4.8E+08	9.66E-01	large

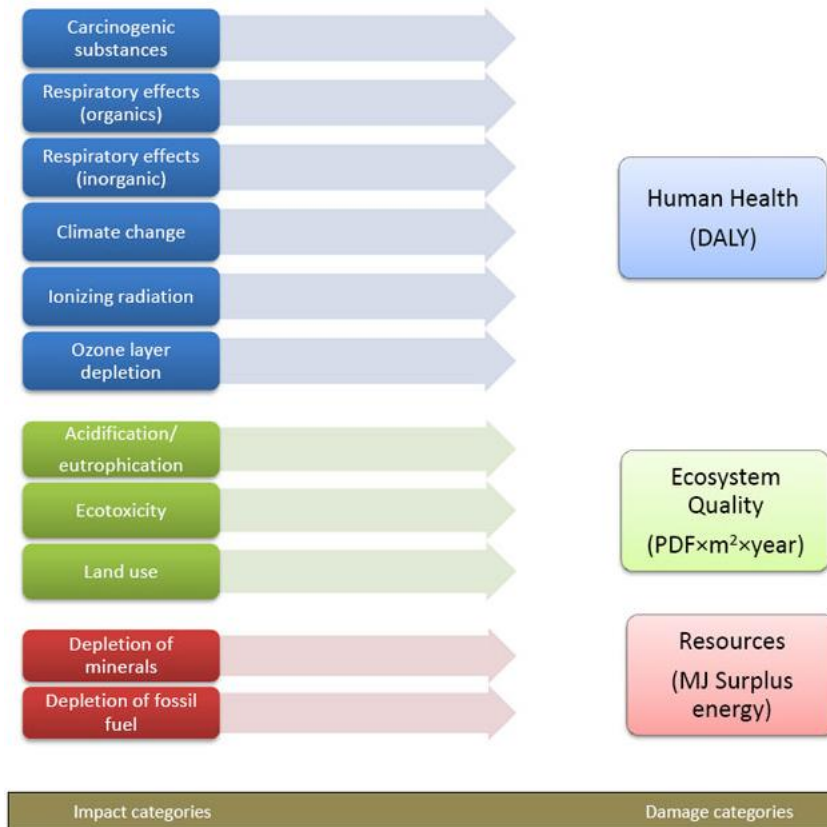
Reference for normalization European value per year 1990

Environmental effect	Weighting factor	Criterion
Greenhouse effect	2.5	0.1°C rise every 10 years, 5% ecosystem degradation
Ozone layer depletion	100	Probability of 1 fatality per year per million inhabitants
Acidification	10	5% ecosystem degradation
Eutrophication	5	Rivers and lakes, degradation of an unknown number of aquatic ecosystems (5% degradation)
Summer smog	2.5	Occurrence of smog periods, health complaints, particularly among the most sensitive and the most exposed
Winter smog	5	Occurrence of smog periods, health complaints, particularly among the most sensitive and the most exposed
Pesticides	25	5% reduction in the number of people
Airborne heavy metals	5	Lead content in children's blood, reduced life expectancy and learning performance in an unknown number of people
Waterborne heavy metals	5	Cadmium content in rivers, ultimately also impacts on people (see airborne)
Carcinogenic substances	10	Probability of 1 fatality per year per million people

The underlying premise is that there is a correlation between the seriousness of an effect and the distance between the current level and the target level. Thus if acidification has to be reduced by a factor of 10 in order to achieve a sustainable society and smog by a factor of 5, then acidification is regarded as being twice as serious; the reduction factor is the weighting factor. This principle has been refined and improved in the project, but there is

$$\text{WeightedIndex} = \sum_{cat} \text{WeightingFactor}_{cat} \times \text{NormalizedIndicatorResult}_{cat}$$

## EcoIndicator99



(Disability Adjusted Life Years), which is the number of disability years caused by exposure to toxic material multiplied by the “disability factor”, a number between 0 and 1 that describes severity of the damage (0 for being perfectly healthy and 1 for being fatal). Per individual.

(Potentially Disappeared Fraction), which is a probability of the plants species to disappear from the area as a result of acidification and eutrophication. Since it is not possible to determine whether the damage is caused by changes in the nutrient level or by acidity, these two impact categories are combined. Land use is also characterized by PDF, which refers to the change in the numbers of all species on the occupied land and at the natural area in the surroundings. The total units of the Ecosystem Quality are PDF times area times year [PDF×m<sup>2</sup>×year].

“surplus energy” in MJ per kg extracted material, and it is related to the expected increase of extraction energy per kg of extracted material.



## Weighting

Perspectief of basishouding	Time perspective	Manageability	Required level of evidence
H (Hierarchist)	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus
I (Individualist)	Short time	Technology can avoid many problems	Only proven effects
E (Egalitarian)	Very long term	Problems can lead to catastrophe	All possible effects

a=yr/yr

	Hierachist (EI'99 H/A)		Egalitarian (EI'99 E/E)		Individualist (EI'99 I/I)	
	Normalisation	Weights	Normalisation	Weights	Normalisation	Weights
Human Health	0.0154 DALYs(0,0)	40%	0.0155 DALYs(0,0)	30%	0.00825 DALYs(0,1)	55%
Ecosystem Quality	5130 PDF*m2*a	40%	5130 PDF*m2*a	50%	4510 PDF*m2*a	25%
Resources	8410 MJ	20%	5940 MJ	20%	150 MJ	20%

## Tools/Software

<http://lca.jrc.ec.europa.eu/lcainfohub/toolList.vm>

Boustead	www.boustead-consulting.co.uk
Eco-it	www.pre.nl
Ecopro	www.sinum.com
Ecoscan	www.ind.tno.nl
Euklid	www.ivv.fhg.de
KCL Eco	www.kcl.fi/eco
Gabi	www.gabi-software.com
LCAit	www.ekologik.cit.chalmers.se
Miet	www.leidenuniv.nl/cml/ssp/software
Pems	www.piranet.com/pack/lca_software.htm
SimaPro	www.pre.nl
Team	www.ecobilan.com
Wisard	www.pwcglobal.com
Umberto	www.umberto.de

**Generic**

**Car specific**

GEMIS	<a href="http://www.oeko.de/service/gemis/en/material.htm">http://www.oeko.de/service/gemis/en/material.htm</a>
GREET	<a href="http://greet.es.anl.gov/">http://greet.es.anl.gov/</a>
LEM	<a href="http://www.its.ucdavis.edu/">http://www.its.ucdavis.edu/</a>
Optiresource	<a href="http://www.optiresource.org">http://www.optiresource.org</a>

## SIMAPRO

**Compare the environmental impact of 3 products to provide mineral water:**

- 1 glass bottle not reusable;**
- 1 glass bottle reusable;**
- 1 plastic bottle PET (poly(ethylene terephthalate))**



+

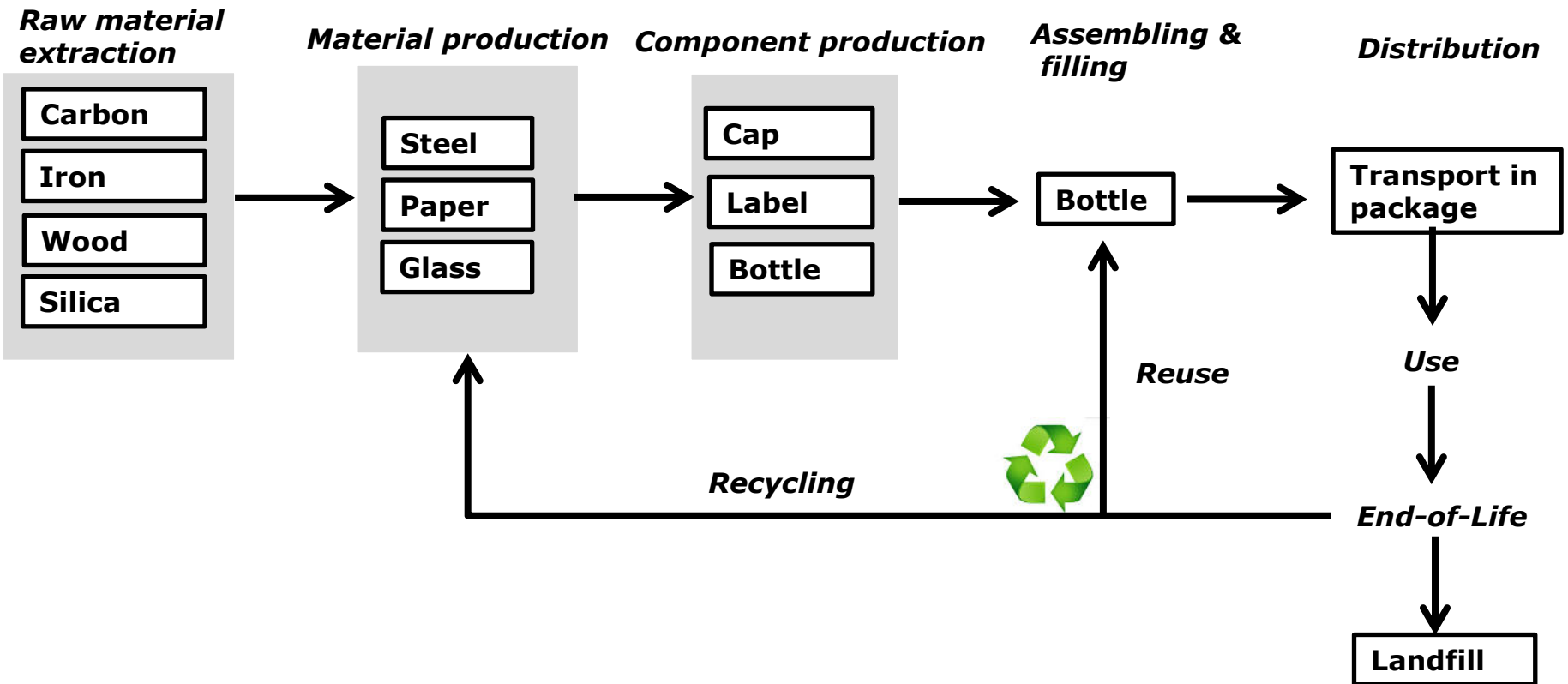


+



## SIMAPRO

### Simplified life cycle for reusable glass bottle

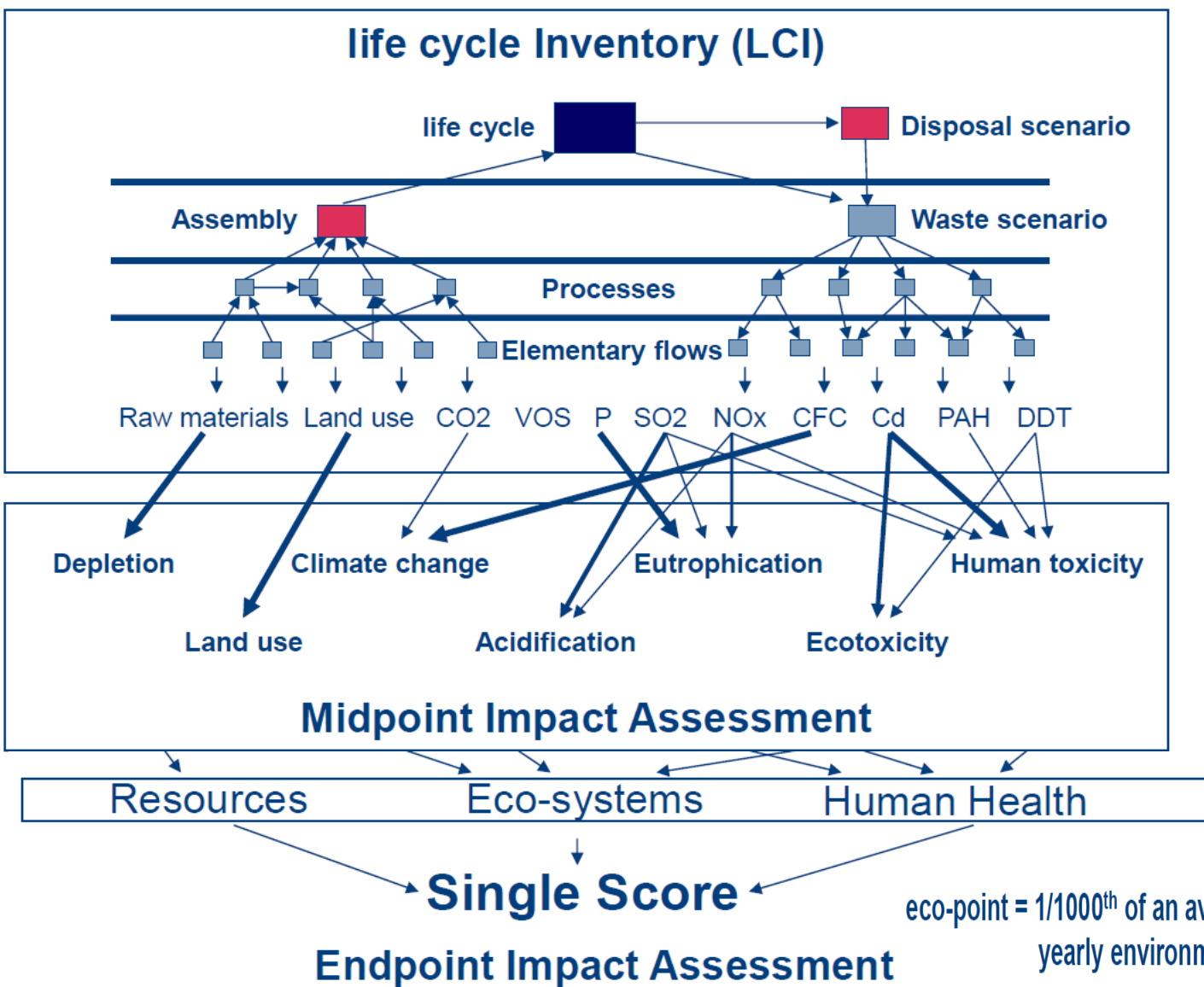


## SIMAPRO

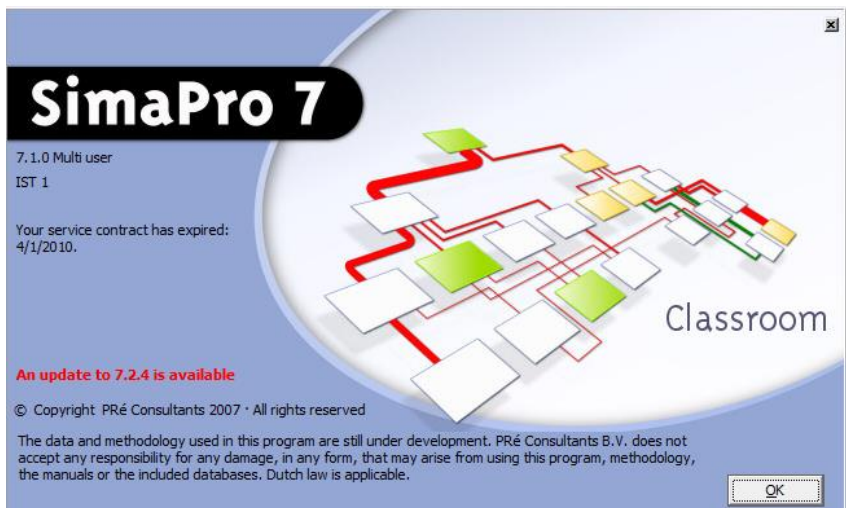
Product	Bottle	Cap	Label	Package
1 glass bottle reusable	Glass 599 g	Steel 2.2 g	Paper 1 g	PEHD 1818 g (12 bottle)
1 glass bottle not "	Glass 599 g	Steel 2.2 g	Paper 1 g	Paperboard 519 g (12 bottle)
1 plastic bottle PET	PET 18 g	PEHD 2.5 g	Paper 1 g	PELD 38 g

**HD-High Density; LD-Low Density; PE- PolyEthylen; \* Relatively to the market available**

Product E-of-L	Reuse (%*)	Recycling (%*)	Landfill (%*)	Incineration (%*)
1 glass bottle reusable	70	10	20	-
1 glass bottle not "	-	40	60	-
1 plastic bottle PET	-	10	30	60



eco-point = 1/1000<sup>th</sup> of an average European's yearly environmental load



Create a new project

Name	Project manager	Type	Protection
biohydrogen life cycle	Expert	Project	
BUWAL250	Manager	Library project	
DK Input Output Database 99	Manager	Library project	
Ecoinvent system processes	Manager	Library project	
Ecoinvent unit processes	Manager	Library project	
		Project	
		Library project	
		Library project	
		Library project	
		Library project	
		Library project	
		Project	
		Library project	

**New project**

Name:

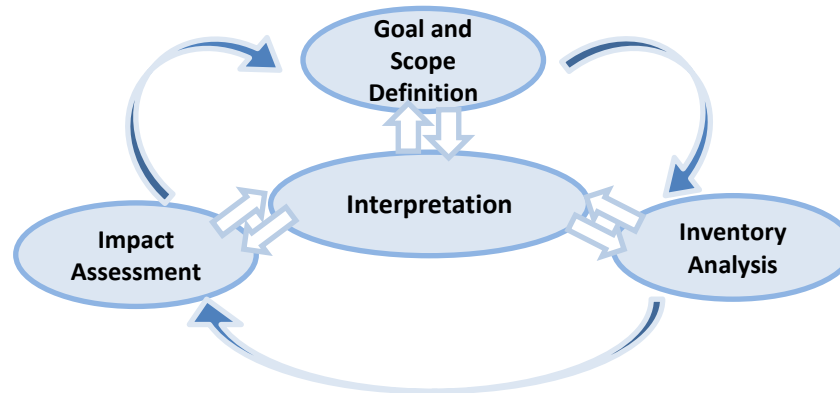
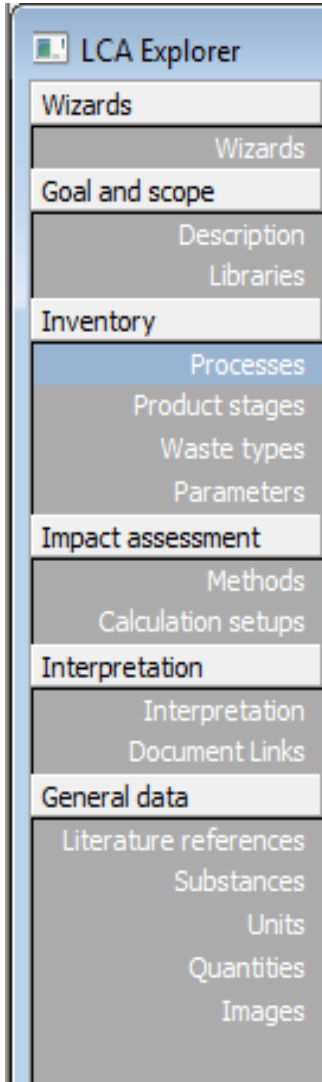
OK Cancel

This Danish input output database is based on the Danish NAMEA for 1999 (Danmarks Statistik 2003: Grundmateriale til miljøøkonomisk regnskab for Danmark (NAMEA). Emissionsmatricer og input-output-matricer for 1999. Copenhagen: Statistics Denmark.). A number of modifications/improvements have been made to these basic data in order to make them more relevant for LCA purposes. These modifications have been described in a background report (Weidema et al. 2005: Prioritisation within the integrated product policy. Copenhagen: Danish Environmental Protection Agency.). It is included in the Database Manuals (see under Help).

Choose New Project and give your project a name. "Industrial ecology"

Ok

Double click in project created



## Goal and Scope

The product or service to be assessed is defined, a functional basis for comparison is chosen and the required level of detail is defined.

## Inventory

Analysis of extractions and emissions. An inventory list of all the inputs and outputs of a product or service.

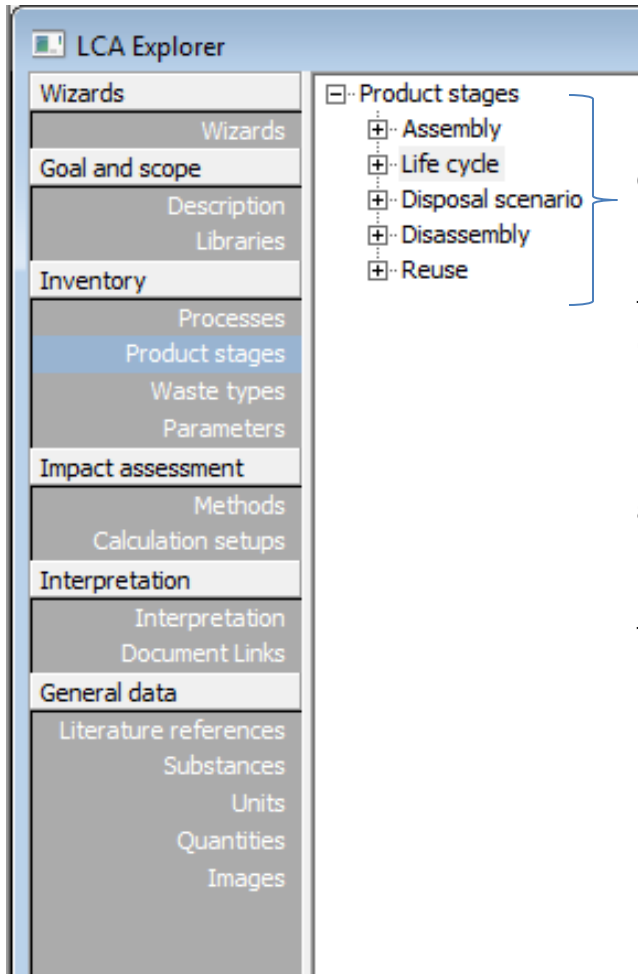
## Impact assessment

The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance.

## Interpretation

The results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.





“Assembly” – is a way of describing the manufacture, distribution and use of any product or service to be analyzed, which is composed of others "assemblies" and processes

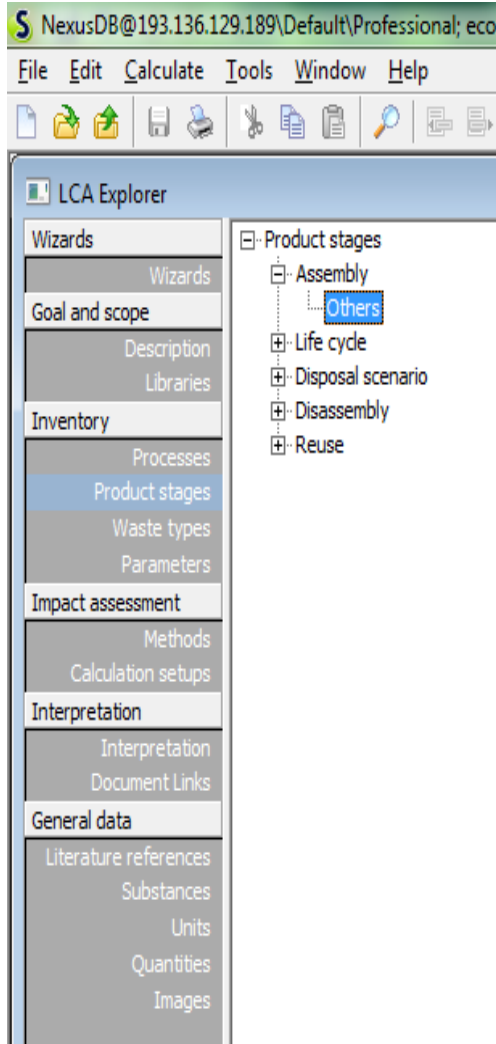
“Waste /Disposal scenario” – The situation of final treatment describes the operations to which the product will be subjected after use. Thus includes screening processes (disassembly), reuse and recycling.

“Life cycle” – The situation of final treatment describes the operations to which the product will be subjected after use. Thus includes screening processes (disassembly), reuse and recycling.

“Reuse” - This item is intended for cases where the product in question can be reused at the end of its useful life, eg. glass bottles with return.

Characterized impact categories are called mid-points.





There are 5 different categories available in the category section:

- ***Assembly***
- ***Life cycle***
- ***Disposal Scenarios***
- ***Disassembly***
- ***Reuse***

First we are going to focus on the key product stage called Assembly

**LCA Explorer**

Wizards  
 Wizards

Goal and scope  
 Description  
 Libraries

Inventory  
 Processes  
**Product stages**  
 Waste types  
 Parameters

Impact assessment  
 Methods  
 Calculation setups

Interpretation  
 Interpretation  
 Document Links

General data  
 Literature references  
 Substances  
 Units  
 Quantities  
 Images

Product stages

- Assembly
- Others**
- Life cycle
- Disposal scenario
- Disassembly
- Reuse

Name	Project	Status
caixa de cartão	ecologia industrial	
Cápsula de aço	ecologia industrial	
cápsula de PEAD	ecologia industrial	
Filme retráctil de PEBD	ecologia industrial	
garrafa de vidro TP	ecologia industrial	
garrafa de PET	ecologia industrial	
Garrafa de vidro TR	ecologia industrial	
garrafas de PET completas	ecologia industrial	
Garrafas de vidro TP Completas	ecologia industrial	
Garrafas de vidro TR completas	ecologia industrial	
Grade de plástco	ecologia industrial	
rótulo de papel	ecologia industrial	

1<sup>st</sup> create the Products  
 'Assembly'

Assembly

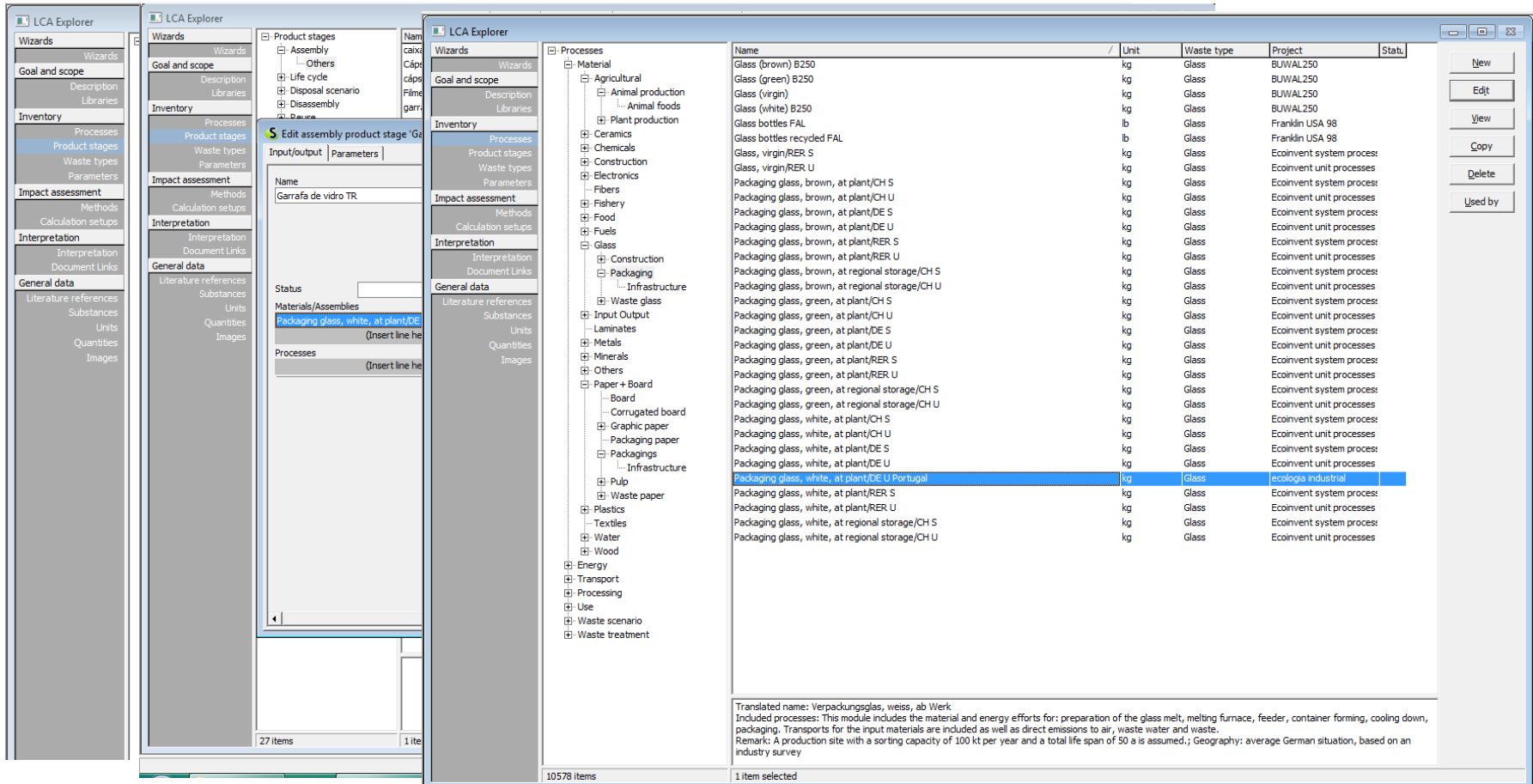
Others

New

Double click:  
Write a name of product

Double click:  
Select the adequate material in processes

In amount: double click and insert the product weight and the associated unit



The screenshot displays the LCA Explorer software interface with three panels illustrating the workflow:

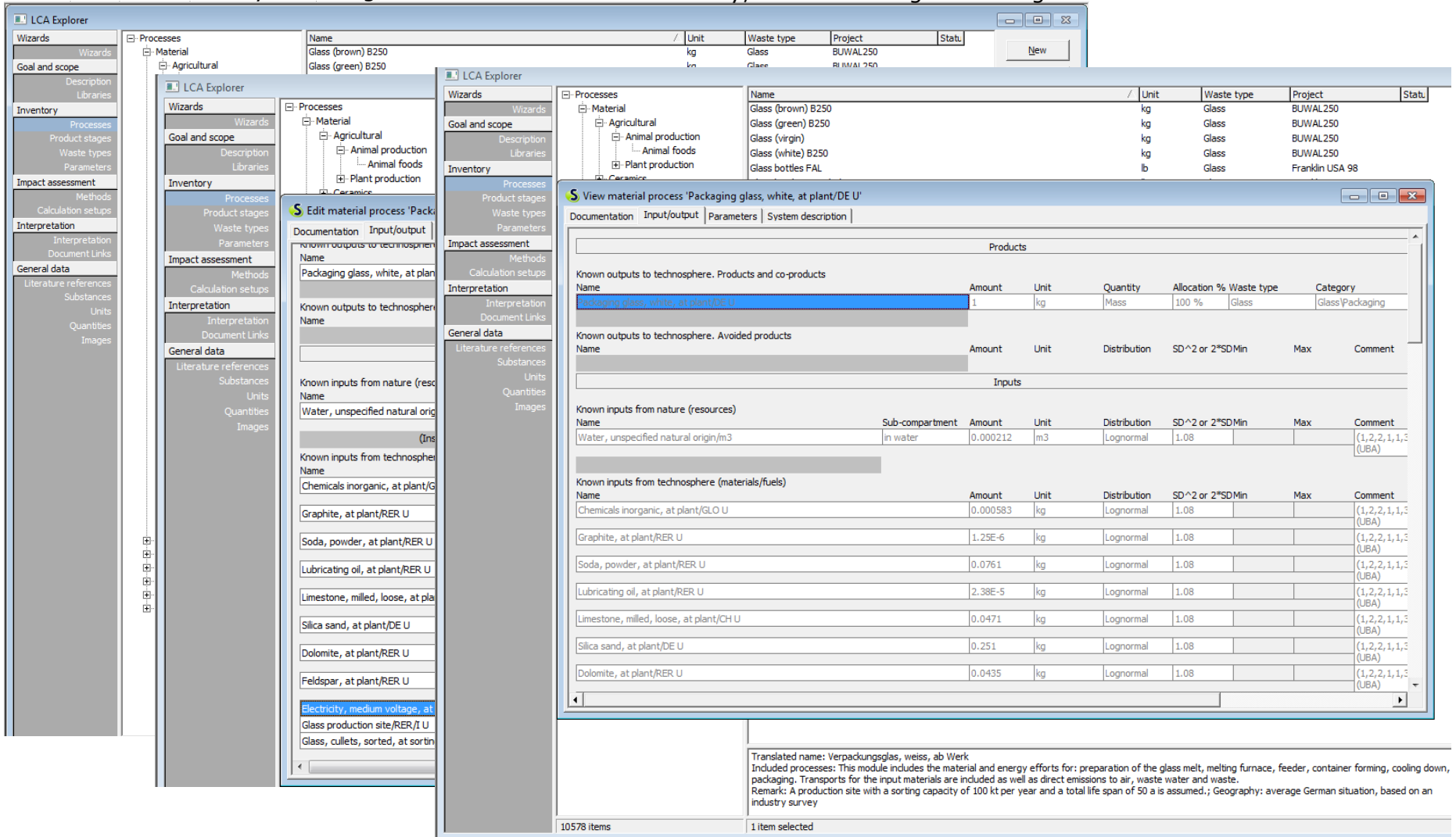
- Left Panel (Edit assembly product stage):** Shows the 'Product stages' tree with 'Assembly' selected. The 'Name' field contains 'Garrafa de vidro TR'. The 'Status' field is empty.
- Middle Panel (Processes tree):** Shows a hierarchical tree of processes. The 'Packaging' process is selected under the 'Glass' category.
- Right Panel (Material list table):** A table listing materials with columns for Name, Unit, Waste type, Project, and Status. The selected material is 'Packaging glass, white, at plant/DE U Portugal' with a unit of 'kg' and waste type of 'Glass'.

Name	Unit	Waste type	Project	Status
Glass (brown) B250	kg	Glass	BUWAL250	
Glass (green) B250	kg	Glass	BUWAL250	
Glass (virgin)	kg	Glass	BUWAL250	
Glass (white) B250	kg	Glass	BUWAL250	
Glass bottles FAL	lb	Glass	Franklin USA 98	
Glass bottles recycled FAL	lb	Glass	Franklin USA 98	
Glass, virgin/RER S	kg	Glass	Ecoinvent system process	
Glass, virgin/RER U	kg	Glass	Ecoinvent unit processes	
Packaging glass, brown, at plant/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, brown, at plant/CH U	kg	Glass	Ecoinvent unit processes	
Packaging glass, brown, at plant/DE S	kg	Glass	Ecoinvent system process	
Packaging glass, brown, at plant/DE U	kg	Glass	Ecoinvent unit processes	
Packaging glass, brown, at plant/RER S	kg	Glass	Ecoinvent system process	
Packaging glass, brown, at plant/RER U	kg	Glass	Ecoinvent unit processes	
Packaging glass, brown, at regional storage/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, brown, at regional storage/CH U	kg	Glass	Ecoinvent unit processes	
Packaging glass, green, at plant/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, green, at plant/CH U	kg	Glass	Ecoinvent unit processes	
Packaging glass, green, at plant/DE S	kg	Glass	Ecoinvent system process	
Packaging glass, green, at plant/DE U	kg	Glass	Ecoinvent unit processes	
Packaging glass, green, at plant/RER S	kg	Glass	Ecoinvent system process	
Packaging glass, green, at plant/RER U	kg	Glass	Ecoinvent unit processes	
Packaging glass, green, at regional storage/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, green, at regional storage/CH U	kg	Glass	Ecoinvent unit processes	
Packaging glass, white, at plant/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, white, at plant/CH U	kg	Glass	Ecoinvent unit processes	
Packaging glass, white, at plant/DE S	kg	Glass	Ecoinvent system process	
Packaging glass, white, at plant/DE U	kg	Glass	Ecoinvent unit processes	
Packaging glass, white, at plant/DE U Portugal	kg	Glass	ecologia industrial	
Packaging glass, white, at plant/RER S	kg	Glass	Ecoinvent system process	
Packaging glass, white, at plant/RER U	kg	Glass	Ecoinvent unit processes	
Packaging glass, white, at regional storage/CH S	kg	Glass	Ecoinvent system process	
Packaging glass, white, at regional storage/CH U	kg	Glass	Ecoinvent unit processes	

Translated name: Verpackungsglas, weiss, ab Werk  
 Included processes: This module includes the material and energy efforts for: preparation of the glass melt, melting furnace, feeder, container forming, cooling down, packaging. Transports for the input materials are included as well as direct emissions to air, waste water and waste.  
 Remark: A production site with a sorting capacity of 100 kt per year and a total life span of 50 a is assumed.; Geography: average German situation, based on an industry survey

Convert all electricity to Portugal case

Insert Electricity, medium voltage to Portugal



The screenshot displays the LCA Explorer software interface. The main window shows a list of processes under 'Material' > 'Agricultural' > 'Plant production'. A secondary window titled 'View material process: Packaging glass, white, at plant/DE U' is open, showing the 'Input/output' tab. This window contains two tables: 'Known outputs to technosphere. Products and co-products' and 'Known inputs from nature (resources)'. The 'Products' table lists 'Packaging glass, white, at plant/DE U' with an amount of 1 kg. The 'Inputs' table lists various materials like 'Water, unspecified natural origin/m3', 'Chemicals inorganic, at plant/GLO U', 'Graphite, at plant/RER U', 'Soda, powder, at plant/RER U', 'Lubricating oil, at plant/RER U', 'Limestone, milled, loose, at plant/CH U', 'Silica sand, at plant/DE U', 'Dolomite, at plant/RER U', and 'Dolomite, at plant/RER U'.

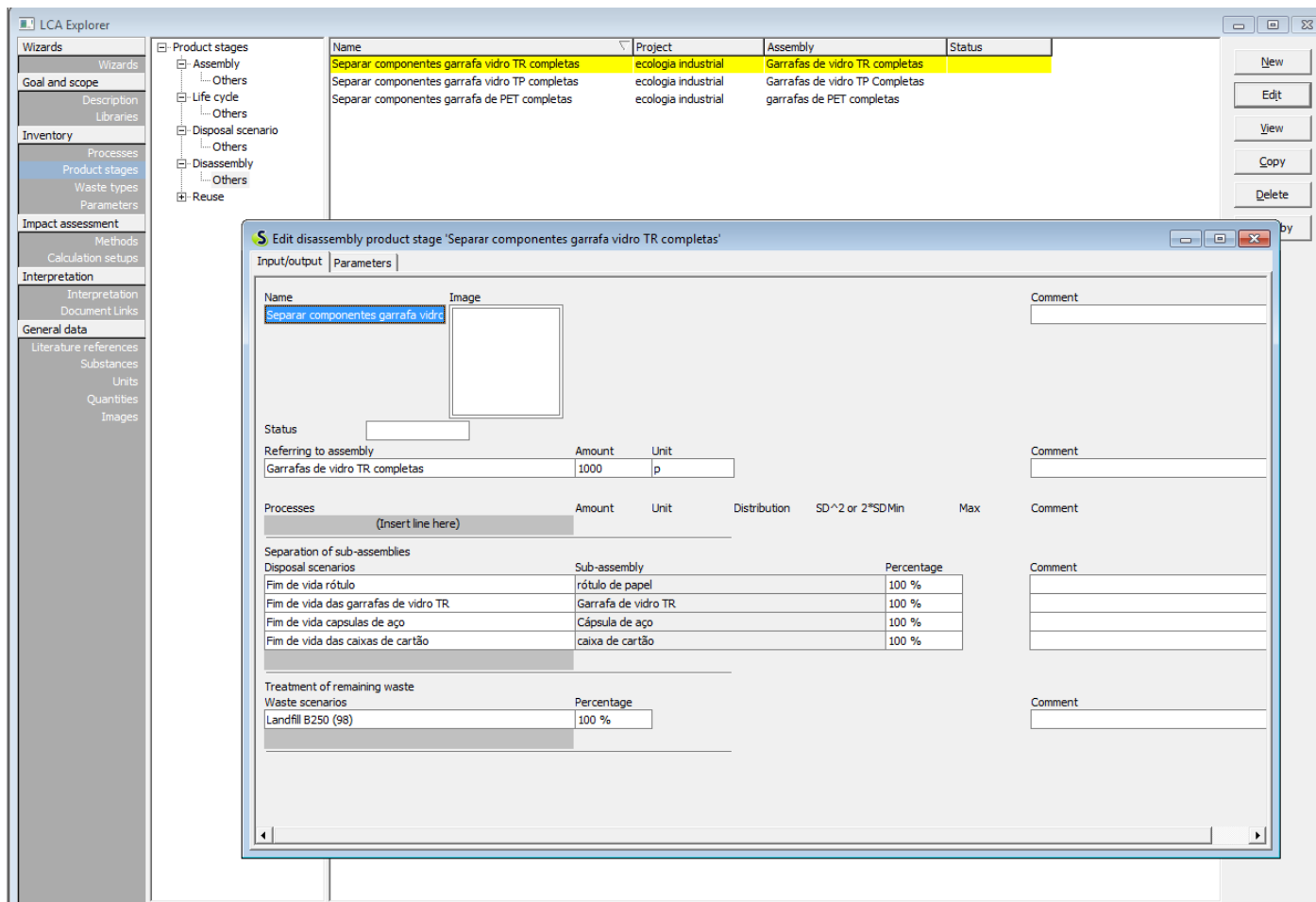
Name	Amount	Unit	Quantity	Allocation %	Waste type	Category
Packaging glass, white, at plant/DE U	1	kg	Mass	100 %	Glass	Glass/Packaging

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
Water, unspecified natural origin/m3	in water	0.000212	m3	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Chemicals inorganic, at plant/GLO U		0.000583	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Graphite, at plant/RER U		1.25E-6	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Soda, powder, at plant/RER U		0.0761	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Lubricating oil, at plant/RER U		2.38E-5	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Limestone, milled, loose, at plant/CH U		0.0471	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Silica sand, at plant/DE U		0.251	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)
Dolomite, at plant/RER U		0.0435	kg	Lognormal	1.08		(1,2,2,1,1,3 (UBA)

Translated name: Verpackungsglas, weiss, ab Werk  
 Included processes: This module includes the material and energy efforts for: preparation of the glass melt, melting furnace, feeder, container forming, cooling down, packaging. Transports for the input materials are included as well as direct emissions to air, waste water and waste.  
 Remark: A production site with a sorting capacity of 100 kt per year and a total life span of 50 a is assumed.; Geography: average German situation, based on an industry survey

In Disassembly:  
Create the component separation for each complete bottle



The screenshot shows the LCA Explorer interface. The main window displays a table of product stages. The selected stage is 'Separar componentes garrafa vidro TR completas'.

Name	Project	Assembly	Status
Separar componentes garrafa vidro TR completas	ecologia industrial	Garrafas de vidro TR completas	
Separar componentes garrafa vidro TP completas	ecologia industrial	Garrafas de vidro TP Completas	
Separar componentes garrafa de PET completas	ecologia industrial	garrafas de PET completas	

The 'Edit disassembly product stage' dialog box is open, showing the configuration for 'Separar componentes garrafa vidro TR completas'.

**Name:** Separar componentes garrafa vidro TR completas

**Status:** [Empty field]

**Referring to assembly:**

Referring to assembly	Amount	Unit	Comment
Garrafas de vidro TR completas	1000	p	

**Processes:**

Processes	Amount	Unit	Distribution	SD ^2 or 2*SDMin	Max	Comment
(Insert line here)						

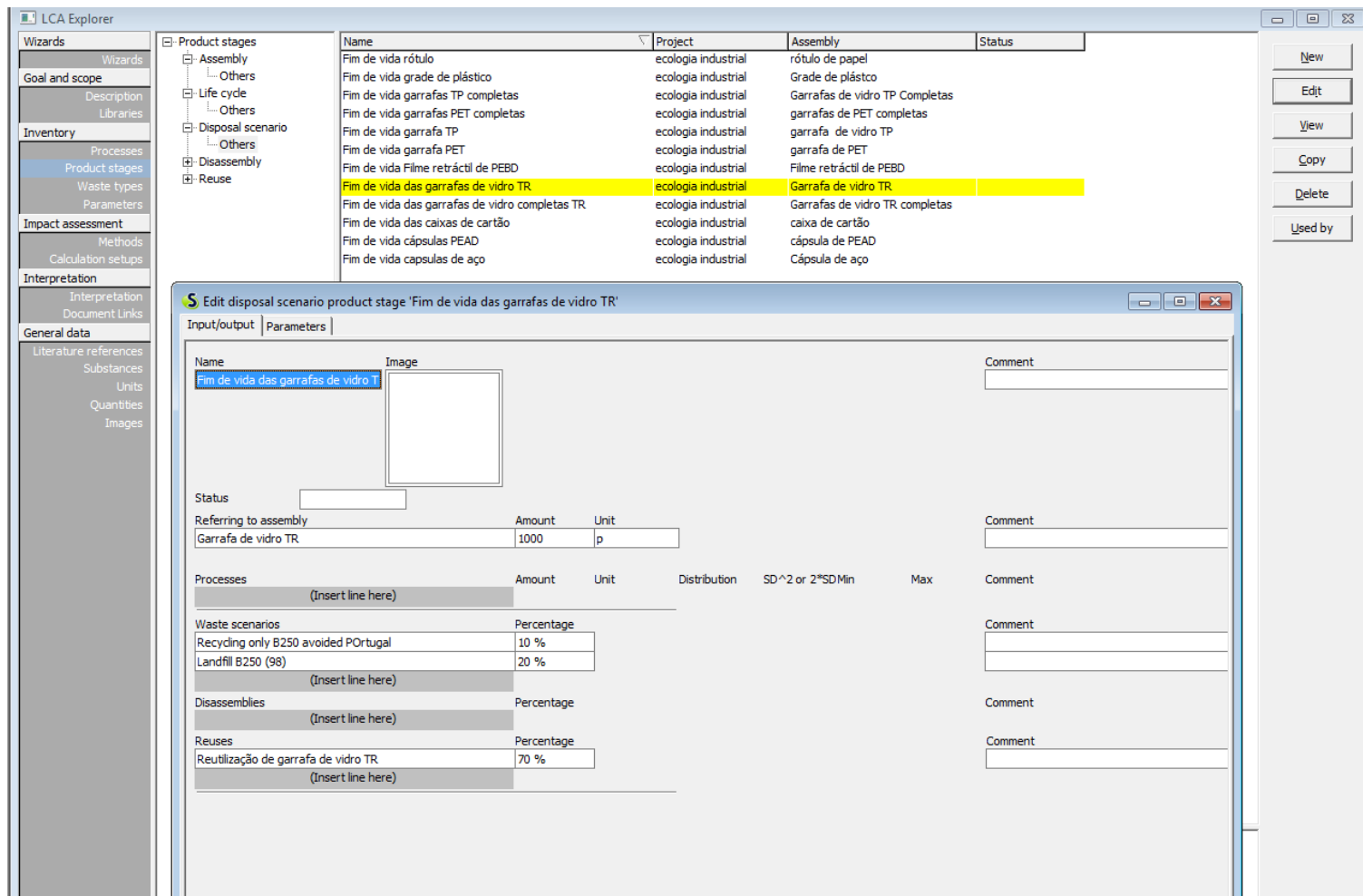
**Separation of sub-assemblies:**

Disposal scenarios	Sub-assembly	Percentage	Comment
Fim de vida rótulo	rótulo de papel	100 %	
Fim de vida das garrafas de vidro TR	Garrafa de vidro TR	100 %	
Fim de vida capsulas de aço	Cápsula de aço	100 %	
Fim de vida das caixas de cartão	caixa de cartão	100 %	

**Treatment of remaining waste:**

Waste scenarios	Percentage	Comment
Landfill B250 (98)	100 %	

In Disposal scenario:  
Create the end product life for each product created



The screenshot shows the LCA Explorer interface. On the left is a navigation pane with categories like Wizards, Goal and scope, Inventory, Impact assessment, and Interpretation. The main area displays a tree view of 'Product stages' under 'Disposal scenario', with 'Fim de vida das garrafas de vidro TR' selected. A table below lists various product stages with columns for Name, Project, Assembly, and Status. The selected row is highlighted in yellow.

Name	Project	Assembly	Status
Fim de vida rótulo	ecologia industrial	rótulo de papel	
Fim de vida grade de plástico	ecologia industrial	Grade de plástico	
Fim de vida garrafas TP completas	ecologia industrial	Garrafas de vidro TP Completas	
Fim de vida garrafas PET completas	ecologia industrial	garrafas de PET completas	
Fim de vida garrafa TP	ecologia industrial	garrafa de vidro TP	
Fim de vida garrafa PET	ecologia industrial	garrafa de PET	
Fim de vida Filme retráctil de PEBD	ecologia industrial	Filme retráctil de PEBD	
<b>Fim de vida das garrafas de vidro TR</b>	<b>ecologia industrial</b>	<b>Garrafa de vidro TR</b>	
Fim de vida das garrafas de vidro completas TR	ecologia industrial	Garrafas de vidro TR completas	
Fim de vida das caixas de cartão	ecologia industrial	caixa de cartão	
Fim de vida cápsulas PEAD	ecologia industrial	cápsula de PEAD	
Fim de vida capsulas de aço	ecologia industrial	Cápsula de aço	

An 'Edit disposal scenario product stage' dialog box is open, showing details for 'Fim de vida das garrafas de vidro TR'. It includes fields for Name, Image, Status, and a table for 'Referring to assembly'.

Referring to assembly	Amount	Unit	Comment
Garrafa de vidro TR	1000	p	

Below this are sections for 'Processes', 'Waste scenarios', 'Disassemblies', and 'Reuses', each with a table for configuration.

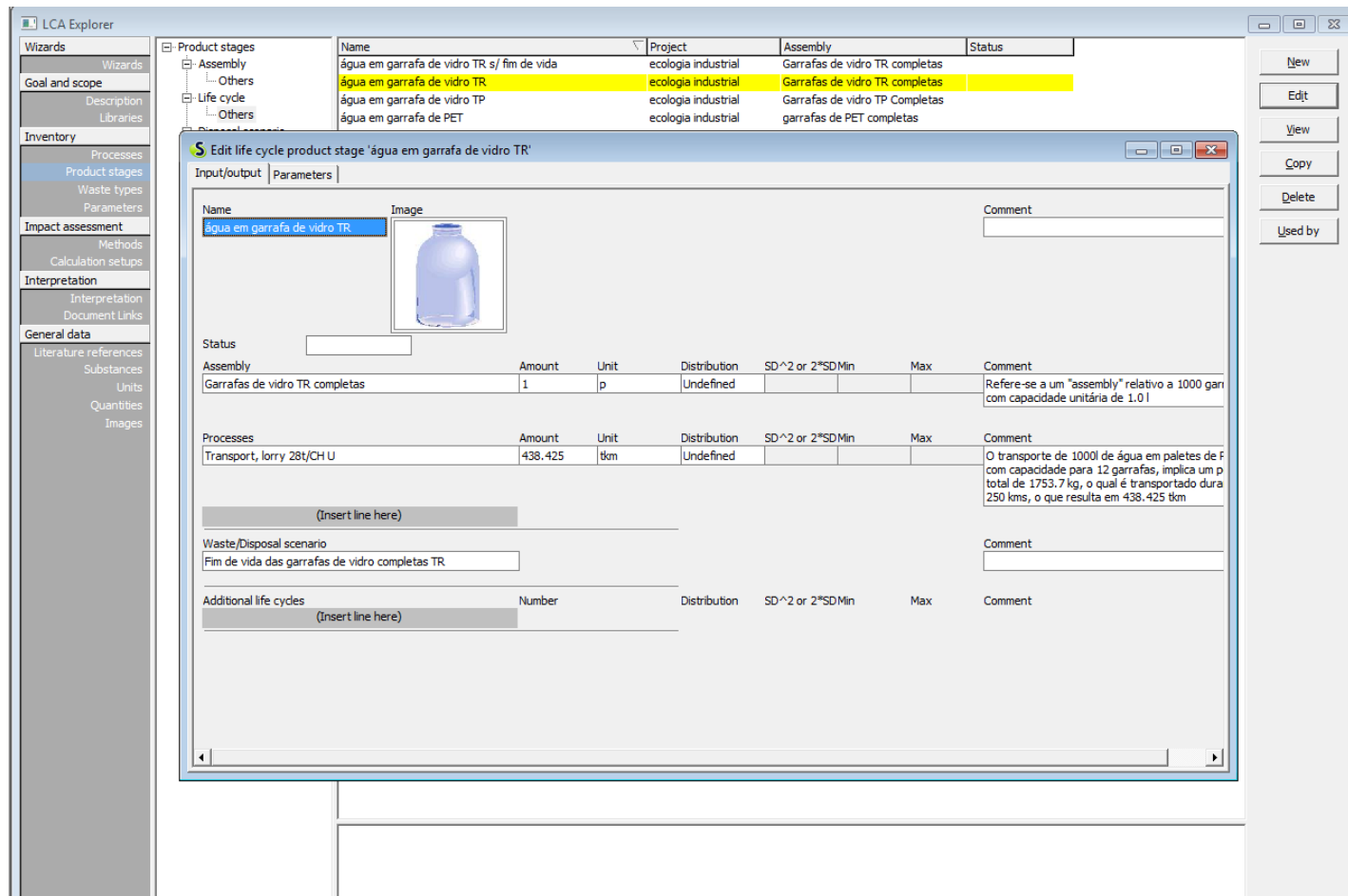
Waste scenarios	Percentage	Comment
Recycling only B250 avoided POrtugal	10 %	
Landfill B250 (98)	20 %	

Reuses	Percentage	Comment
Reutilização de garrafa de vidro TR	70 %	



Finally create a life cycle considering:

- Complete Glass bottle TR or PT or complete PET bottle;
- Transport;
- End of life of Complete Glass bottle TR or TP or complete PET bottle



The screenshot shows the LCA Explorer interface. The main window displays the 'Edit life cycle product stage' for 'água em garrafa de vidro TR'. The interface includes a sidebar with navigation options like 'Wizards', 'Goal and scope', 'Inventory', 'Processes', 'Waste types', 'Impact assessment', 'Methods', 'Interpretation', 'General data', 'Literature references', 'Substances', 'Units', 'Quantities', and 'Images'. The main area shows a table of data for the selected product stage.

Name	Project	Assembly	Status
água em garrafa de vidro TR s/ fim de vida	ecologia industrial	Garrafas de vidro TR completas	
água em garrafa de vidro TR	ecologia industrial	Garrafas de vidro TR completas	
água em garrafa de vidro TP	ecologia industrial	Garrafas de vidro TP Completas	
água em garrafa de PET	ecologia industrial	garrafas de PET completas	

Assembly	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
Garrafas de vidro TR completas	1	p	Undefined			Refere-se a um "assembly" relativo a 1000 gar com capacidade unitária de 1.0l

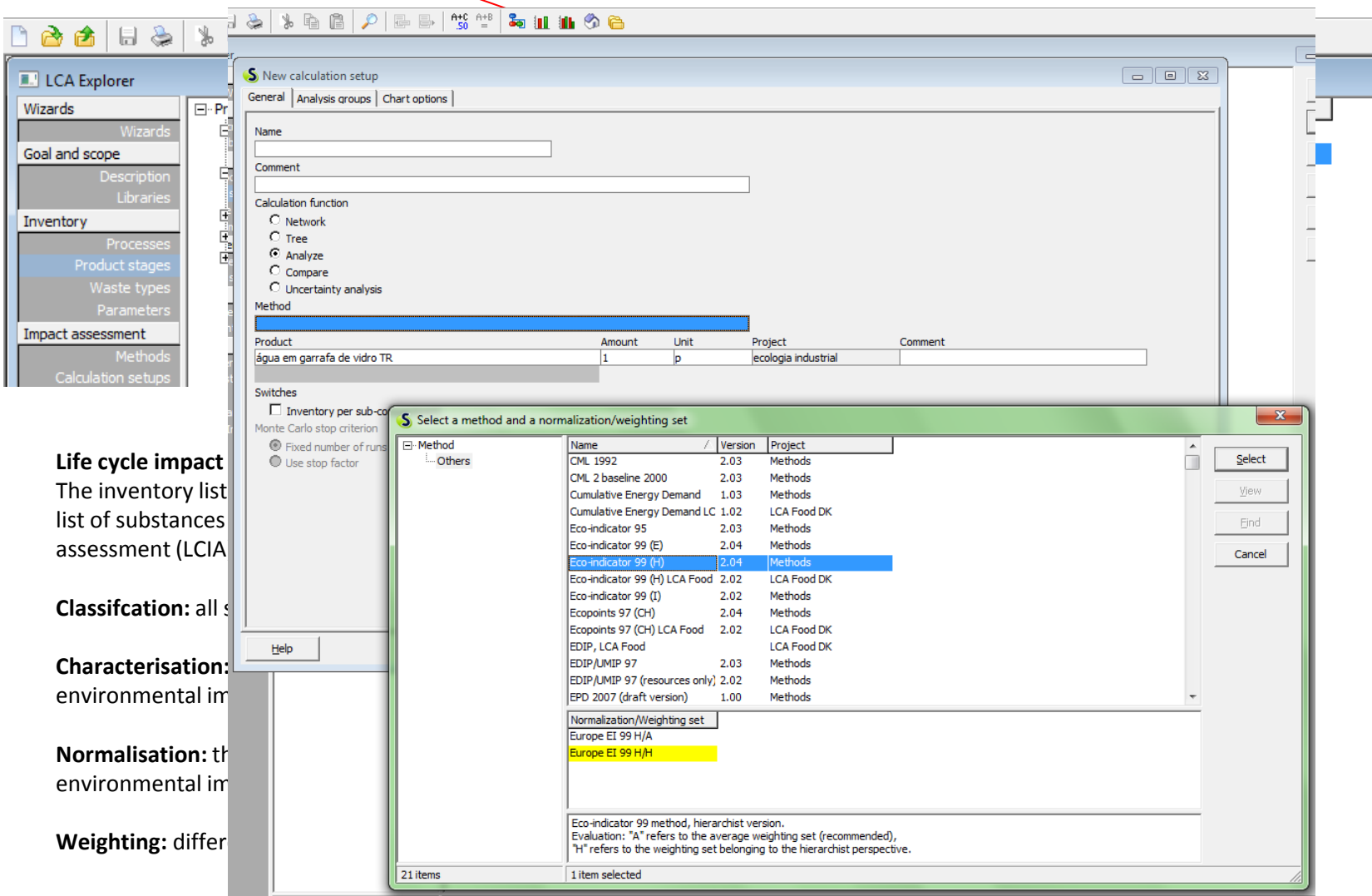
Processes	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
Transport, lorry 28t/CH U	438.425	tkm	Undefined			O transporte de 1000l de água em paletes de F com capacidade para 12 garrafas, implica um p total de 1753.7 kg, o qual é transportado dura 250 kms, o que resulta em 438.425 tkm

Waste/Disposal scenario: Fim de vida das garrafas de vidro completas TR.

Additional life cycles: (Insert line here)

Analyze

Choose appropriate method



The screenshot shows the LCA Explorer software interface. The main window is titled 'New calculation setup' and has tabs for 'General', 'Analysis groups', and 'Chart options'. The 'General' tab is active, showing fields for 'Name', 'Comment', and 'Calculation function'. The 'Calculation function' is set to 'Analyze'. Below this is a table for 'Method' with columns for 'Product', 'Amount', 'Unit', 'Project', and 'Comment'. The first row shows 'água em garrafa de vidro TR' with an amount of 1 and unit 'p', under the project 'ecologia industrial'. There are also 'Switches' and 'Monte Carlo stop criterion' options.

A sub-dialog box titled 'Select a method and a normalization/weighting set' is open, showing a list of methods. The 'Eco-indicator 99 (H)' method is selected. Below the list, the 'Normalization/Weighting set' is set to 'Europe EI 99 H/H'. A note at the bottom explains the evaluation: 'Eco-indicator 99 method, hierarchist version. Evaluation: "A" refers to the average weighting set (recommended), "H" refers to the weighting set belonging to the hierarchist perspective.'

**Life cycle impact**  
 The inventory list  
 list of substances  
 assessment (LCIA)

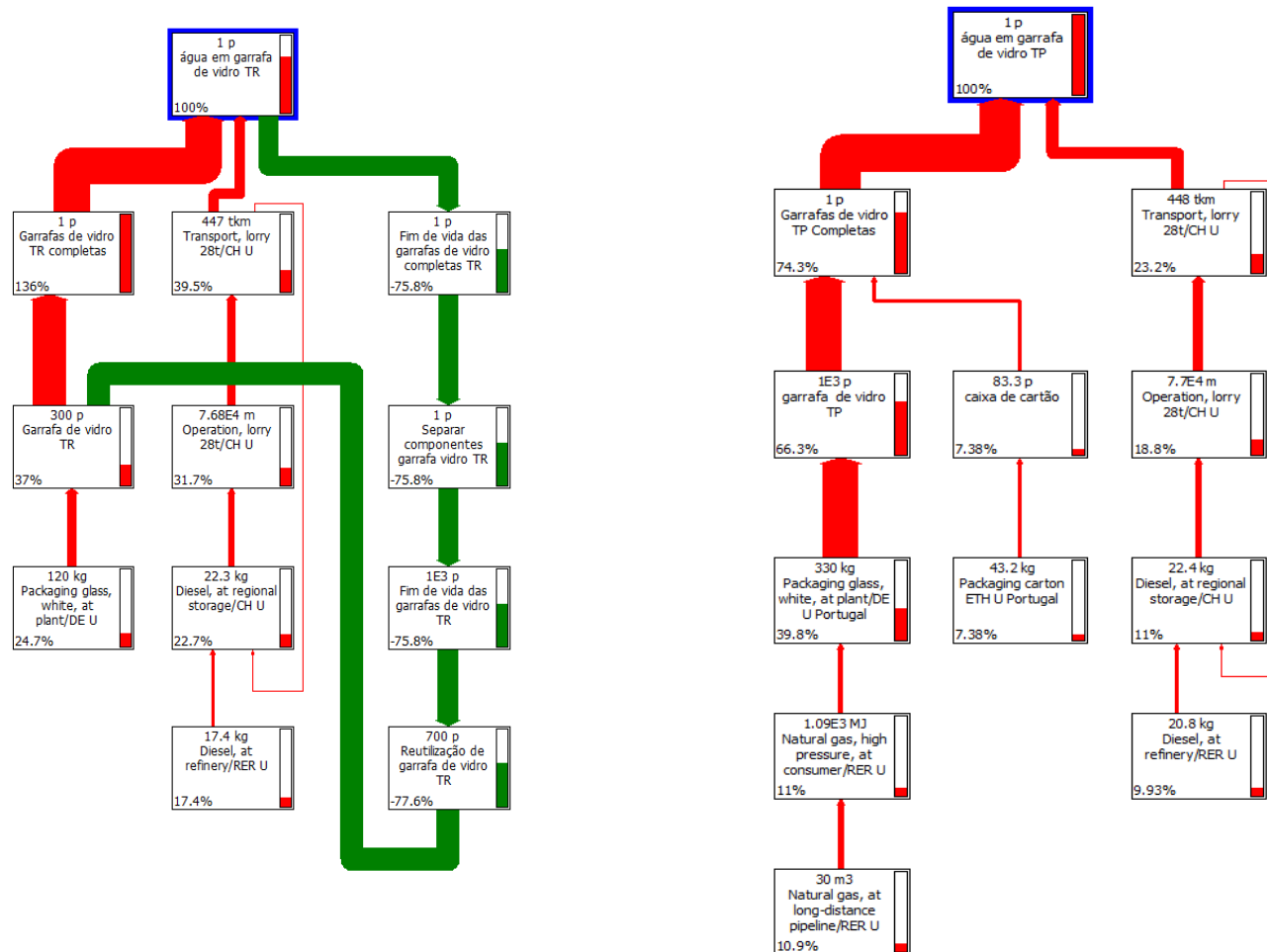
**Classification:** all s

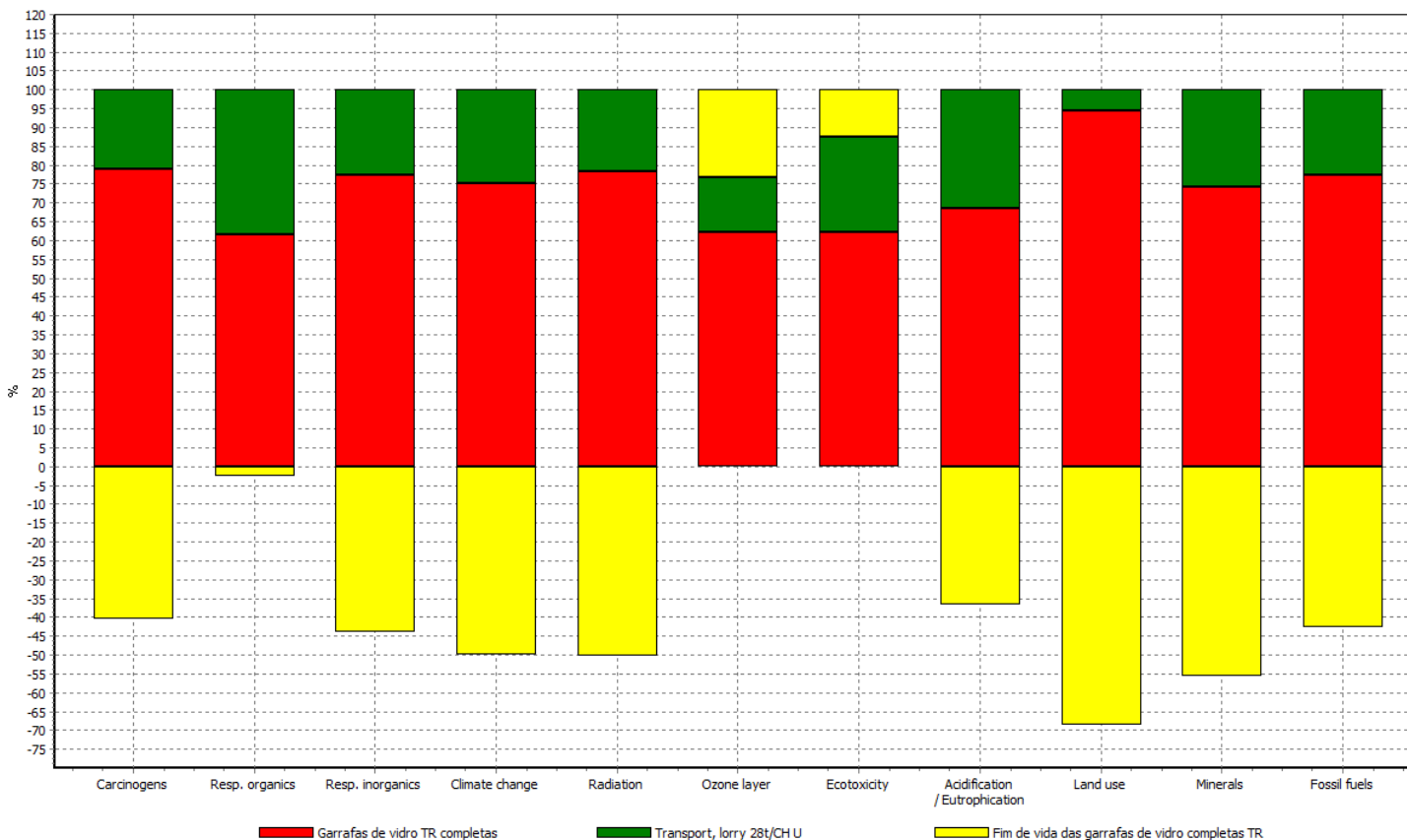
**Characterisation:**  
 environmental im

**Normalisation:** th  
 environmental im

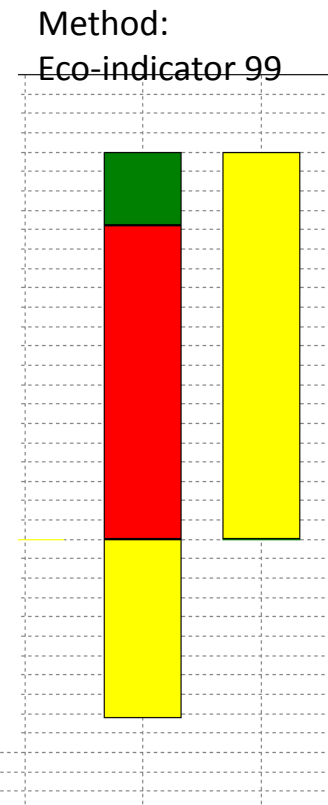
**Weighting:** differ

## Network: Scheme of life cycle

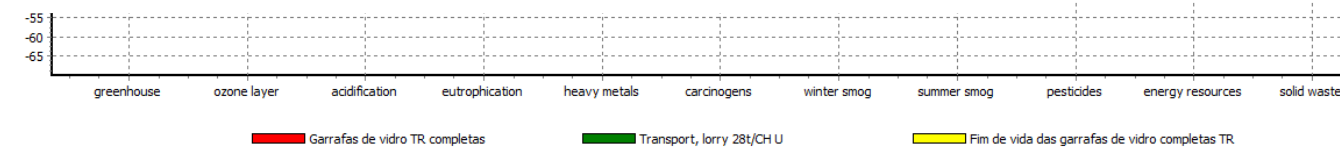




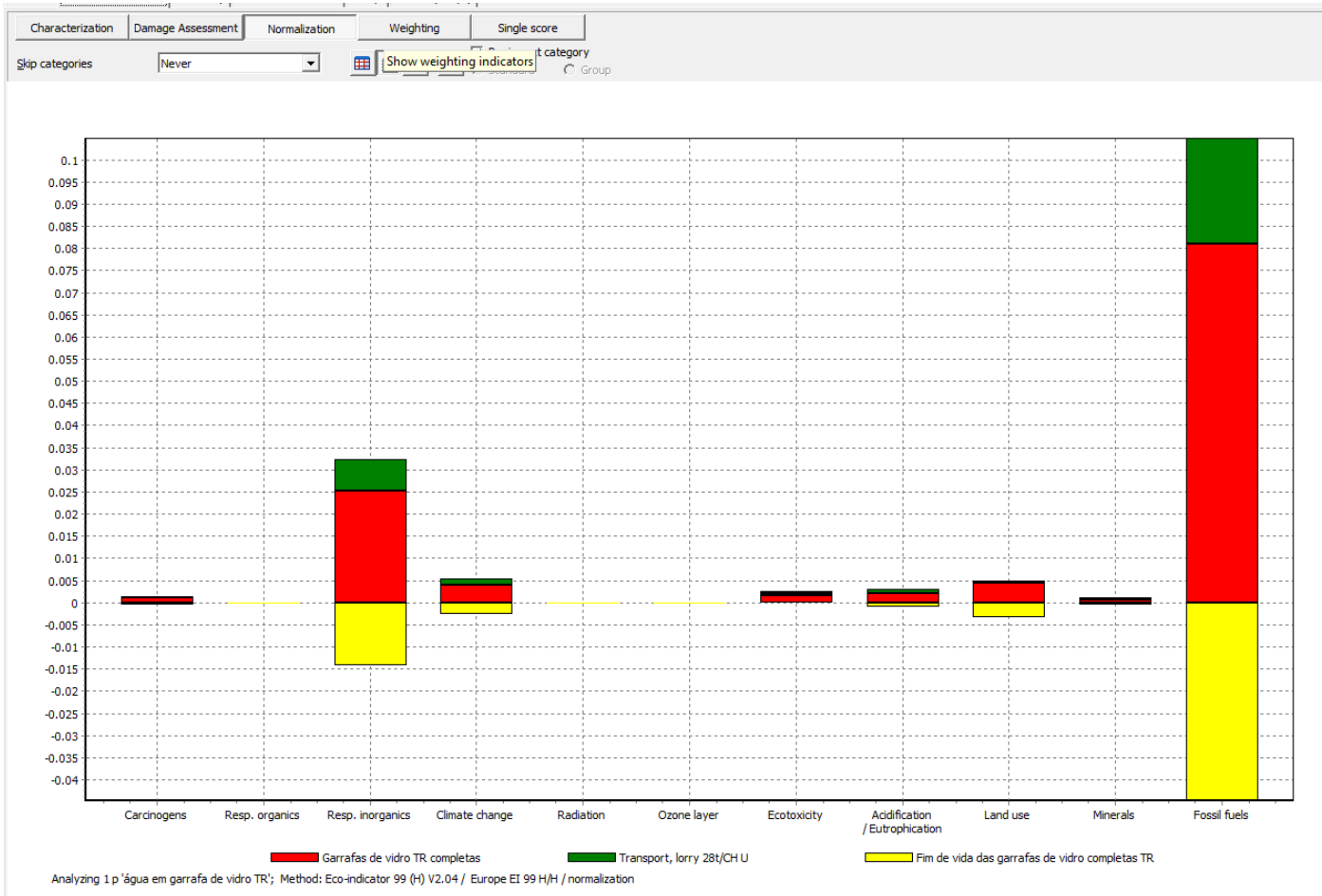
Analyzing 1 p 'água em garrafa de vidro TR'; Method: Eco-indicator 99 (H) V2.04 / Europe EI 99 H/H / characterization

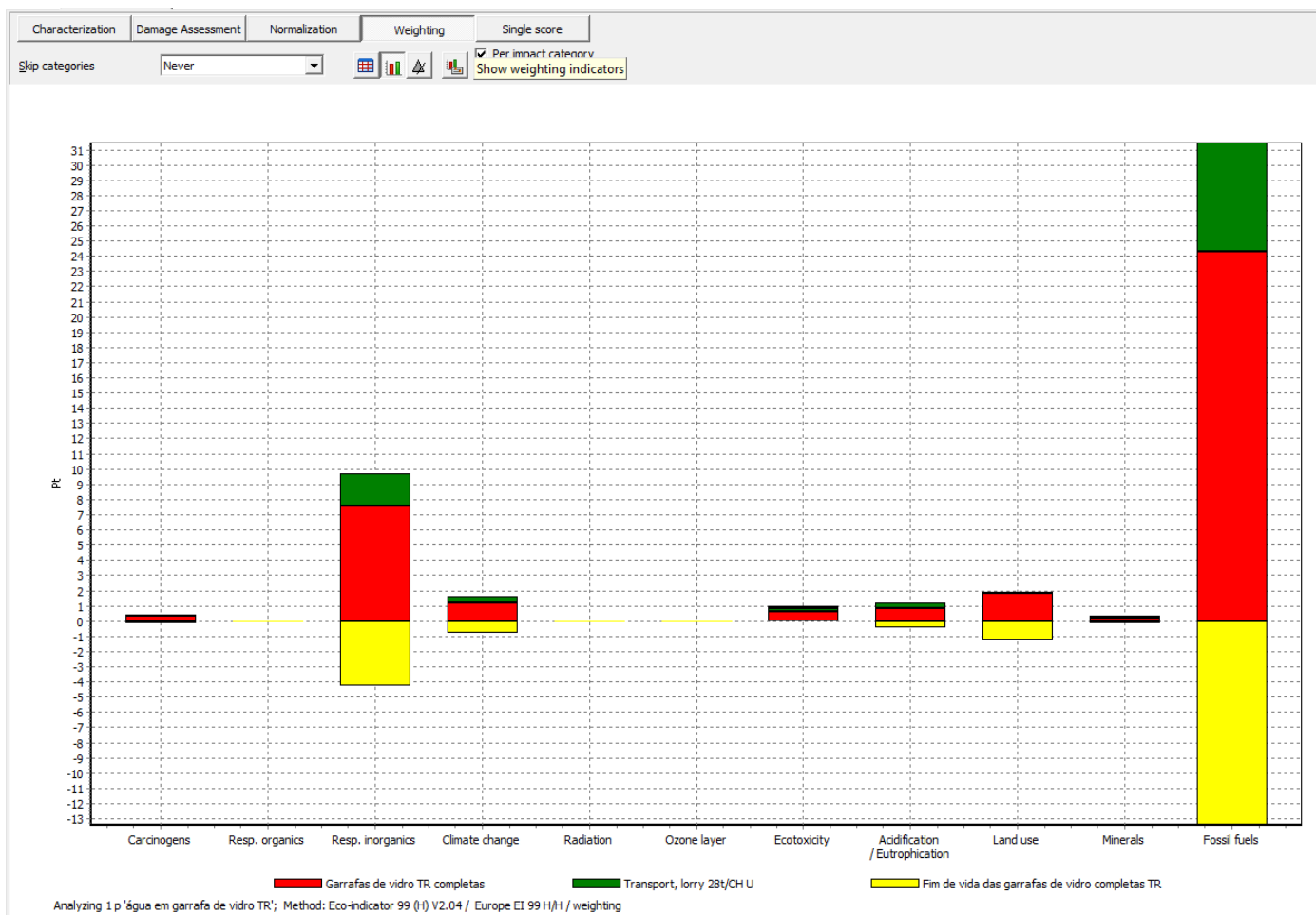


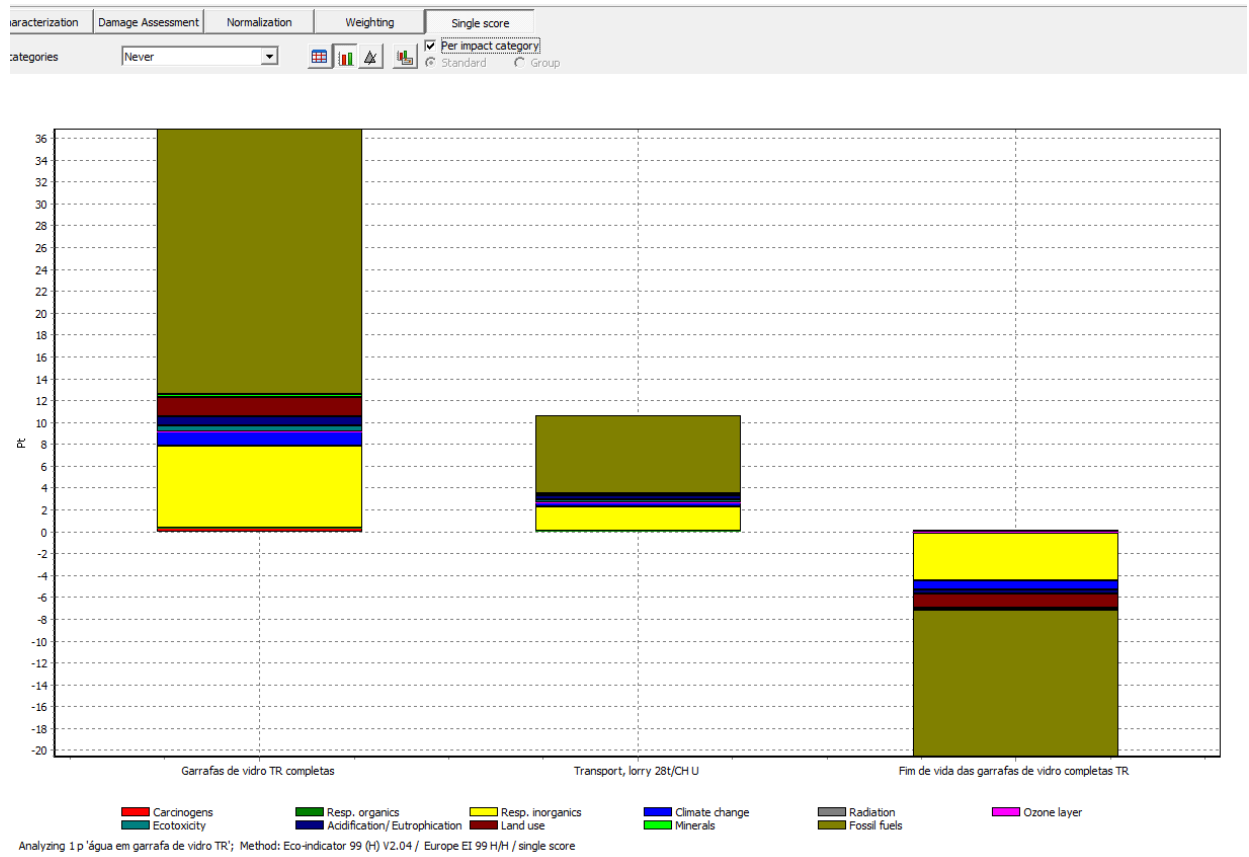
Method:  
Eco-indicator 95

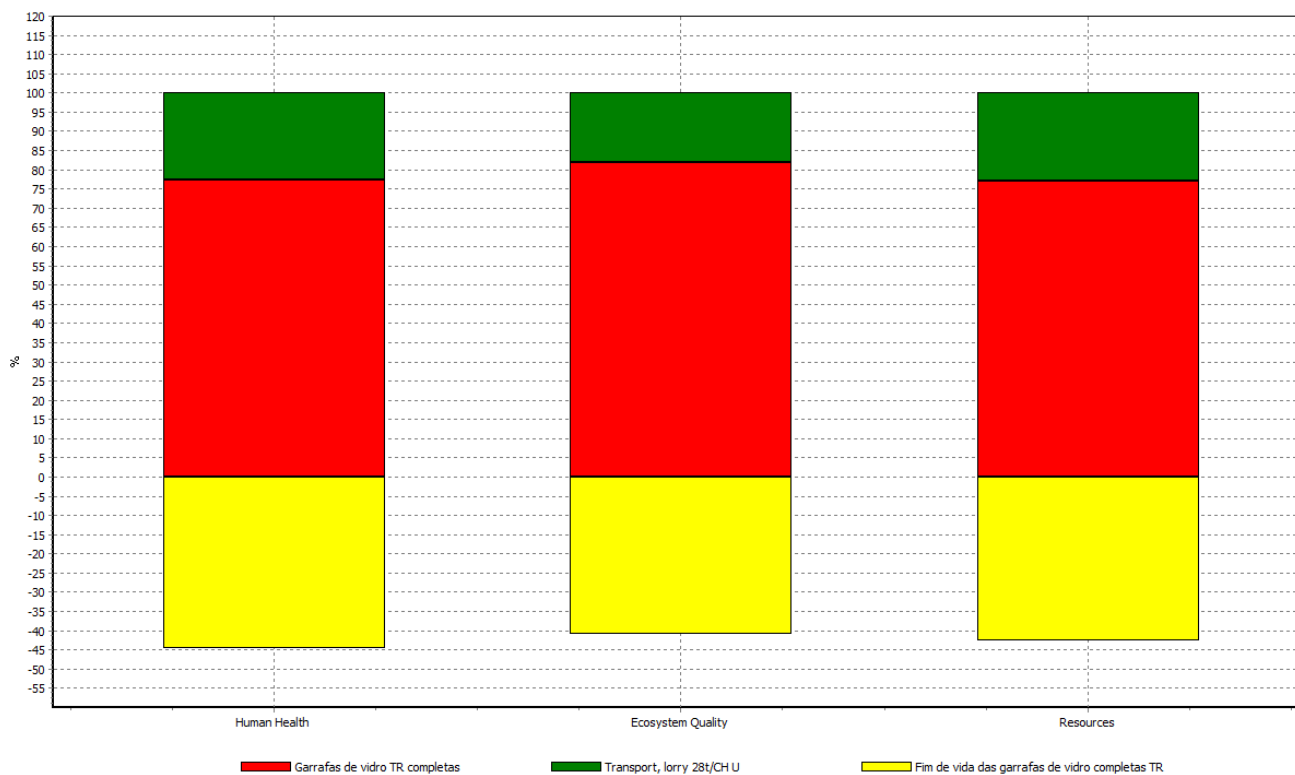
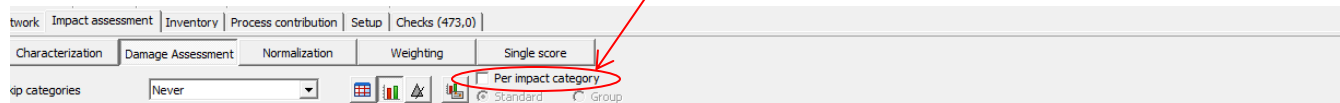


Analyzing 1 p 'água em garrafa de vidro TR'; Method: Eco-indicator 95 V2.03 / Europe g / characterization





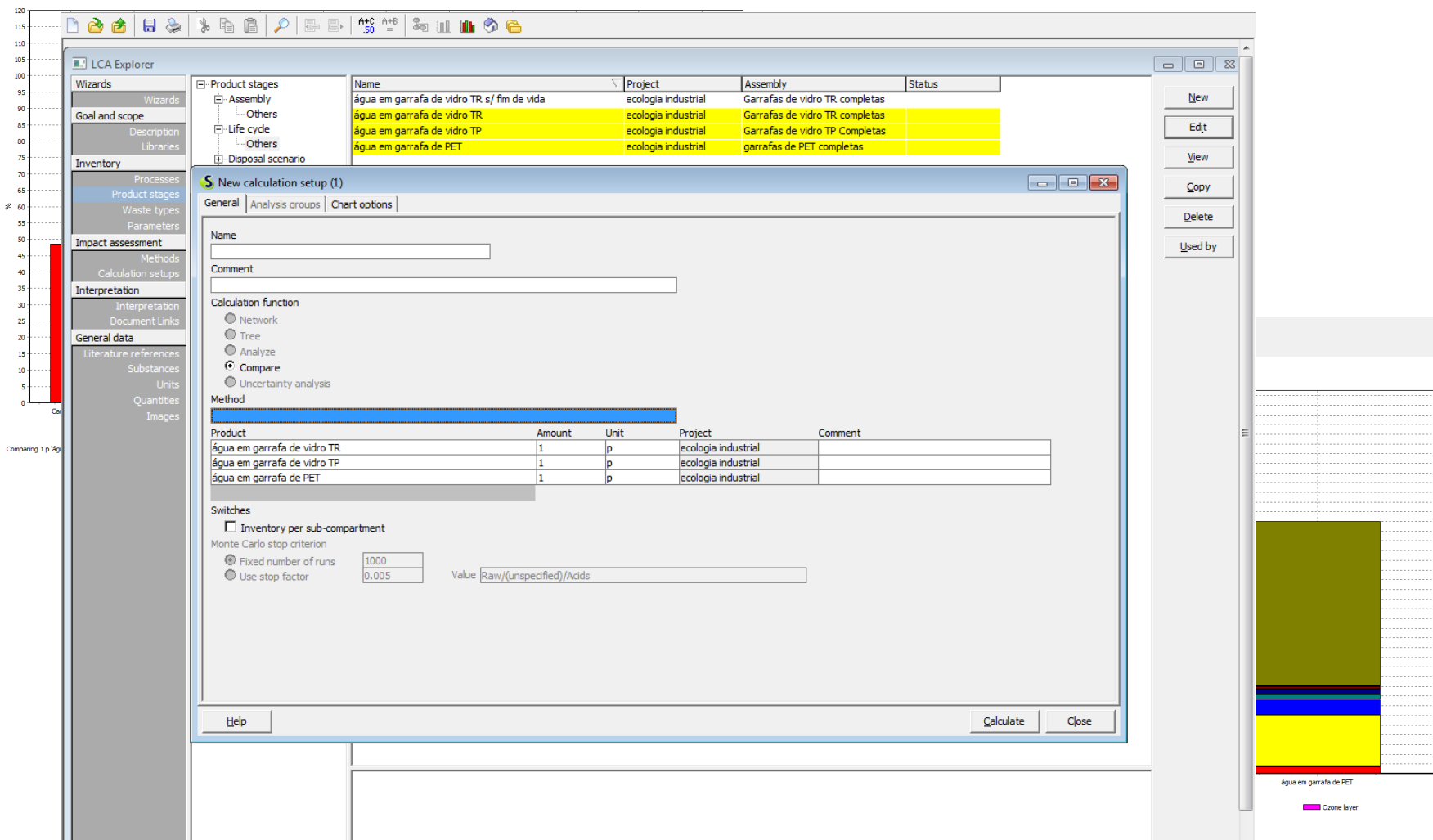




Analyzing 1 p água em garrafa de vidro TR; Method: Eco-indicator 99 (H) V2.04 / Europe EI 99 H/H / damage assessment



## Comparative analysis



The screenshot shows the LCA Explorer software interface. A table lists product stages for a comparative analysis:

Name	Project	Assembly	Status
água em garrafa de vidro TR s/ fim de vida	ecologia industrial	Garrafas de vidro TR completas	
água em garrafa de vidro TR	ecologia industrial	Garrafas de vidro TR completas	
água em garrafa de vidro TP	ecologia industrial	Garrafas de vidro TP Completas	
água em garrafa de PET	ecologia industrial	garrafas de PET completas	

A "New calculation setup (1)" dialog box is open, showing the following configuration:

- General** tab selected.
- Calculation function:** Compare (selected).
- Method:** Network.
- Product table:**

Product	Amount	Unit	Project	Comment
água em garrafa de vidro TR	1	p	ecologia industrial	
água em garrafa de vidro TP	1	p	ecologia industrial	
água em garrafa de PET	1	p	ecologia industrial	
- Switches:**
  - Inventory per sub-compartment
  - Monte Carlo stop criterion:
    - Fixed number of runs: 1000
    - Use stop factor: 0.005
  - Value: Raw/(unspecified)/Acids

On the right side, a partial bar chart is visible, showing a large green bar for "água em garrafa de PET" and a small pink bar for "Ozone layer".

## Life Cycle based studies

Bottle	{	• Exercice Simapro
Biofuel	{	• LCI Energy & CO <sub>2</sub> / WTW
Aluminum packadge	{	• LCA midle point

Biofuel

- LCI Energy & CO<sub>2</sub>/ WTW

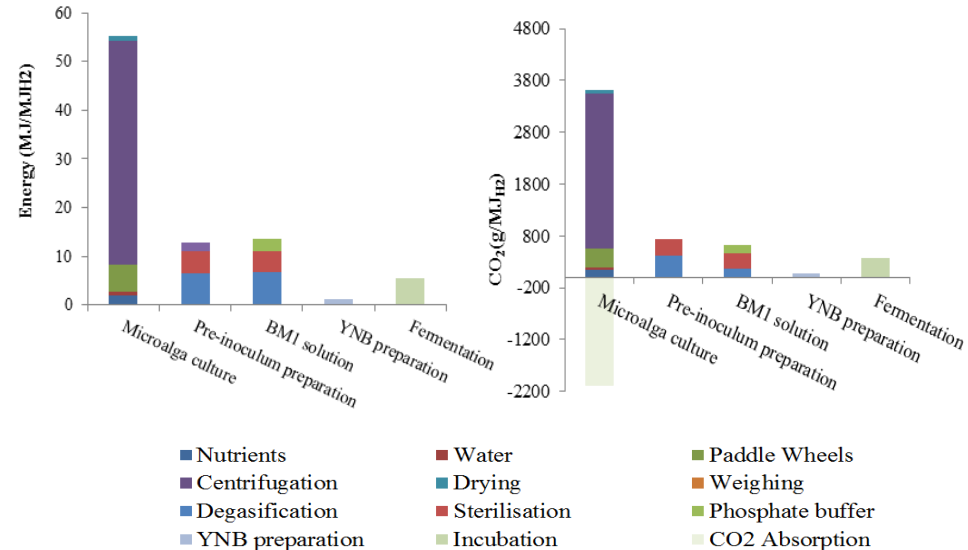
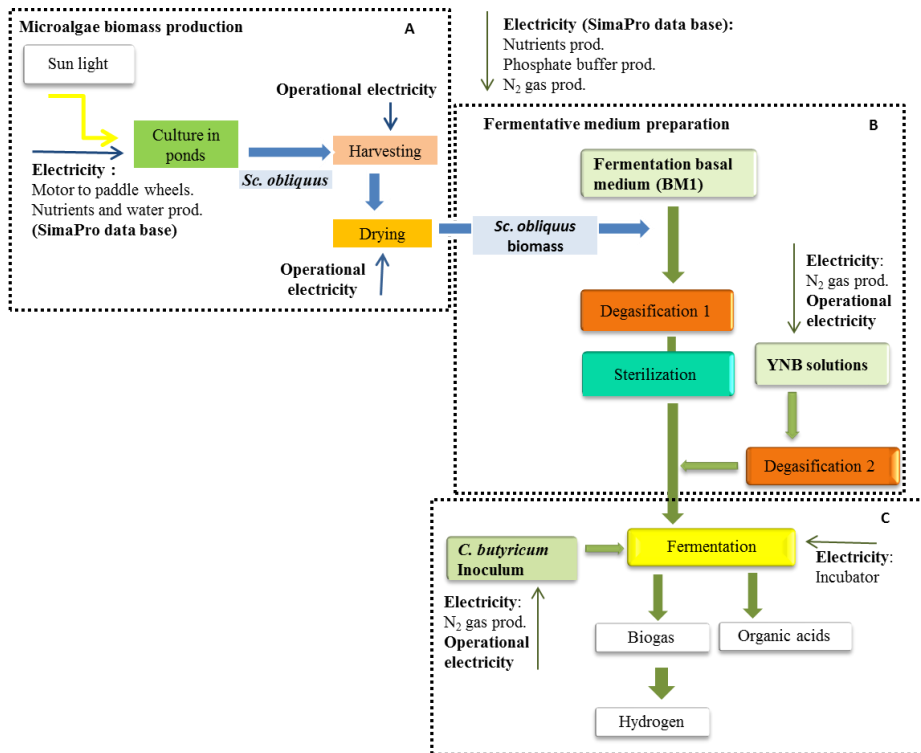
algal/H<sub>2</sub> production



Fuel cell road vehicles



## *Scenedesmus obliquus* microalgae

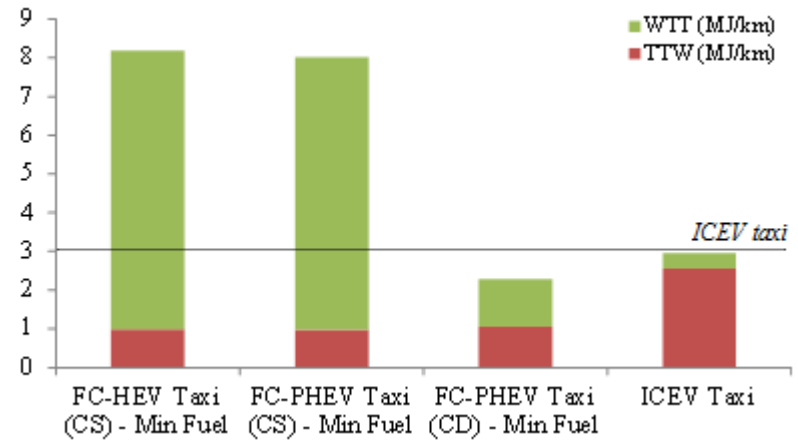
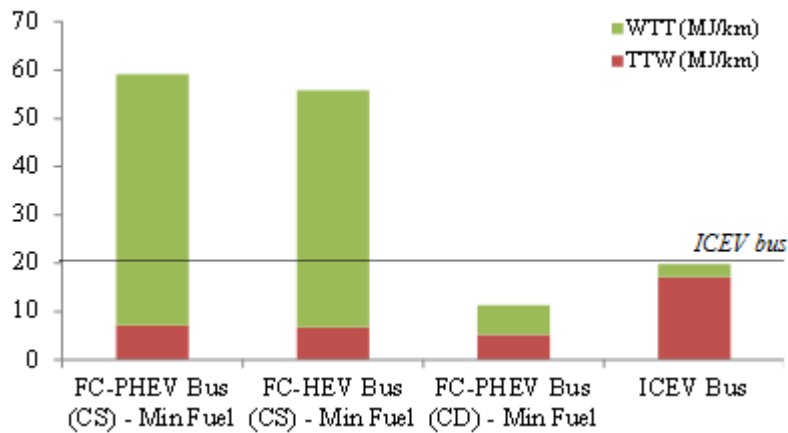


- BioH<sub>2</sub> production yield: 7.3 g<sub>H<sub>2</sub></sub>/kg<sub>biomass</sub>
- The use of open raceway ponds show a reduction of 10 orders of magnitude than the ones of the works referred above.
- Microalga culture accounted only for 62% of the global energy consumption.
- Considering CO<sub>2</sub> absorption, values of CO<sub>2</sub> emissions decrease 36.1%

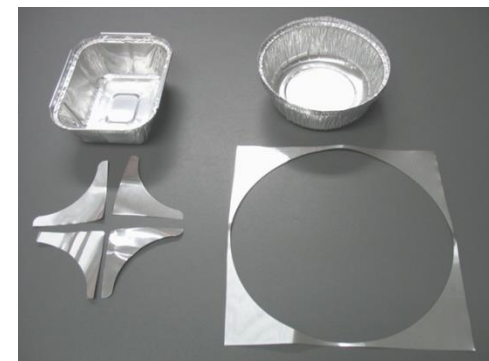
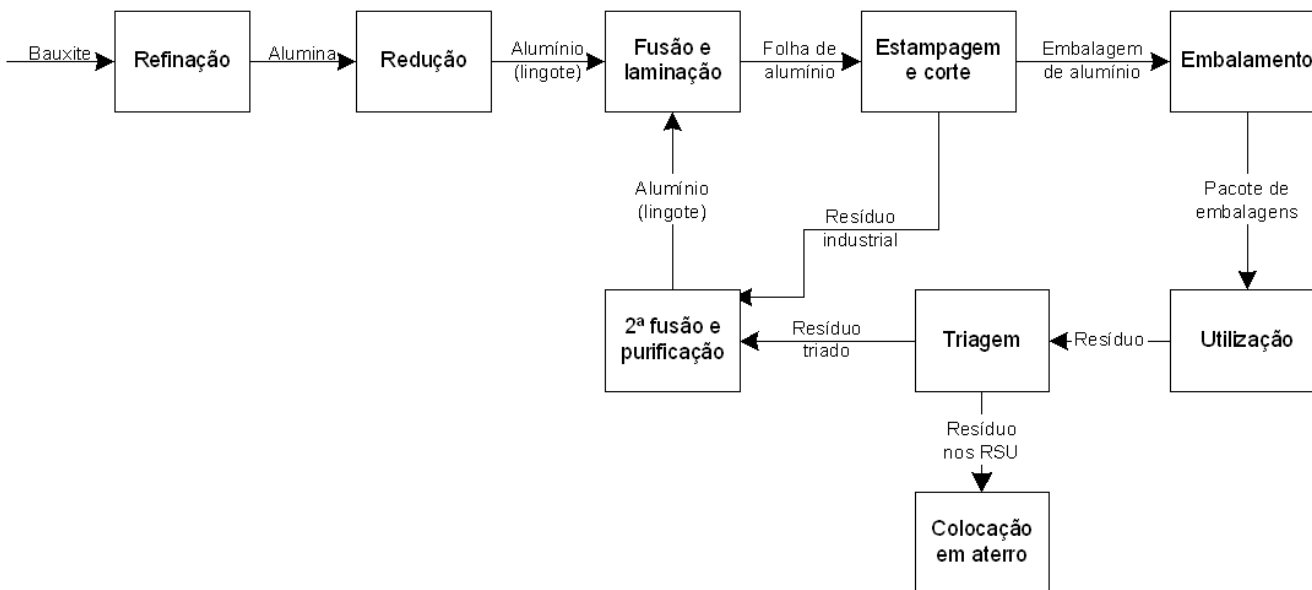
## H<sub>2</sub>

### Cradle-to-Gate results

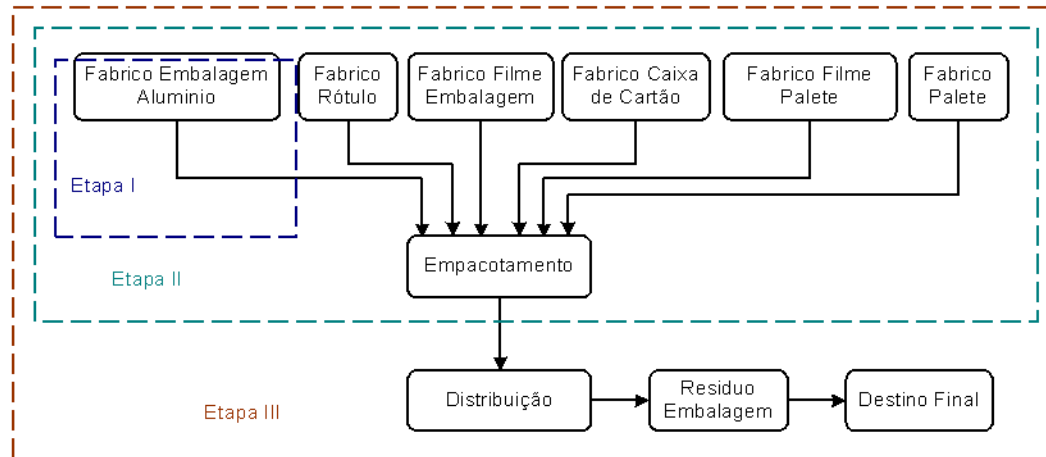
BioH <sub>2</sub> chain	Algae sugar content DW	Energy (MJ/MJ <sub>H<sub>2</sub></sub> )	Min	Max	CO <sub>2</sub> (g/MJ <sub>H<sub>2</sub></sub> )	Min	Max
<b>BioH<sub>2</sub> from dried <i>Sc. obliquus</i> - best scenario</b>	30 %	7.20	5.72	8.23	-659	-716	-613
<b>BioH<sub>2</sub> from dried <i>Sc. obliquus</i> - optimized scenario</b>	30%	12.48	9.80	14.60	-311	-419	-209
<b>BioH<sub>2</sub> as by-product from dried <i>Sc. obliquus</i></b>		33.28	27.28	37.26	2172.0	1935.1	2331.6
<b>BioH<sub>2</sub> from dried <i>Sc. obliquus</i></b>	30%	88.00	70.31	99.49	5776.0	5118.4	6268.0
<b>BioH<sub>2</sub> as by-product from bioref 1 <i>Nannochloropsis</i> sp.</b>		147.00	119.00	164.00	9665.0	8645.0	10369.0
<b>BioH<sub>2</sub> as by-product from bioref 2 <i>Nannochloropsis</i> sp.</b>		168.00	136.00	187.00	11020.0	9858.0	11820.0
<b>BioH<sub>2</sub> as by-product from <i>Sc. Obliquus</i> hydrolyzate</b>		364.30	281.20	404.90	27198.0	24149.0	29218.0
<b>BioH<sub>2</sub> by <i>Anabaena</i> sp. (Photoautotrophic)</b>	25-30%	1538.00	1184.00	1715.00	114641.0	101476.0	123587.0
<b>BioH<sub>2</sub> by <i>Anabaena</i> sp. cyanobacteria (Photoauto.+Ferm.)</b>	25-30%	1723.00	1327.00	1919.00	128502.0	113825.0	266887.0
<b>BioH<sub>2</sub> from <i>Sc. obliquus</i> hydrolyzate</b>	10-17%	8884.14	7614.14	9866.14	758743.8	673892.4	813576.4
<b>BioH<sub>2</sub> from <i>Nannochloropsis</i> sp.</b>	17%	9058.00	7285.00	10123.00	591112.0	527022.0	634402.0



## Lusoforma vs ideal



Comparing: Real vs. Ideal with volume 1 litre and thickness 0.07mm  
 FU: 1000 packages 1 litre

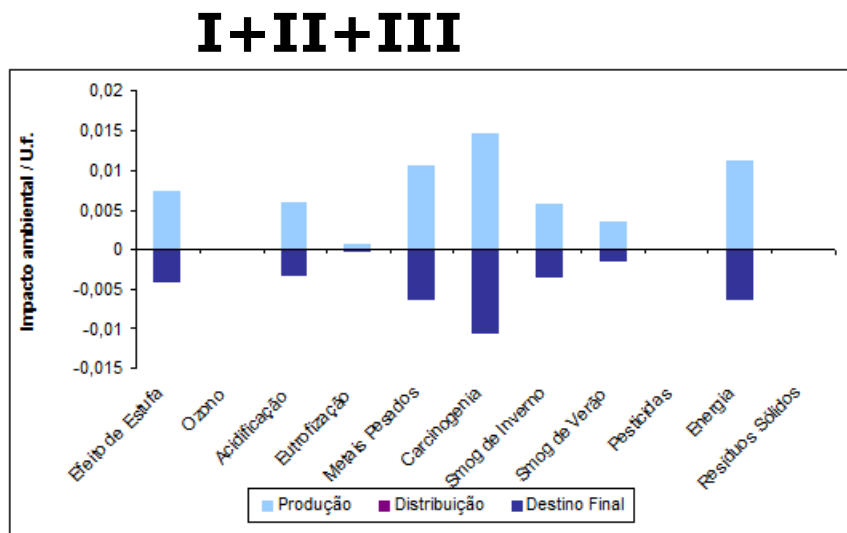
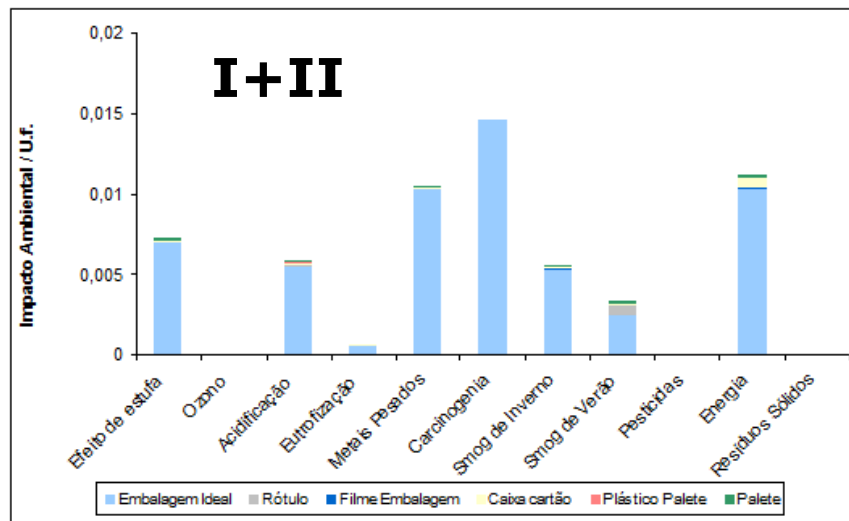
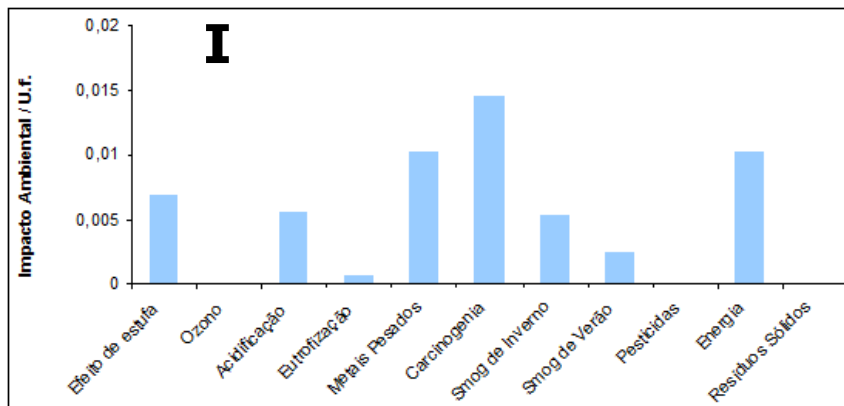


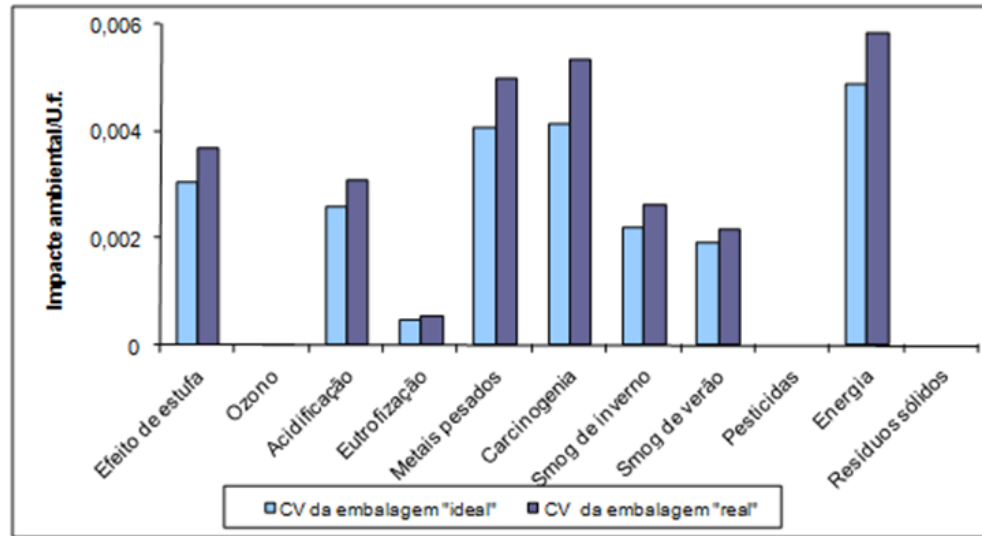
Etapa I - a produção da embalagem de alumínio (inclui os valores relativos às etapas de processamento da matéria-prima);

Etapa II - o produto embalado, considerando todos os materiais de empacotamento;

Etapa III - todo o ciclo de vida da embalagem, incluindo as fases de produção, distribuição e destino final.







## Exercises (Functional Unit)

Problem setting → System → Base for comparisons:

What is the function of the system?



Transport passengers valid FU p\*km



## Exercises (Functional Unit)

What is the function of the system?



Transport merchandise valid FU ton\*km



Provide water valid FU 1000 l water provided

## Exercises (Functional Unit)



Provide washes valid FU 50 showers or 100 g of soap used

**one-way or rechargeable batteries**



Provide energy to the remote control valid FU ?

## Exercises (Functional Unit)



Provide biodiesel valid FU?

***Online or conventional book***



Provide info valid FU?

## Exercises (allocation)



Production of a wooden shed.

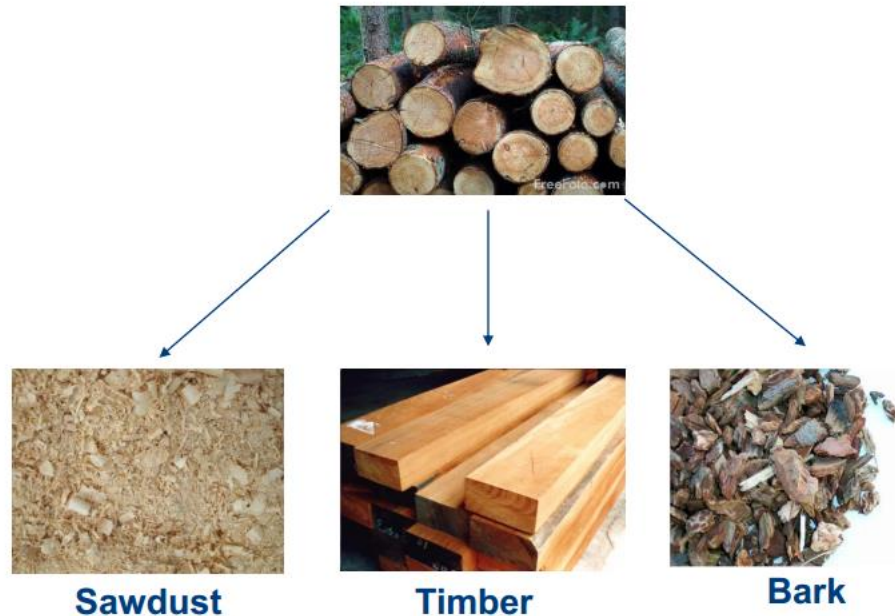


The shed is built from timber which is produced from logs.



## Exercises (allocation)

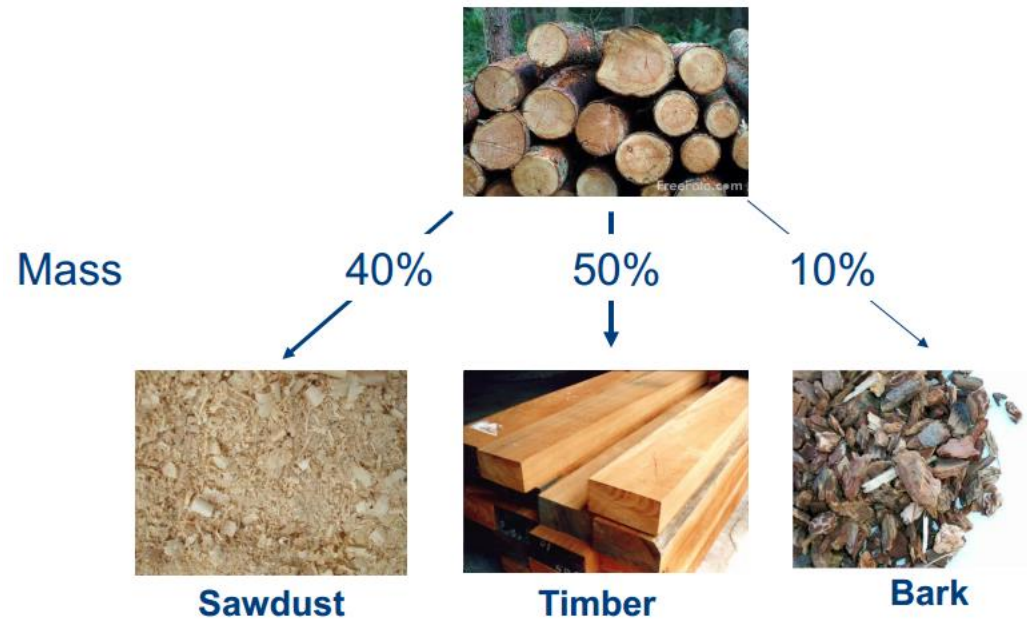
However, logs also produce a number of other co-products, so how much of the impact of logs do we allocate to the timber?





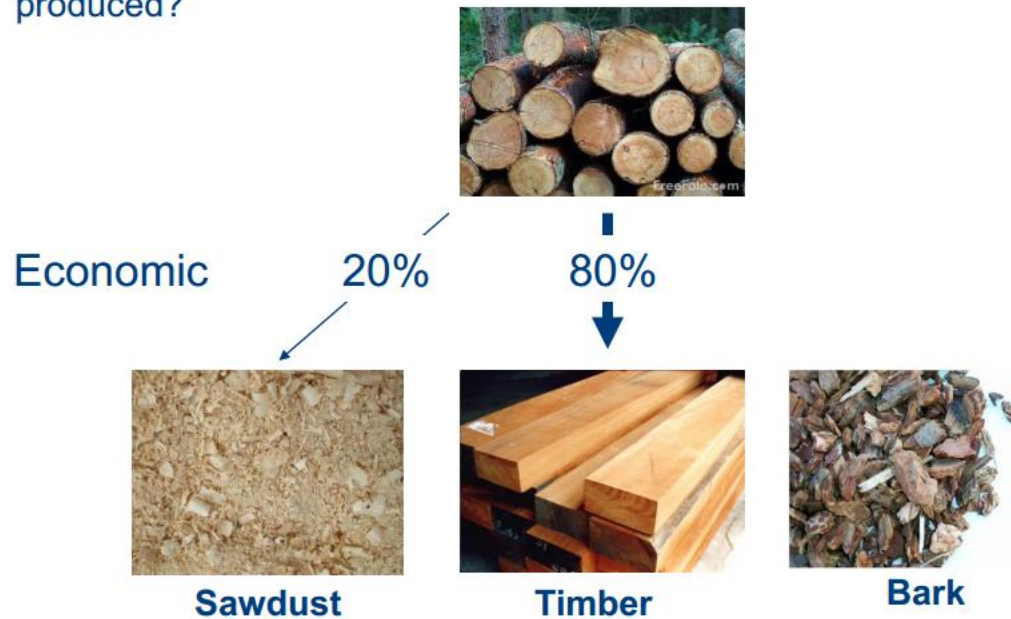
## Exercises (allocation)

We could allocate based on the mass of each product produced by the logs?



## Exercises (allocation)

However, the logs are produced for economic reasons. Therefore, is it fairer to allocate impact based on the value of the products produced?



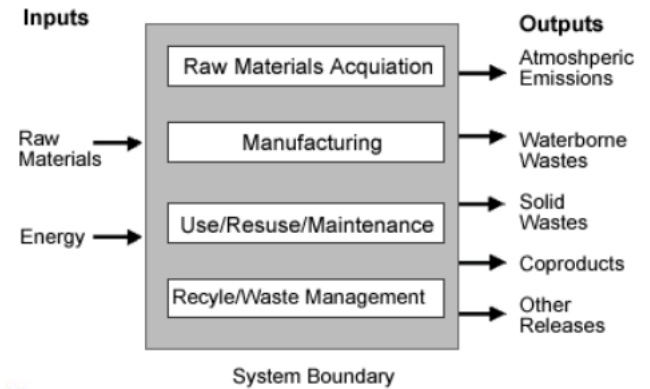
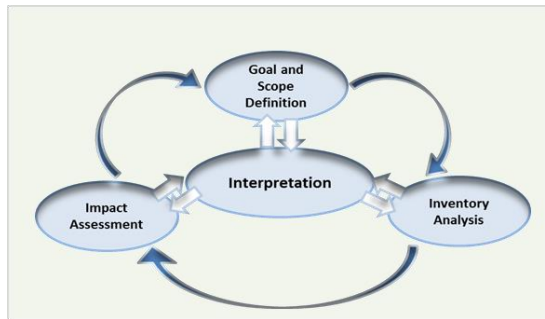
## Exercises (Impact assessment)



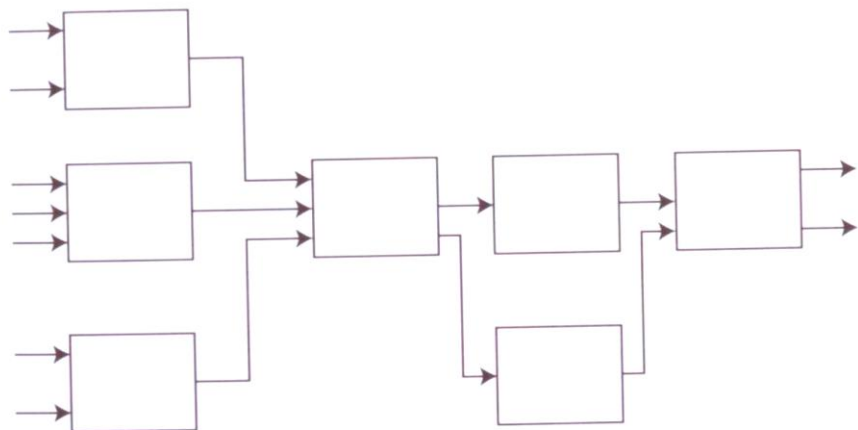
**Glass bottle**

FU 1000 l of provided water

Inventory table



## Exercises (Impact assessment)



Inventory Table	per FU
CO2	915 g
CH4	1.08 g
N2O	6.37 mg
Halon-1301	53.93 microg
CO	1.74 g
NO2	4.95 g
SO2	2.86 g
NO	3.23 mg
Hydrochloric acid (HCL)	64.63 mg
HF	14.66 mg
Amonia (NH3)	34.86 mg
Ni	808.34 mg
Benzene (C6H6)	7.43 mg
Chromium (Cr)	1.8 microg
PAH	5.95 microg
Cd	12.37 microg
Pb	40.57 mg
Mn	29.62 microg
Hg	2.7 microg
Aldehydes	273.46 microg
NMVOC	2.58 g
dust	1.28 g
Cu	3.72 microg
Zn	615.49 microg
Cr	1.8 microg

## Exercises (Impact assessment)

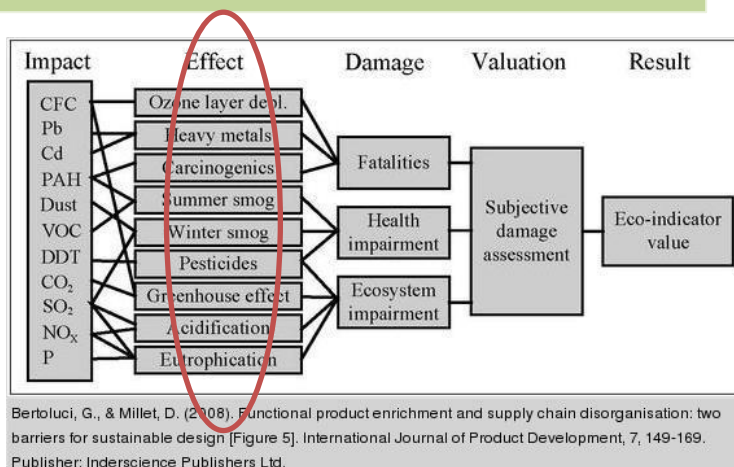
### Calculate impact category, per FU:

- Global warming gCO<sub>2</sub> eq;
- Ozone depletion gCFC11 eq;
- Acidification gSO<sub>2</sub> eq;
- Carcinogenic gPAH eq;
- Eutrophication gPO<sub>4</sub> eq;
- Heavy metal g Pbeq;
- Summer smog gC<sub>2</sub>H<sub>4</sub> eq;
- Winter smog g dust eq;
- Human toxicity g.

## Exercises (Impact assessment)

### Mid point assessment table

Global Warming	943.89826 g CO2 eq
Ozone depletion	0.00064716 g CFC11 eq
Acidification	6.4787823 g SO2 eq
Carcinogenic	0.000362493 g PAH eq
Eutrophication	0.6554237 g PO4 eq
Heavy metal	0.041195347 g Pb eq
Summer smog	5.5089685 g C2H4 eq
Winter smog	4.14 g dust eq
Human toxicity	14.30546657 g



End point Damage,  
 Valuation  
 Eco-Indicator?

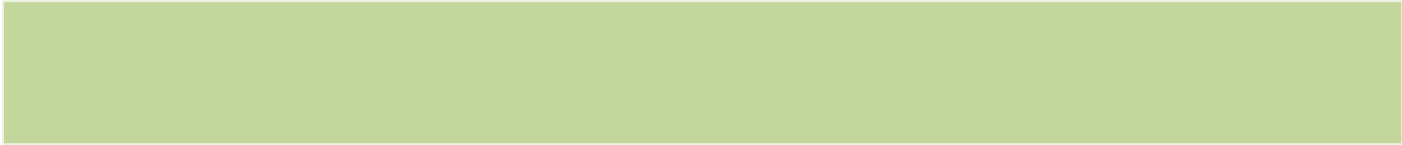
**normalization**  
**distance to target**

## Exercises (Impact assessment)

### Ecoindicator95

		Mid point	End point
Global Warming	943.89826 g CO2 eq	<b>1.45215E-13</b>	<b>1.21211E-11</b>
Ozone depletion	0.00064716 g CFC11 eq	<b>1.40687E-15</b>	
Acidification	6.4787823 g SO2 eq	<b>1.15693E-13</b>	
Carcinogenic	0.000362493 g PAH eq	<b>6.71284E-14</b>	
Eutrophication	0.6554237 g PO4 eq	<b>3.4496E-14</b>	
Heavy metal	0.041195347 g Pb eq	<b>1.52575E-12</b>	
Summer smog	5.5089685 g C2H4 eq	<b>6.18985E-13</b>	
Winter smog	4.14 g dust eq	<b>8.80851E-14</b>	
Human toxicity	14.30546657 g		

ISO: “weighting shall not be used for comparative assertions disclosed to the public”



**Compare the environmental impact of 3 products to provide mineral water:**

- 1 glass bottle not reusable;**
- 1 glass bottle reusable;**
- 1 plastic bottle PET (poly(ethylene terephthalate))**



+



+





## Exercises (Simapro)

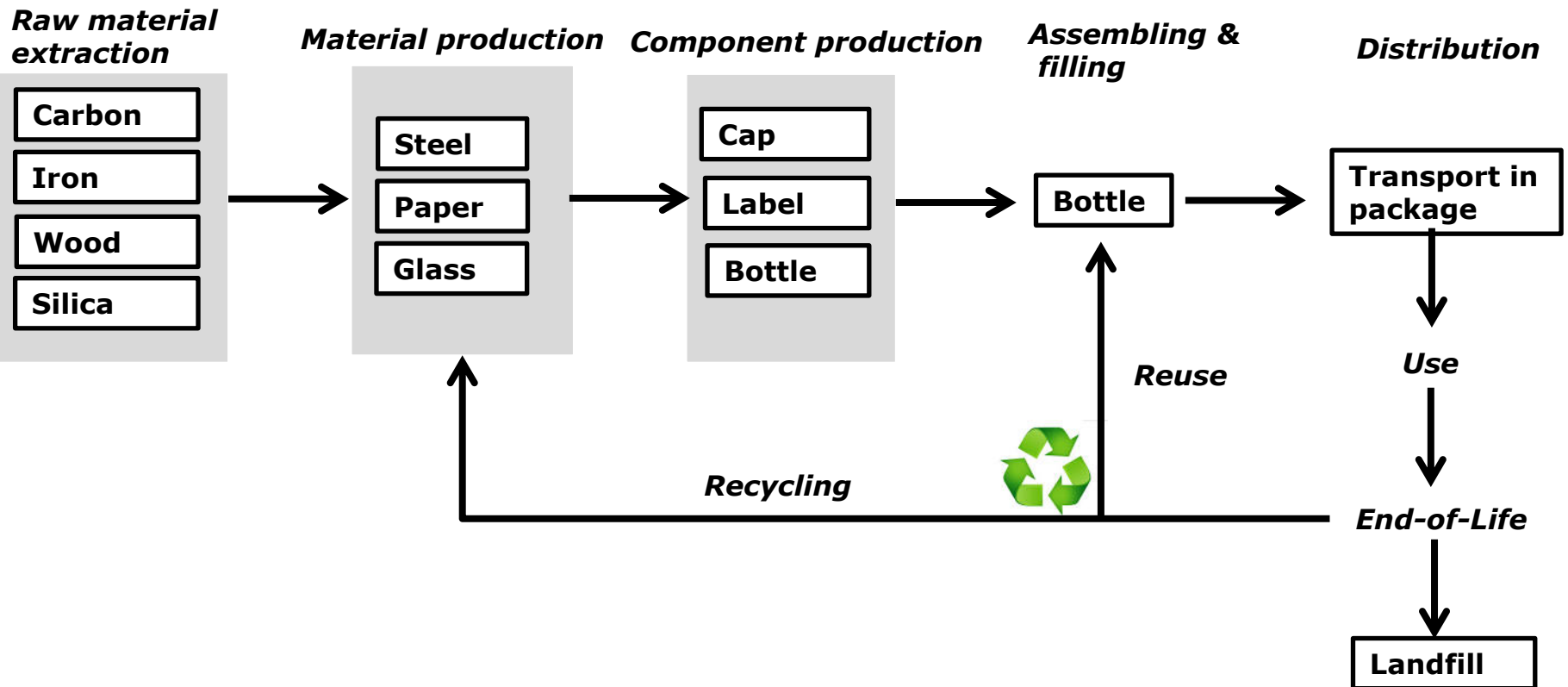
Product	Bottle	Cap	Label	Package
1 glass bottle reusable	Glass 599 g	Steel 2.2 g	Paper 1 g	PEHD 1818 g (12 bottle)
1 glass bottle not "	Glass 599 g	Steel 2.2 g	Paper 1 g	Paperboard 519 g (12 bottle)
1 plastic bottle PET	PET 18 g	PEHD 2.5 g	Paper 1 g	PELD 38 g

**HD-High Density; LD-Low Density; PE- PolyEthylen; \* Relatively to the market available**

Product E-of-L	Reuse (%*)	Recycling (%*)	Landfill (%*)	Incineration (%*)
1 glass bottle reusable	70	10	20	-
1 glass bottle not "	-	40	60	-
1 plastic bottle PET	-	10	30	60

## Exercises (Simapro)

### Simplified life cycle for reusable glass bottle



# Industrial Ecology – LCA module

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