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Building Integration of Solar Thermal Systems – TU1205 – BISTS

Life-cycle analysis of solar systems

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AGENDA

- To discuss the **importance of the LCA method** in the Building Sustainability Assessment;
- To present the indicators used in the **assessment of the environmental performance** of a building integrated or added solar system;
- To present the **steps and methods for the quantification of the potential environmental impacts** using the SimaPro software;
- Application to case studies.

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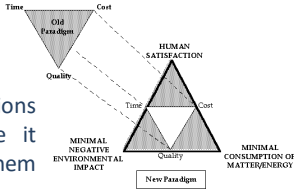
INTRODUCTION



- Optimizing building sustainability involves various relations between built, natural and social systems. Therefore it comprises **hundreds of parameters,** most of them interrelated and partly contradictory.

- This way, this process is only possible through a **systematic approach**.

- Sustainability assessment tools are useful to **gather** and **report** information for **decision-making** during different phases of construction, design and use of a building (holistic approach).

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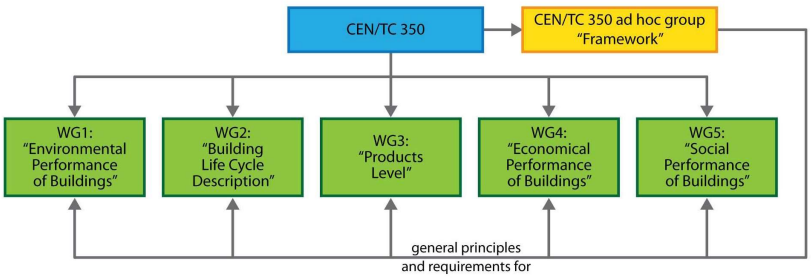
- In order to **standardize** and **promote** the **interpretation and comparison of results** from different assessment methods developed in Europe, the European Committee for Standardization (CEN) created the Technical Committee 350 (CEN/TC 350).



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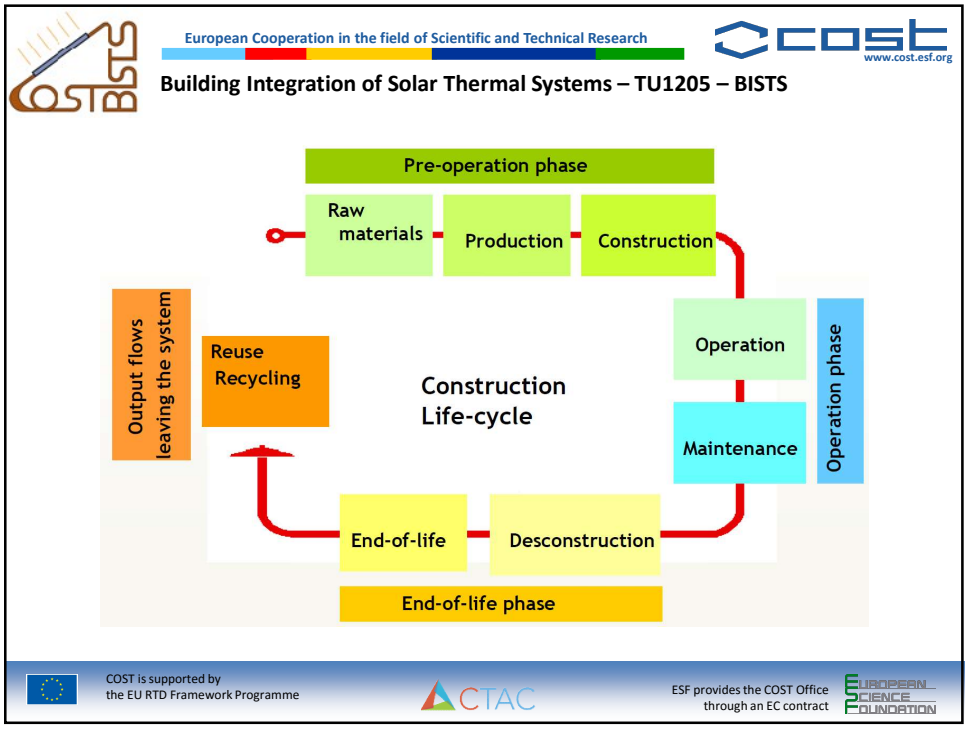
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Pre-operation phase
Raw materials
Production
Construction
Operation
Maintenance
Operation phase
Output flows leaving the system
Reuse Recycling
Construction Life-cycle
End-of-life
Desconstruction
End-of-life phase
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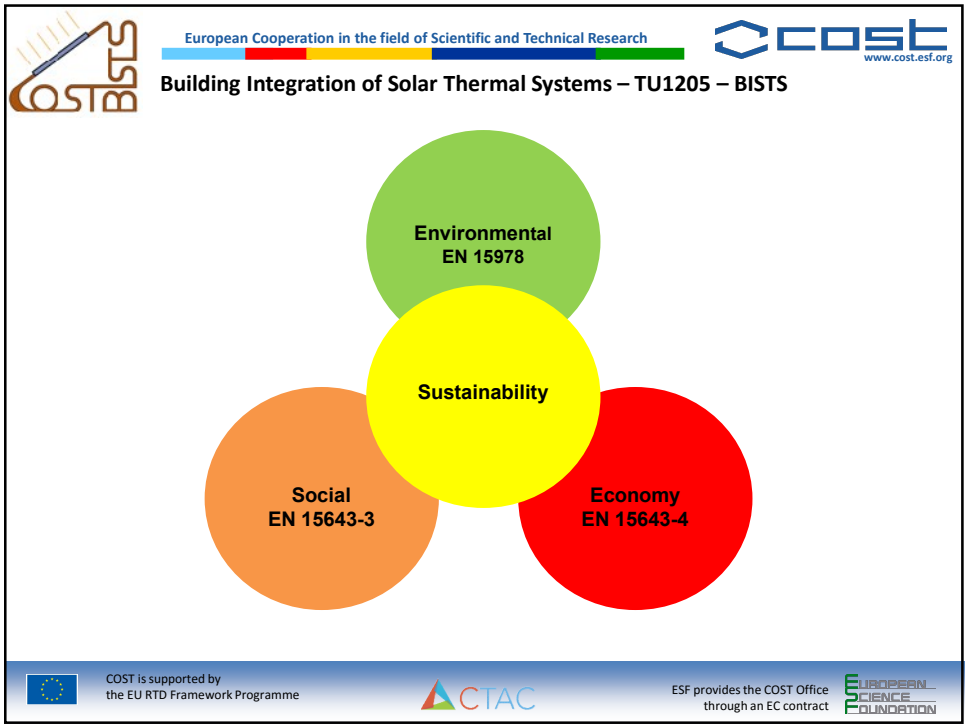
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Environmental EN 15978
Sustainability
Social EN 15643-3
Economy EN 15643-4
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- According to standard **EN 15978:2011** the assessment of the environmental performance of a building is based in **4 types of environmental indicators** (**total of 22**):

1 - Indicators describing environmental impacts:

Indicator	Unit
Global warming potential, GWP	kg CO_2 equiv
Depletion potential of the stratospheric ozone layer, ODP;	kg CFC 11 equiv
Acidification potential of land and water; AP;	kg SO_2^- equiv
Eutrophication potential, EP;	kg $(PO_4)^{3-}$ equiv
Formation potential of tropospheric ozone photochemical oxidants, POCP;	kg Ethene equiv
Abiotic Resource Depletion Potential for elements; ADP_elements	kg Sb equiv
Abiotic Resource Depletion Potential of fossil fuels ADP_fossil fuels	MJ

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Environment EN 15978

2 - Indicators describing resource use:

Indicator	Unit
Use of renewable primary energy excluding energy resources used as raw material	MJ, net calorific value
Use of renewable primary energy resources used as raw material	MJ, net calorific value
Use of non-renewable primary energy excluding primary energy resources used as raw material	MJ, net calorific value
Use of non-renewable primary energy resources used as raw material	MJ, net calorific value
Use of secondary material	kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ
Use of net fresh water	m^3

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Environment EN 15978

3 - Indicators describing additional environmental information:

Indicator	Unit
Hazardous waste disposed;	kg
Non-hazardous waste disposed	kg
Radioactive waste disposed	kg

4 - Indicators describing the output flows leaving the system:

Indicator	Unit
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery (not being waste incineration)	kg
Exported energy	MJ for each energy carrier

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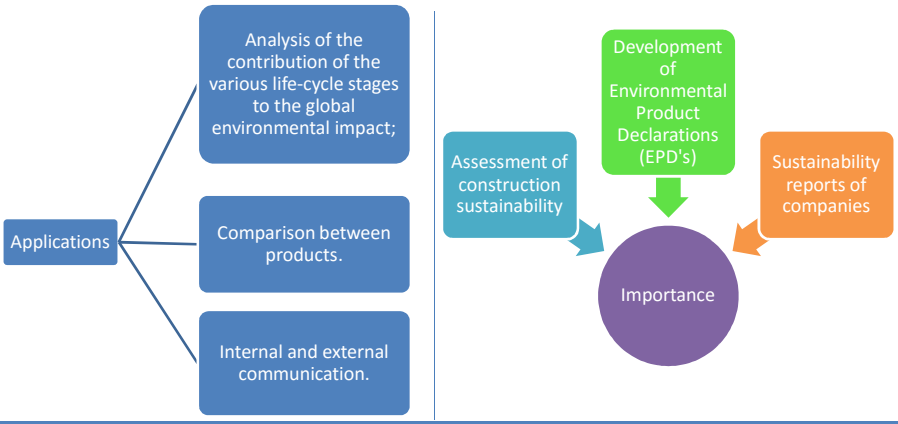
- Life-cycle analysis (LCA) is an analytical methodology that is aimed **to assess the resources content** and the **environmental impacts** associated with the life-cycle of a manufactured product.



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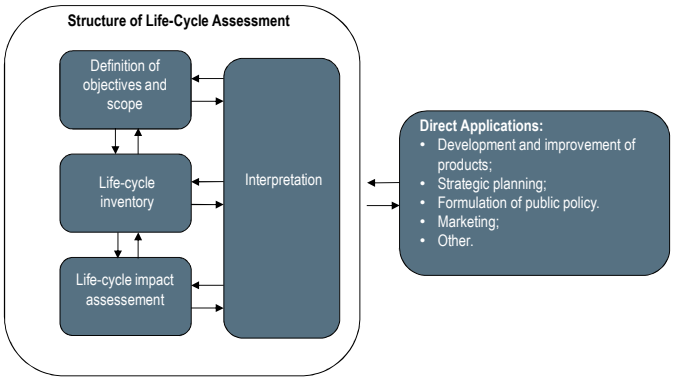
STAGES OF LCA (according to standard ISO 1040:2006)



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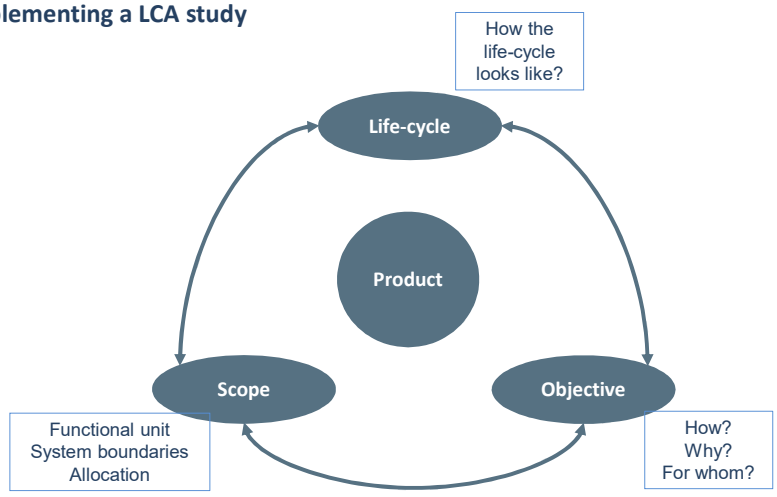
Implementing a LCA study



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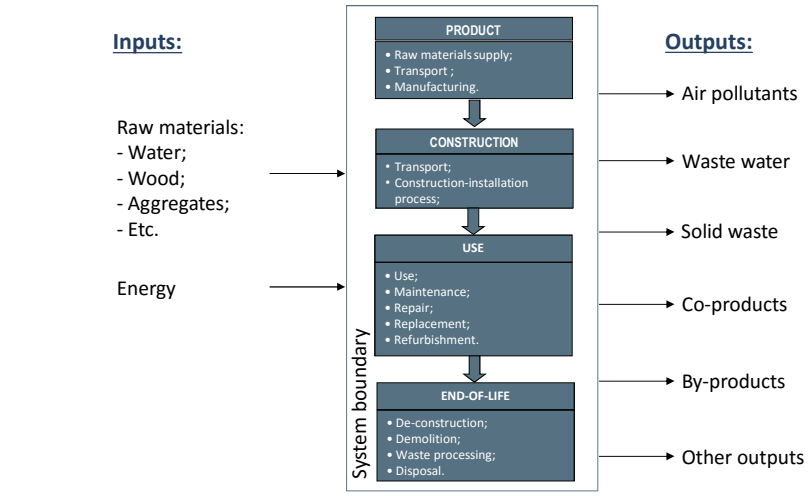
Generic life-cycle stages (EN 15978:2011)



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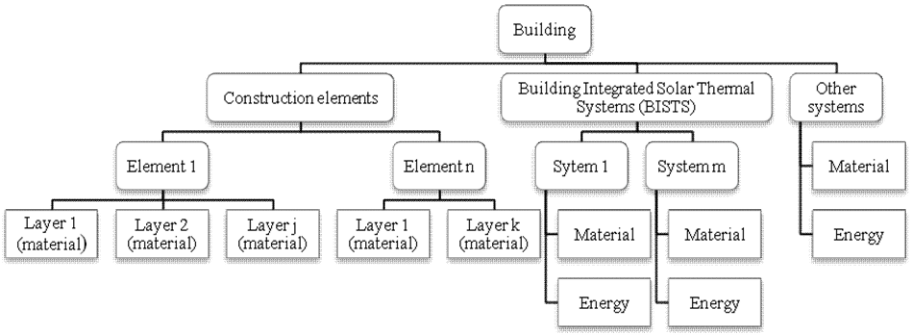
Structure of the building model used for LCIA



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Steps and methods for the quantification of the environmental impacts

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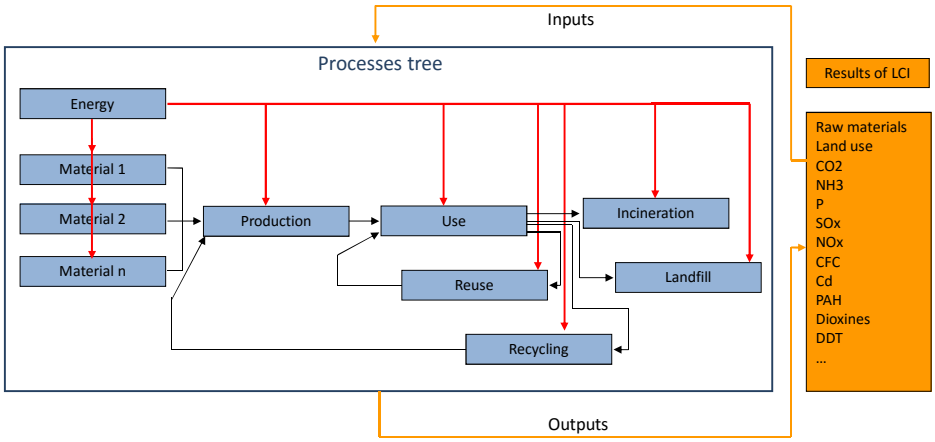
1st Step: Life-cycle *Inventory* (LCI)

The goal is to **identify all inputs and outputs** of the processes tree.



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1st Step (cont.)

How to get LCI data?

Some solutions…

1. To search for specific **Environmental Product declarations** (EPDs);
2. To use **LCI databases** of the LCA software;
3. To perform a **web search** :
   - Eco-invent center (www.ecoinvent.org);
   - Sustainability consultants' Webpages;
   - Google, Freepatents.com, Wikipedia;
   - *Material safety datsheets (MSDS)*
   - Ullman's Encyclopedia and other manuals;
   - Scientific journals (e.g. International Journal of LCA).
4. To **develop questionnaires** to collect specific LCI data from the company that produces the product to assess.

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1st Step (cont.)

Most used LCI Libraries at European level

- **Ecoinvent: Switzerland**
  - contains life-cycle inventory data **for over 4000 industrial processes**, including **energy supply**, **resource extraction**, **materials supply**, **chemicals**, **metals**, **waste management systems** and **transport** services;
  - has data for **different European countries contexts**;
  - works with **Simapro** and **Gabi** LCA software.

- **Gabi datasets: Germany**
  - based on **Gabi's co-operation with industry** as well as **patent**, **technical** and **scientific** literature;
  - include more than **8000 entries**, covering **metals** (steel, aluminum and non ferrous metals), **organic** and **inorganic** intermediate products, **plastics**, **mineral materials**, **energy supply** (power grid mixes, steam, thermal energy), **end-of-life**, **coatings**, **manufacturing and electronics**, **construction materials**, **renewable materials**, and **textile processing**.

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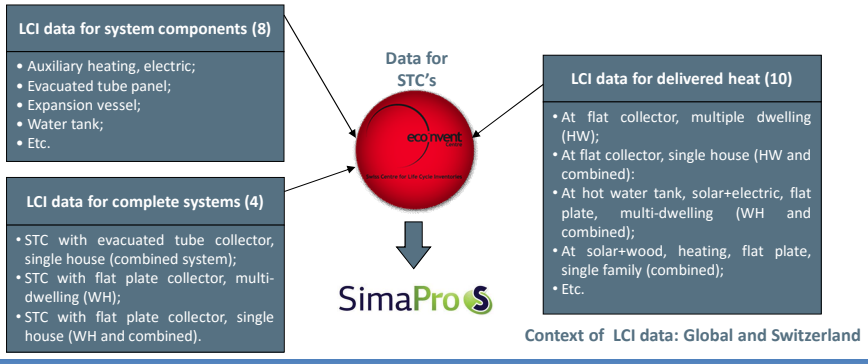
LCI data for STCs and PVs in Ecoinvent 3.1

➢ Covers **building-added solar thermal systems** plus both **building-added and building-integrated photovoltaic systems. No information about Hybrid photovoltaic/thermal** is found.



Context of LCI data: Global and Switzerland

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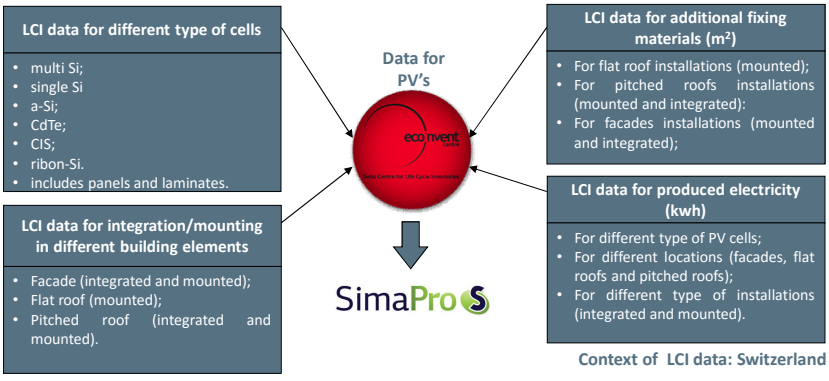
LCI data for PVs in Ecoinvent 3.1

➢ **Included processes**: all components for the installation of a 3 kWp photovoltaic plant, including **energy use for the mounting, transport of the materials and persons** to the construction place and disposal of components after the **end of life (21 processes)**.



Context of LCI data: Switzerland

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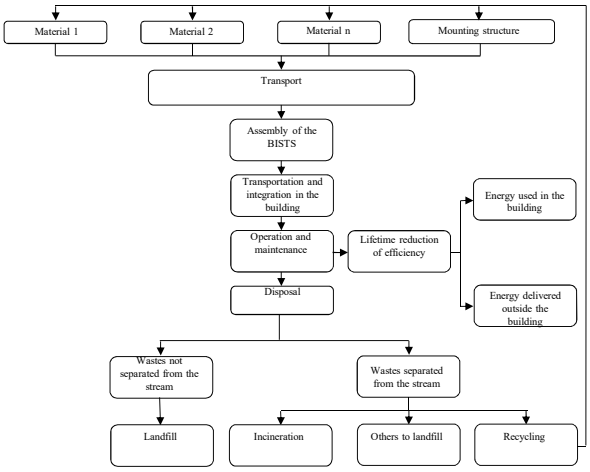
LCI for a specific ST or PV system



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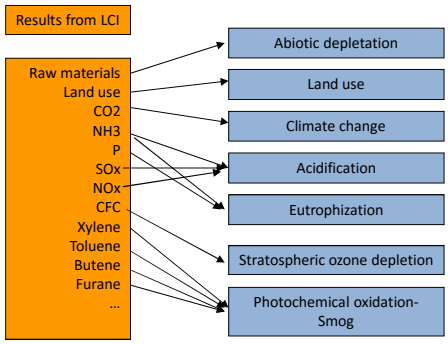
2nd Step: Life-cycle Impact Assessment (LCIA)

The inputs and outputs from and to the system boundaries are linked to **environmental impacts.**



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LCIA methods convert LCI data into indicators of environmental impact

- **CML 2000** — Used to assess indicators describing environmental impacts according to EN 15978
- **Cumulative Energy Demand**
- **EDIP 2003**
- **Traci, 2005**

→ **10 Categories of environmental impact**

Used categories →

- Abiotic depletion
- Global warming (GWP)
- Ozone depletion (ODP)
- Photochemical oxidation - Smog
- Acidification
- Eutrofization

There is an high level of uncertainties in the assessment of the toxicity and therefore these indicators are not considered in the actual set of CEN standards. →

- Human Toxicity
- Freshwater aquatic ecotoxicity
- Marine aquatic ecotoxicity
- Terrestrial ecotoxicity

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Midpoint LCI methods in detail

Classification / characterization

LCI result	Global warming	Acidification	Human toxicity
1000g CO_2	x 1 = 1000		
10g CH_4	x 21 = 210		
10g SO_2		x 1 = 10	x 1,2 =12
5g NOx		x 0.7 = 3,5	x 0,78 =3,9
10^{-6} g dioxins			x 3,3e6=3,3
Total	**1210**	**13,5**	**19,4**

◯ Characterization factors

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LCA method at a glance

LCIA databases with the environmental impacts of products (e.g. EPD's, https://repositorium.sdum.uminho.pt/handle/1822/20481, etc.)

Inventory (LCI)	Life-cyle impact assessment methods	Environmental impacts
• LCI libraries: e.g. Ecoinvent, Gabi datassets, Idemat 2001, Franklin USA 98; • Environmental Product Declarations (EPD's); • Questionaires to collect specific LCI data from the companies.	• CML 2 baseline 2000 • Eco-indicator 99; • Cumulative Energy Demand; • IPCC 2001 GWP100 • TRACI • (…)	• Global warming potential (GWP); • Acidification potential(AP); • Eutrophincation potential (EP); • Photochemical oxidation –smog (POCP) • Use of non-renewable primary energy(n_RE); • (…)

LCA tools: p.e. SimaPro, LISA, BEES, GABI, etc.

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Life-cycle impact assessment of Building-Added STCs – results from SimaPro

STCs (Infrastructure)	Life-cycle impact category						Embodied energy	
	ADP	GWP	ODP	AP	POCP	EP	ADP_FF	ERE
Evacuated tube collector	6.74E-01	9.03E+01	8.42E-06	7.81E-01	3.26E-02	6.55E-01	1.48E+03	1.38E+02
Flat plate collector	6.81E-01	1.02E+02	9.69E-06	9.76E-01	5.00E-02	6.65E-01	1.52E+03	2.46E+02
Solar system with evacuated tube collector, one-family house, combined system	1.77E+01	2.35E+03	3.06E-04	1.58E+01	1.03E+00	1.25E+01	3.90E+04	3.68E+03
Solar system, flat plate collector, multiple dwelling, hot water	7.00E+01	1.02E+04	1.47E-03	8.44E+01	5.21E+00	6.24E+01	1.60E+05	1.85E+04
Solar system, flat plate collector, one-family house, hot water	9.83E+00	1.33E+03	1.35E-04	8.77E+00	6.24E-01	5.93E+00	2.13E+04	2.55E+03
Solar system, flat plate collector, one-family house, combined system	1.95E+01	2.74E+03	3.52E-04	1.98E+01	1.34E+00	1.39E+01	4.35E+04	5.29E+03

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Case Study 1

Quantification of the environmental benefits resulting from the application of a **conventional solar thermal system** for domestic hot water (DHW) for a single family residential building with 3 rooms (in a renovation project).

Data

- **Life time of the project**: 40 years;
- DHW heating system (**before renovation**): non-modulating and non-condensating light oil boiler with an efficiency of 94%;
- DHW heating system (**after renovation**): DHW is produced by solar thermal collectors and by the air-water heat pump. The solar thermal installation (5 m² of flat plate collectors) yearly covers 65% of the energy needs. The heat pump provides the rest;
- **Life time for the STC, heat pump and light oil boiler** : 20 years;
- **Environmental indicators**: CED_Tot (MJ); CED_nRE (MJ); GWP (kg_eq/CO2).

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- Energy balance – **before renovation**

Consumer	Delivered energy (Kwh/year)	Vector	Cover (%)	Efficiency (%)
Domestic hot water	1912	Light fuel oil	100	94

- Energy balance – **after renovation**

Consumer	Delivered energy (Kwh/year)	Vector	Cover (%)	COP
Domestic hot water	1912	Electricity	35	3
		Solar thermal	65	-

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How the life-cycle looks like?

- **before renovation**

Embodied impacts of the boiler (year 0) + Replacement of the boiler (year 20) + Energy consumption In the boiler (40 years) = **Cumulative environmental Impacts before renovation (40 years)**

- **after renovation**

Embodied impacts of the STS (year 0) + Embodied impacts of the heat pump (year 0) + Replacement of the STC (year 20) + Replacement of the heat pump (year 20) + Energy consumption In the heat pump (40 years) = **Cumulative environmental Impacts after renovation (40 years)**

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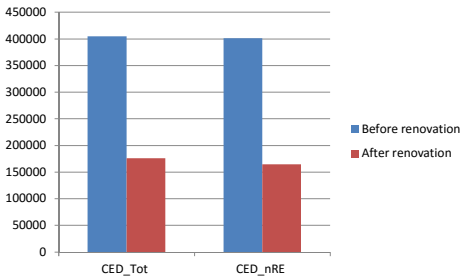
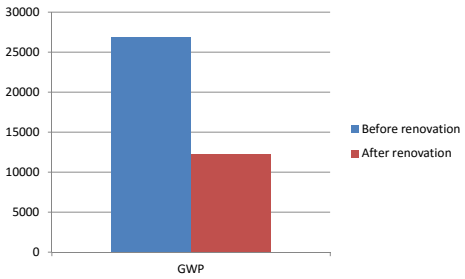
Results

Scenario	CED_Tot (MJ)	CED_nRE (MJ)	GWP (Kg.eq. CO_2)
Before renovation	404 517.50	400 800.50	26 800.00
After renovation	175 780.50	164 500.50	12 200.00





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Using SimaPro to quantify the life-cycle impacts of a tailored STC

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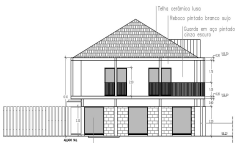
Case study 2

Quantification of the environmental benefits resulting from the application of a **tailored solar thermal system** for domestic hot water (DHW) for a single family residential building with 3 rooms (in a renovation project).



Data

- **Life time of the project**: 40 years;
- **Location**: Oporto;
- DHW heating system (**before renovation**): non-modulating and non-condensating light oil boiler with an efficiency of 94%;
- DHW heating system (**after renovation**): DHW is produced by a new type of solar thermal collectors and the by the air-water heat pump. The solar thermal installation (5 m² of flat plate collectors) yearly covers 80% of the energy needs. The heat pump provides the rest;
- **Life time for the STC, heat pump and light oil boiler** : 20 years.

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LCI Data for Pre-operation phase

Materials used in the solar collector + water tank (hypothetical system):

	Material	Quantity (kg)
Solar collector	Aluminium sheet (primary aluminium)	15.40
	Flat glass	14.20
	Copper tube	5.10
	Mineral wool	2.31
	Polyester	0.17
Water tank	Chromium steel	28.00
	Mineral wool	8.20
	Copper tube	11.30
	Tube insulation (elastomere)	3.60
	Propylene glycol	2.80

Impacts related with the assembly of the solar system components: Analyzing the the LCI data for the conventional STCs, a scenario where these impacts are 30% of the materials related impacts is considered.

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LCI Data for Assembly phase (cont.)

Transportation and Mounting processes:

Transportation	Weighted average transportation distance	50 km
	Type of transportation	Light van
Mounting processes	Considered scenario for consumed energy (.In state-of-art there are some studies that state that the environmental impacts resulting from the mounting processes are around 3% of the components embodied impacts).	1 kWh
System substitution	Life time of STC, water tank and heat pump	20 years

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Operation phase

Operation	Electricity (heat pump)	382.4 kWh/year
	Solar	1529.6 kWh/year
Maintenance	Maintenance impacts are not considered in this study (In state-of-art there are some studies that state that the environmental impacts resulting from the mounting processes are around 10% of the components embodied impacts).	Not considered

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End-of-life (considered scenario)

	Wastes	
Recycling	Aluminium	95% recycling
	Glass	95% recycling
Landfill	Remaining materials	100% landfill

Transportation distance: 50 km.

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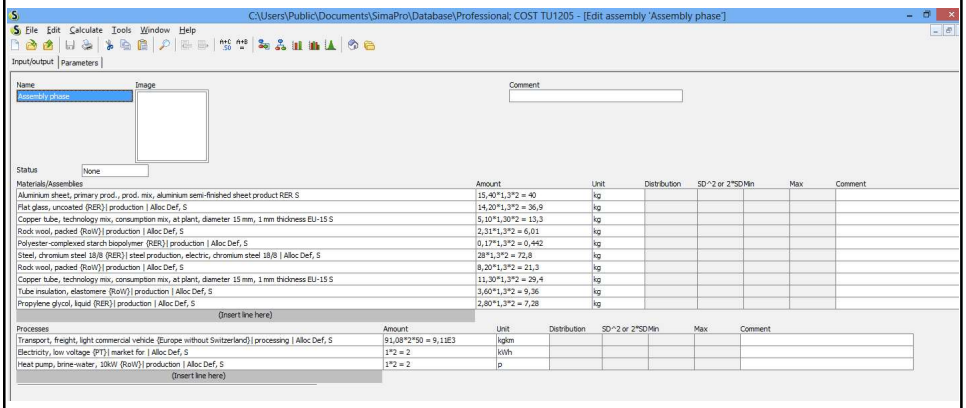
Inserting Data in SimaPro (Assembly phase)



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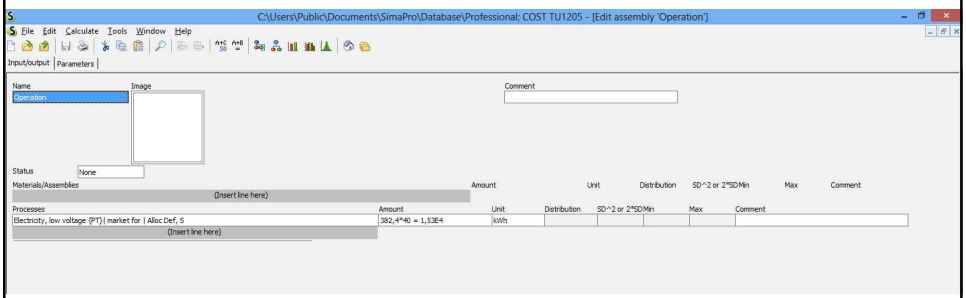
Inserting Data in SimaPro (Operation phase)



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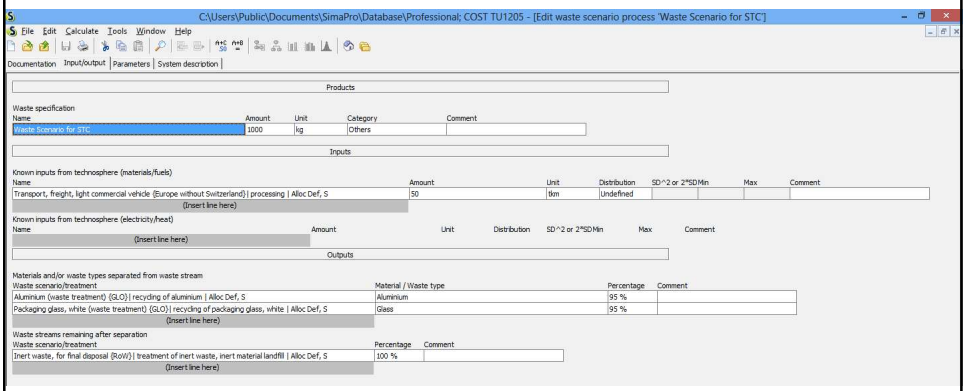
Inserting Data in SimaPro (End-of-life scenario)



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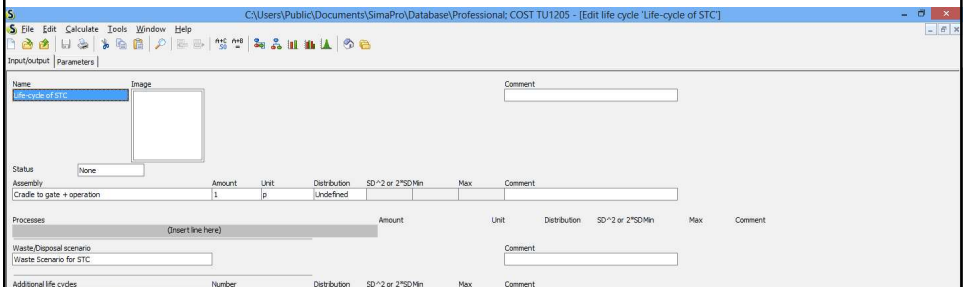
Inserting Data in SimaPro (whole life-cycle)



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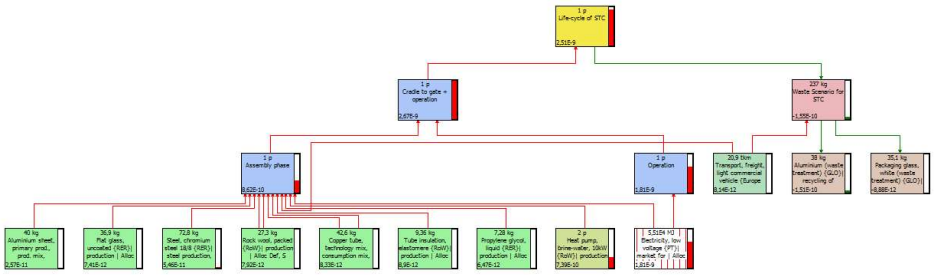
Results (LCA tree)



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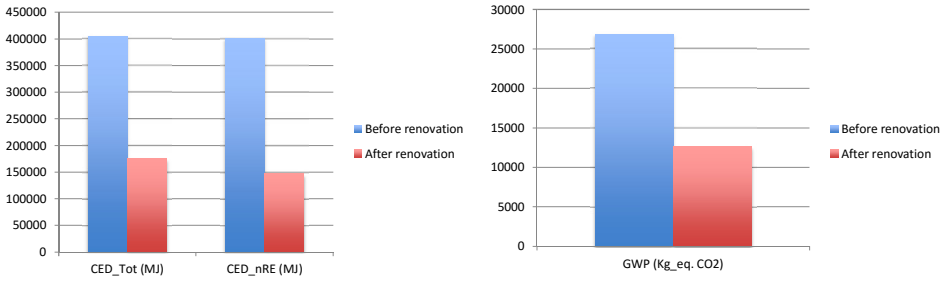
Results (environmental indicators)

Scenario	CED_Tot (MJ)	CED_nRE (MJ)	GWP (Kg.eq. CO_2)
Before renovation	404 517.50	400 800.50	26 800.00
After renovation	174 982.40	146 508.60	12 600.00



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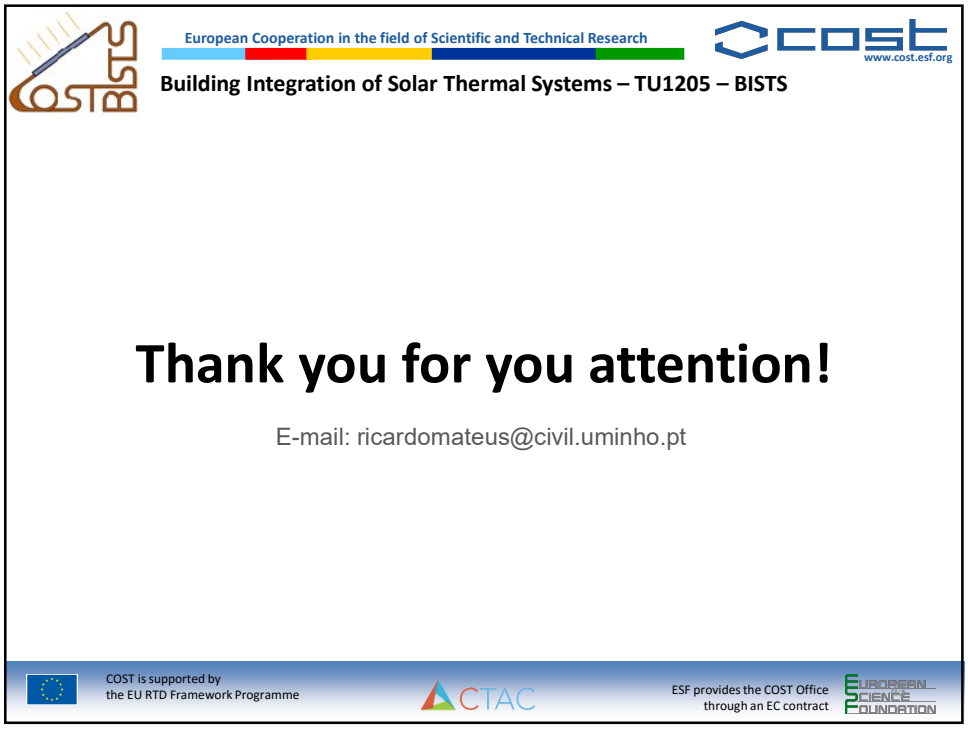
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Thank you for you attention!
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