Final Deliverable

Report on Life cycle analysis

Date: 25.09.2014

By Marco Beccali[1], Maurizio Cellura[1], Sonia Longo[1]

Contributors: Pietro Finocchiaro[1], Tim Selke[2]

[1]Institution	Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici – Università degli Studi di Palermo
Address	Viale delle Scienze Ed.9, 90128 - Palermo
Phone	+39-09123861911
E-mail	marco.beccali@dream.unipa.it
[2]Institution	Department ENERGY - Sustainable Building Technologies - AIT Austrian Institute of Technology GmbH
Address	Giefinggasse 2, 1210 - Vienna
Phone	+43 50550-6651
E-mail	tim.selke@ait.ac.at

IEA Solar Heating and Cooling Program

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The member countries of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 53 such projects have been initiated to-date, 39 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding with solar thermal trade organizations
- Workshops and conferences

Country Members

Australia	Germany	Singapore
Austria	Finland	South Africa
Belgium	France	Spain
China	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	Turkey
European Commission	Norway	United Kingdom
	Portugal	United States

Sponsor Members

European Copper Institute	Gulf Organization for Research and Development
ECREEE	RCREEE

Contents

Executive Summary

This technical report describes the research activities developed within Subtasks A2 “Life cycle analysis at component level” and B3 “Life cycle analysis at system level”.

Subtask A2 is focused on developing studies to assess the energy and environmental performances of components of solar cooling and heating (SHC) systems. In detail, the Life Cycle Assessment (LCA) approach applied to SHC systems, started by IEA Task 38, is further developed to give a ready to use collection of datasheets allowing estimating the energy and environmental impacts of different SHC systems during their life cycle. The results of the activities developed within Subtask A2 are used to update and complete a database of life cycle inventories for components of SHC systems, already developed within Task 38, to be used for the development of a LCA method tool.

As outcome of Task 38, two machines have been already analysed: PINK PSC-10 (12 kW) with H_2O/NH_3 and SorTech AG ACS 08 (8 kW) with H_2O/Silica Gel. In addition, the energy and environmental impacts of other components of SHC plants have been assessed (e.g. solar thermal collectors, gas boiler, pumps, etc.) starting from data of international LCA databases. As outcome of Subtask A2 of Task 48, the energy and environmental impacts of Pink PC19 Ammonia Chiller and of a Packed Adsorbed Bed have been assessed and the database of life cycle inventories for components of SHC systems, developed within Task 38, has been updated and completed.

Furthermore the LCA database now includes solar PV components (photovoltaic panels, inverter, storage, etc.) giving the possibility to perform analysis on conventional systems which use renewable electricity with or without connection with the grid.

Subtask B aims at developing a user-friendly LCA method tool, useful to calculate the energy and environmental impacts and the payback time indices of different SHC systems and to compare SHC systems and conventional ones. The tool contains the database developed in Subtask A2. An important step of the tool development has been the analysis of international LCA databases to check the LCA data availability for components of the SHC systems and for conventional equipment (pipes, pumps, electric components, photovoltaic panels, etc.).

Within Subtask B, the results of the SolarCoolingOpt project are also illustrated.

1. Activity A2: Life cycle analysis at component level

The main goal of this activity is to update and develop a set of life cycle analyses of components of SHC systems, by applying the LCA methodology according to the international standards of the series ISO 14040. The input data for the LCA have been provided with the support of manufacturers, and by a detailed analysis of the international LCA databases.

The database of life cycle inventories for components of SHC systems, already developed in Task 38, has been updated (by using new versions of the impact assessment methods) and completed with new data.

In detail, data on the following components have been added (see Annex 1): photovoltaic panels, inverters, batteries, pumps, pipes.

Furthermore, the LCA methodology has been applied to the following components:

1. Pink PC19 Ammonia Chiller (see Section 1.1);
2. Packed Adsorption Bed (see Section 1.2);

Other two components (Sortech ADCH ACS08 and DEC wheel) have been analysed. However a complete LCA has not been performed, due to the unreliability and incompleteness of available data (see Sections 1.3 and 1.4).

Further analyses have been attempted but not completed due to the difficulty to provide complete data by some of the interested manufacturers.

1.1 LCA of Pink PC19 Ammonia Chiller

The LCA of Pink PC19 ammonia chiller has been carried out. The main assumptions and the obtained results of the analysis are described in the following. The examined product is showed in Figure 1. The chiller, filled with ammonia/water solution, generates cold through a closed, continuous cycle.

Figure 1: **The Absorption Chiller Pink PC19**

The absorption chiller consists of four main components: the generator, the condenser, the evaporator and the absorber. Inside the generator, hot water is supplied to the chiller through a heat exchanger. A part of the ammonia is expelled from the ammonia/water solution and condensed again inside the condenser. The ammonia condensed is fed to the evaporator where it is evaporated. During this process, heat energy is discharged from the cooling cycle, which cools it down. Inside the absorber, the ammonia is absorbed from the low concentrated refrigerant ammonia/water solution and the cycle starts over again.

The energy and environmental performances of the chiller have been quantified using the LCA) methodology regulated by the international standards ISO Series 14040 (ISO 14040, 2006; ISO 14044, 2006).

The main choices and assumptions considered for carrying out the LCA are detailed in the following:

- the selected functional unit (FU) is “one Absorption Chiller Pink PC19”;
- system boundaries, defined following a “cradle to gate” approach, include the production and transport of raw materials and the manufacturing process in the factory;

- a cut off rule of 3% has been adopted. Electronic components (electric cables, sensors, and motor parts), that represent the 2.5% of the overall system mass, have been neglected;
- concerning the assessment of the specific consumption of electricity and natural gas, and the production of wastes per FU, allocation has been undergone with a mass criterion. In particular, the yearly consumption of electricity (50,000 kWh/year), the yearly natural gas consumption (155,000 kWh/year from biomass district heating) and the yearly disposed wastes (metal scraps 10,000 kg/year) have been allocated considering that the produced absorption chiller represents about 6% of the yearly company's production;
- eco-profiles of raw materials are referred to Ecoinvent database (Frischknecht et al., 2007);
- the absorption chiller is produced in the plant of the "Pink" company, sited in Austria. Impacts related to the use of electricity refer to the Austrian energy mix. Eco-profiles of raw materials refer to average European data;
- concerning the insulation, Armaflex is employed. It is a closed cell, CFC free elastomeric rubber material made in tube and sheets form for insulating piping, ducts and vessels. Missing data about such insulation, the eco-profile of a common rubber has been considered;
- the energy and environmental impact categories selected to show the performances of the investigated system are: non renewable energy requirement (NRE), renewable energy requirement (RE), global energy requirement (GER), global warming potential (GWP);
- the methodology used to assess the energy impacts is "Cumulative Energy Demand" (Frischknecht et al., 2007b; Prè, 2012), that allows to estimate the consumption of renewable (biomass, wind, solar, geothermal, water) and non renewable (fossil, nuclear) energy sources;
- the methodology used to assess the environmental impacts is "ILCD 2011 Midpoint" (European Commission, 2012), elaborated according to the recommendations of the ILCD Handbook of the European Commission (European Commission, 2011).

The supplying of raw metal materials comes mainly from North Italy, France and North Europe (Table 1). Few components are locally purchased. Almost all the transportations occur by road, except a short shipping from Sweden to Denmark. Total transportations amount to 294 tkm by large capacity trucks and 2.8 tkm by ship.

The production of the chiller consists mainly in the cutting, TIG welding (Tungsten Inert Gas welding with argon gas)[1] and assembling of semi-manufactured components. Altogether, about 10 hours of TIG are carried out in the production of one chiller. A detail of the production process flow is shown in Figure 2.

[1] Compared to other welding technologies, TIG is characterized by lower impacts because it avoids using consumables electrodes. Anyway, few data have been found into references concerning TIG emissions. Some data have been derived by a private company report and it considers specific emissions of: PM_{10} 8.16 g/hr and Mn 0.9 g/hr. Argon consumption amounts to 5.5 l/min (Krűgher, 1994).

Data on the manufacturing process of chiller have been elaborated to assess the eco-profile of the FU. Results are shown in Table 2, and in Figures 3 and 4.

Table 1: Detail of system components and transports

System Component	Material	Mass [kg]	Supplying from:
Housing	Carbon Steel	125	France
Tube & shell HEX	Stainless steel	150	North Italy
Vessels	Stainless steel	20	North Italy
Working solution	Ammonia (50%) & water (50%)	36	Austria
Plate-HEX	Stainless steel	29	Sweden
Piping	Stainless steel	20	North Italy
Pumping system	Carbon Steel	30	Austria
	Stainless steel	5	North Italy
	Aluminium	10	
	Copper	5	
	Others	6	
Electric, Sensors,	Electronics (various)	5	Austria
Insulation	Armaflex ®	6	Germany
Valves	Cast iron	2	Denmark
	Total	**449**	

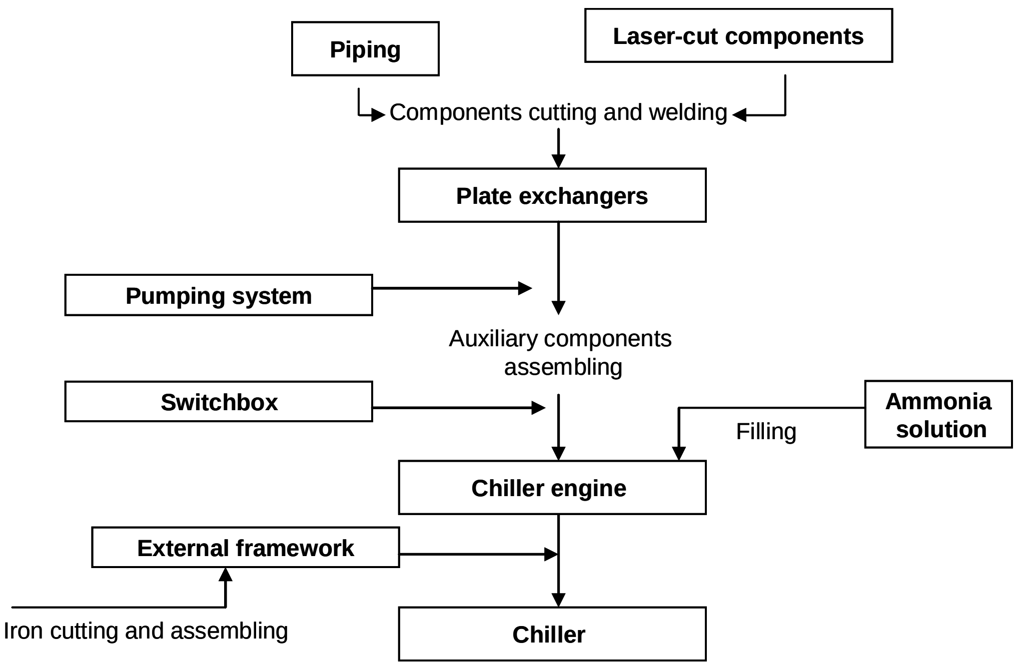


Figure 2: Production diagram flow

Table 2: Energy and environmental impacts of the absorption chiller

	NRE (MJ)	RE (MJ)	GER (MJ)	GWP (kg CO_{2eq})
Production of chiller components	25,668	3,938	29,606	1,720
Manufacturing process	3,296	9,053	12,350	222
Raw materials transport	884	11	895	54
Total	29,849	13,002	42,851	1,996

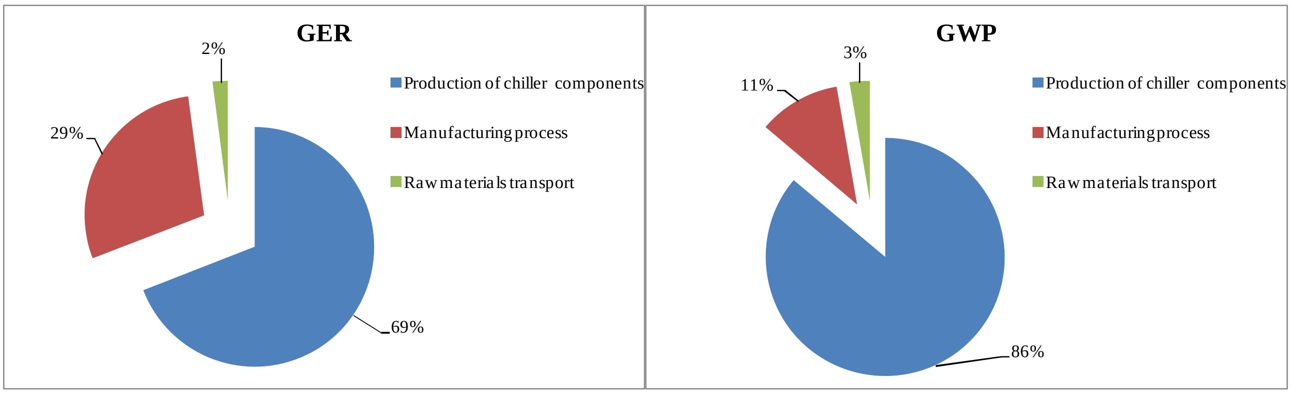


Figure 3: Percentage contribution of the each life-cycle step to GER and GWP

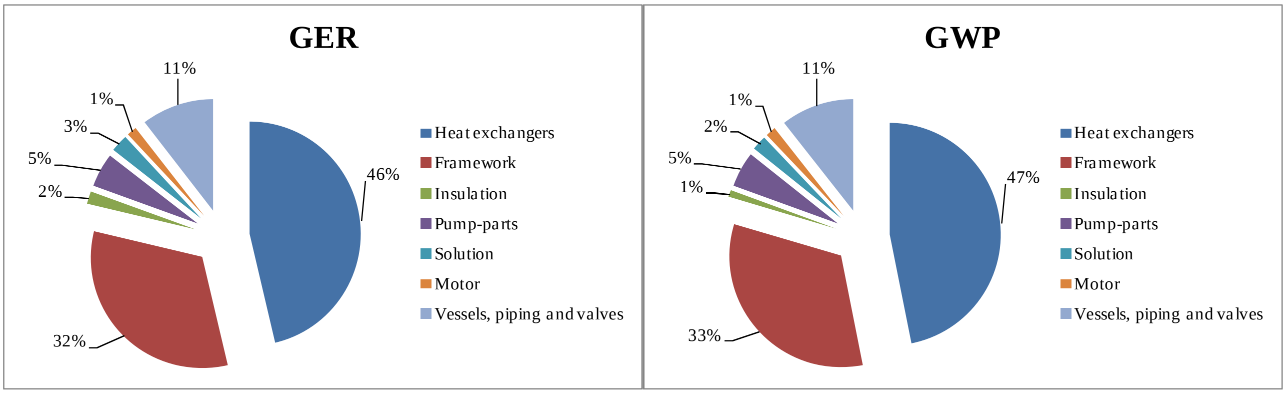


Figure 4: Percentage contribution of different chiller components to GER and GWP

An analysis of the above data allows observing that:

- GER amounts to about 42.8 GJ and GWP amounts to 1,996 $kgCO_{2eq}$;

- the production of chiller components has a large incidence on the GER (69%) and GWP (86%);

- in the production step of the chiller components, the main contributions to GER and GWP are due to the heat exchanger (46% for GER and 47% for GWP) and to the framework (32% for GER and 33% for GWP). Each of the other components gives a contribution to the impacts variable from 1% (motor) to 11% (vessels, piping and valves).

1.2 LCA of a Packed Adsorption Bed

The main goal of the study is the assessment of the energy and environmental performances of a Packed Adsorption bed filled with silica gel (Figure 5), and the identification of the main components that are responsible of the calculated impacts.

The examined system is composed by the following main components:

- galvanized steel grill (7.92 kg);
- silica gel (18 kg);
- heat exchanger (steel sheet: 8.8 kg; copper pipes: 3.66 kg; aluminum fin: 2.54 kg);
- galvanized steel screws and plates (0.2 kg).

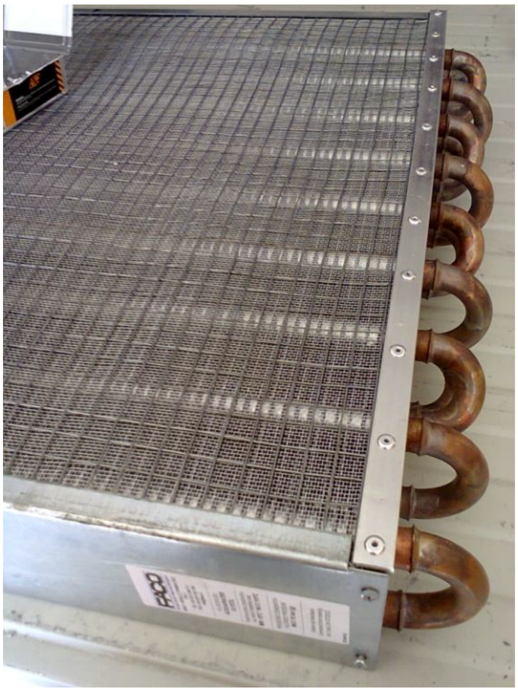


Figure 5: Packed adsorption bed

The main choices and assumptions of the LCA study are the following:

- Functional Unit: a Packed Adsorption Bed;
- System boundaries: production of the main components of the system.

- Cut-off: due to the unavailability of reliable and complete data, the energy and environmental impacts related to the following life cycle steps have not been taken into account: transports, operation, maintenance and end-of-life steps.
- The useful life of the Packed Adsorption Bed is hypothesized to be 20 years.
- The eco-profiles of the input data are referred to the environmental database Ecoinvent.

Once the input data have been collected, they have been implemented in a LCA software to estimate the energy and environmental impacts of the examined functional unit. In detail, the impact assessment methods Cumulative Energy Demand and ILCD 2011 Midpoint have been used for the impact calculation. Results are shown in Table 3.

Table 3: Energy and environmental impacts of the packed absorption bed

	NRE (MJ)	RE (MJ)	GER (MJ)	GWP (kg CO_{2eq})
Grid	142.97	0.15	143.12	11.31
Silica gel	5.89	0.1	5.99	0.38
Screws and plates	3.61	0	3.61	0.29
Heat exchanger	624.64	91.26	715.89	43.75
Total	776.91	91.51	868.42	55.73

An analysis of the above data allows observing that:

- GER amounts to about 0.87 GJ and GWP amounts to about 77.7 kgCO_{2eq};

- the production of heat exchanger has a large incidence on the GER (82.4%) and GWP (78.5%);

- the contributions to GER and GWP of silica gel and screws and plates is negligible (lower than 0.7%).

1.3 LCI material data Sortech ADCH ACS08

The main materials and related weights of Sortech ADCH ACS08 are showed in Table 4. The available input data are not sufficient to develop a complete LCA.

Table 4: Main materials and related weights of Sortech ADCH ACS08

Main component	Approx. life time	Material	Weight [kg]
Adsorber			
Vacuum module	>15	high-grade steel 1.4301	78,8
Adsorber	>15	Silica gel	45
Adsorber	15	Copper/Aluminium	41
frame / casing	>15	Steel	40,8
Heat exchanger	15	Copper	19,5
Vacuum module	>15	H_2O	14
Adsorber	>15	Epoxy resin	10
Hydraulic unit	>15	Copper	9,3
mini devices	>15	PV polyvinyl chloride, Copper, Aluminium	5
Hydraulic unit	>15	Brass	3,3
Insulation	>15	PE-Schaum (PE foam)	2
Hydraulic unit	>15	Steel	1
Steam damper	>15	EPDM (Ethylene-Propylene-Dien-Monomer)	0,9

1.4 LCI material data for DEC wheel

The main characteristics, materials and related weights of the DEC wheel have been defined. The available data are not sufficient to develop a complete LCA.

The desiccant wheel manufactured by Klingenburg (type SECO) is the core component of the DEC system. It works based on the principle of sorption, which is the accumulation of a substance in a medium. Absorption takes place in hygroscopic fluids. Absorption describes the bonding of molecules on the phase interface of a solid substance. This process is reversible due to regeneration of the absorbent at 80 -120°C (Mair von Tinkhof, 2010). Figure 6 illustrates the difference between the two processes.

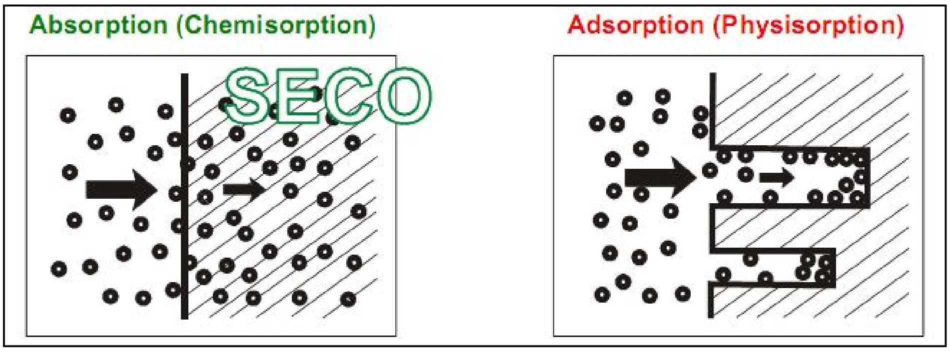


Figure 6: Comparison of the principles of absorption and adsorption (Klingenburg, 2011)

The desiccant wheel consists out of the rotor and the housing. The matrix of the rotor material is constructed out of cellulose. It has a very high capacity of moisture absorption. The housing is fabricated of strong welded sea water resistant aluminium performed with rectangular profiles. The driving motor is fixed on housing construction and is performed as a rotating current asynchrony motor with a self-tightening V-belt. The air flows are in counter flower like shown in Figure 7 (Klingenburg, 2011).

The desiccant wheel, which is employed in a SDEC system, has a specific operating point in the summer. The following values of the air conditions are related to summer operation, when cooling and dehumidification of supply air is required. The outside air temperature is 32°C and is elevated after the rotor up to 48°C. While increasing temperature the humidity is decreasing to 11% relative humidity (r.h.). (KWI Consulting Engineers, 2007) Due to regeneration of the sorption material with solar heat, the return air flow entrances the desiccant wheel with high temperatures of 70°C. The extract air flow is then released to ambient air. A detailed list of key figures of an operating desiccant wheel is given in Table 5.

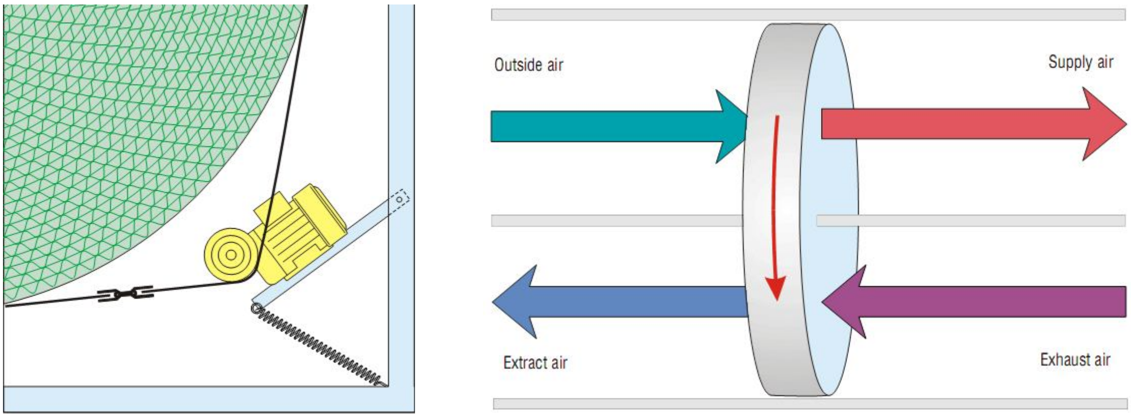


Figure 7: Motor location and air flows of desiccant wheel (Klingenburg, 2011)

Table 5: Detailed operation mode of desiccant wheel in summer (own tabulation due to contract specifications of ENERGYbase)

Volume flow	8240 m^3/h
Pressure loss	165 Pa
Outside air	32 °C / 40% r.h.
Supply air	48.4°C / 11% r.h.
Return air	70 °C / 7% r.h.
Extract air	53.6 °C / 19% r.h.

Every 8 years the sorption material has to be changed (Klingenburg, 2011). This has been taken into account by multiplying the sorption material employed in a SDEC plant by 3.1. This factor is resulting when the useful lifetime of the system (25 year) is divided by 8. LiCl is at the end of it useful lifetime, which is in the application of the desiccant wheel after 8 years, dangerous waste and therefore has to be treated in an incinerator for dangerous wastes (Hach Lange, 2010).

Figure 8 shows the data generated from research of materials. The values are calculated for both desiccant wheels of the twin plants, thus for a whole SDEC system. Absolute weights for the desiccant wheels and corresponding calculations can be looked up in Figure 9.

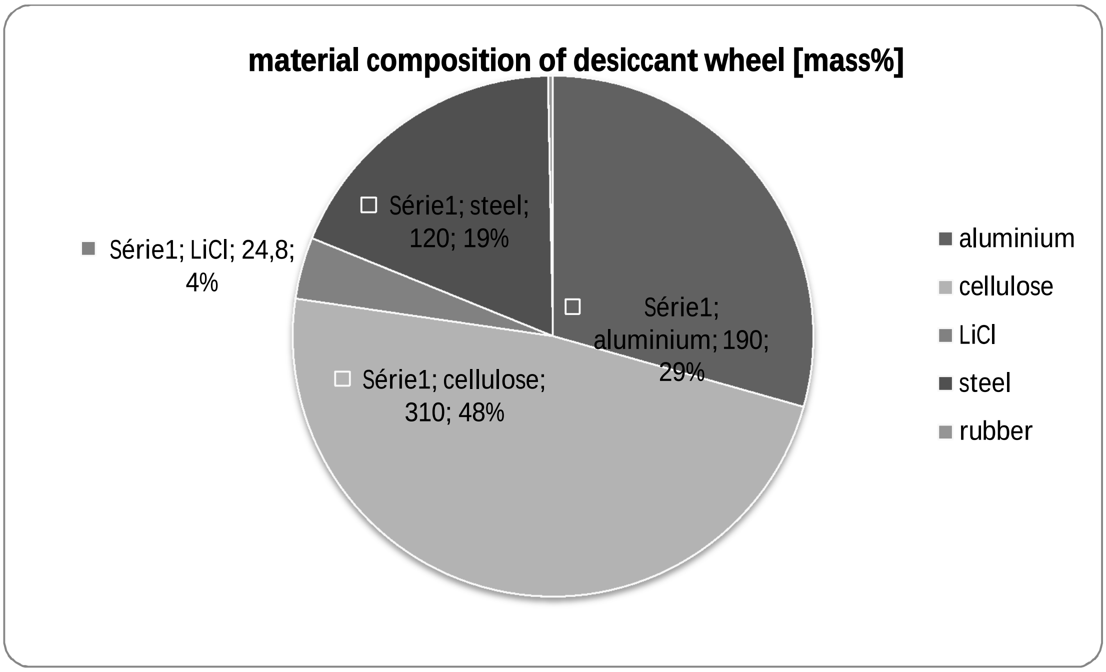


Figure 8: Material composition of desiccant wheel in a SDEC system (based on information from robatherm and Klingenburg)

Data box desiccant wheels	
materials	**Weight [kg]**
aluminium	190
cellulose	310
LiCl	24.8
Steel	120
rubber	2
total	**646.8**

Figure 9: Data box desiccant wheel employed materials and their weight (based on data from robatherm and Klingenburg)

2. Activity B3: Life cycle analysis at system level

The main goal of this activity is the development of a user-friendly LCA method tool for assessing the energy and environmental impacts of SHC systems following a life cycle approach. The tool can be useful to carry out simplified LCAs of SHC systems localized in different geographic contexts. It can be used only for educational and research activities.

The tool has been developed in xls format with the following characteristics:

- easy-to-use: it can be used both by LCA practitioners and non-professional users;
- easy to update: new LCA data can be added in the tool after its development;
- applicable to different geographic contexts;
- mainly devoted to perform parametric analyses for systems similar to the ones included in the database develop in Subtask A2;
- with limited possibility to include new components by the user (to avoid errors or use of not homogeneous datasets);
- with the possibility to do some “extrapolations” on component sizes but with a “warning about the results”.

The tool allows calculating:

- Global warming potential (GWP);
- Global energy requirement (GER);
- Energy payback time (EPT);
- GWP payback time (GWP-PT);
- Energy return ration (ERR).

The following section reports a guide for users, which contains a detailed description of the LCA method tool and some applicative examples.

2.1 LCA Method Tool manual

2.1.1 Introduction

The LCA Method Tool is a tool for applying the Life Cycle Assessment (LCA) methodology, which is a technique for assessing the energy and environmental impacts associated with all stages of a product's life cycle from cradle to grave. LCA Method Tool can be used to create life cycle energy and environmental balances of SHC systems, to carry out simplified LCAs, and to compare the SHC systems with conventional ones.

Data on specific energy and environmental impacts of different components of SHC and conventional systems are provided with the tool. LCA Method Tool can easily be expanded with the life cycle data of new components or updated with new life cycle data for the existing components.

The visualization approach of the tool enables users to build the SHC system model by using a clear and transparent structure. Input data, specific impacts, total impacts are reported in separate worksheets; therefore, each worksheet can be easily consulted or compiled. The LCA results are displayed both in tables and in figures and are referred both to specific life cycle steps (manufacturing, operation and end-of-life steps) and to the total life cycle.

The tool is developed in xls format and contains the following worksheets:

- Index;
- SHC system;
- Conventional system;
- Specific impacts SHC system;
- Specific impacts conventional system;
- Calculation (hidden sheet used to make calculations);
- Total impacts SHC system;
- Total impacts conventional system;
- Impacts comparison;
- Payback indices.

<u>The tool can be used only for academic and research activities.</u>

2.1.2 Working with LCA Method Tool

This chapter describes the LCA Method Tool features and functionalities. In addition, three different examples are illustrated, selected as following:

1. A SHC system located in Palermo (Italy) with a cold backup configuration compared with a conventional system. The corresponding example is available in the LCA Method Tool format with the name "Case study 1";
2. A SHC system located in Palermo (Italy) with a cold backup configuration compared with a conventional system assisted by a grid-connected PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 2";
3. A SHC system located in Palermo (Italy) with a cold backup configuration compared with a conventional system assisted by a stand-alone PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 3";
4. A SHC system located in Zurich (Switzerland) with a cold backup configuration compared with a conventional system assisted by a stand-alone PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 4".

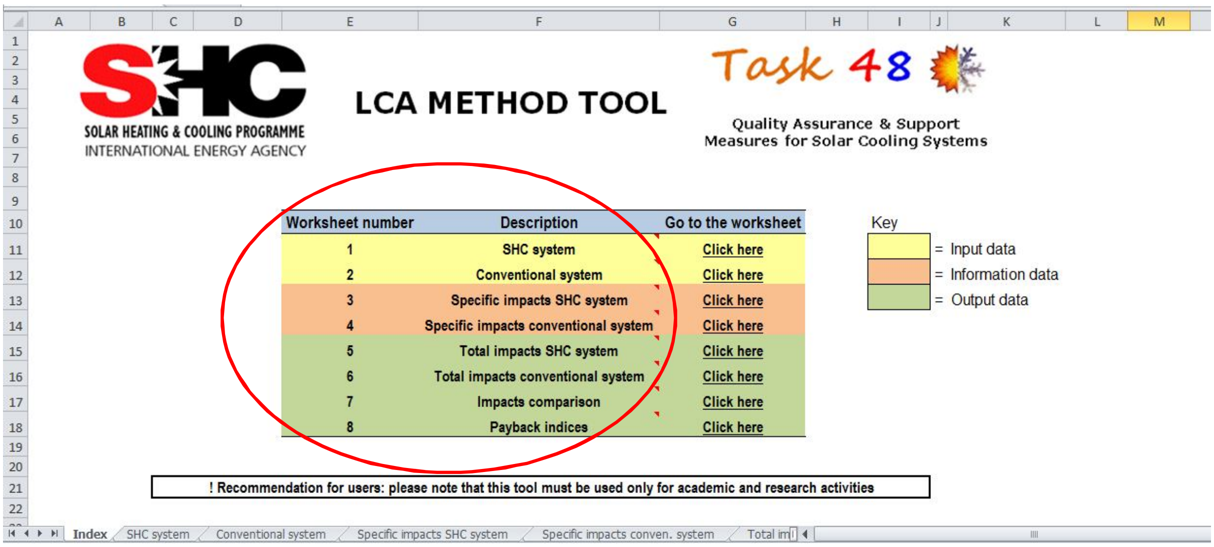
2.1.2.1 LCA Method Tool: description of the worksheets

Index

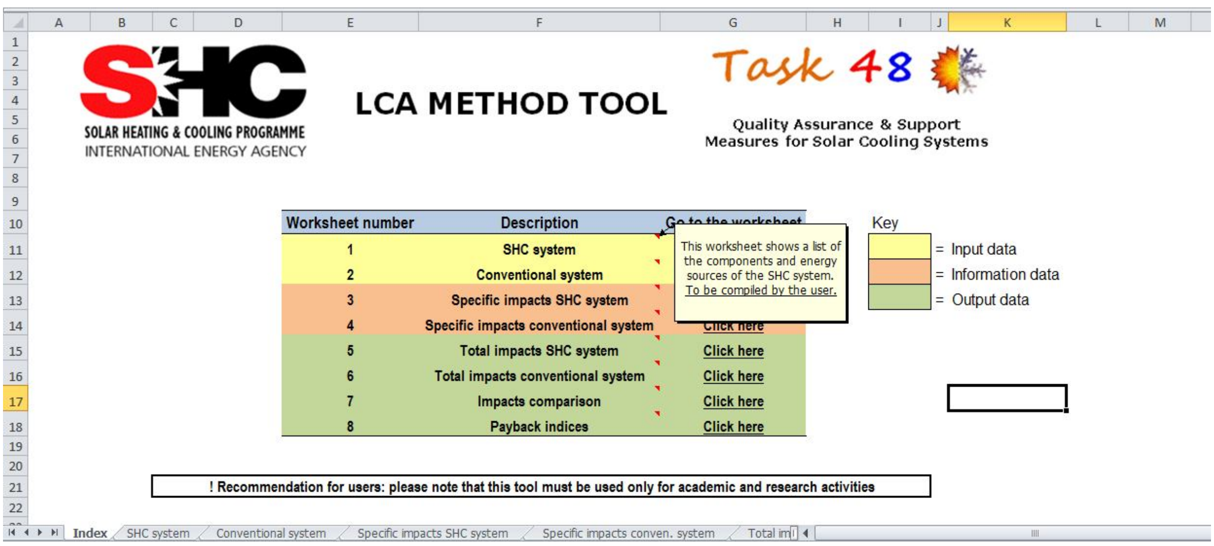
It shows a list of the worksheets contained in the xls file. There are three typologies of worksheets: 1) worksheets that contain input data (yellow color); 2) worksheets that contain information data (orange color); 3) worksheets that contain output data (green color).

For each worksheet, the following information is given:

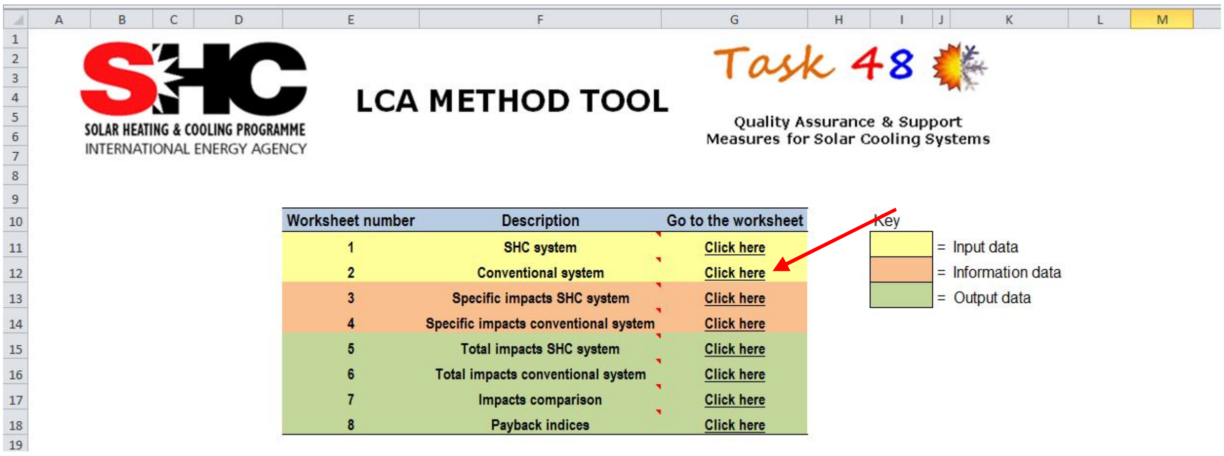
- Worksheet number: it indicates the position of the worksheet in the xls file (the calculation worksheet is not included in this list being a hidden worksheet);
- Description: it indicates the content of the worksheet.



By clicking on the symbol, it is possible to display a brief description of each worksheet.

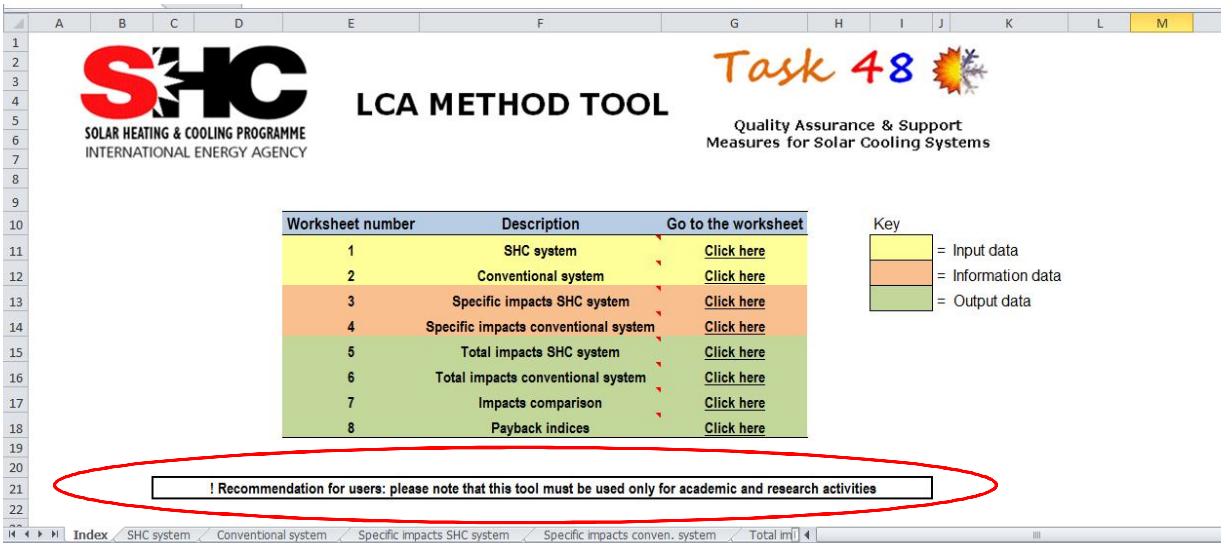


Using the "Click here" button, it is possible to display the corresponding worksheet.



Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

It is important to note that a recommendation for users is provided. It indicates that the LCA Method Tool can be used only for academic and research activities and cannot be applied for professional purposes.

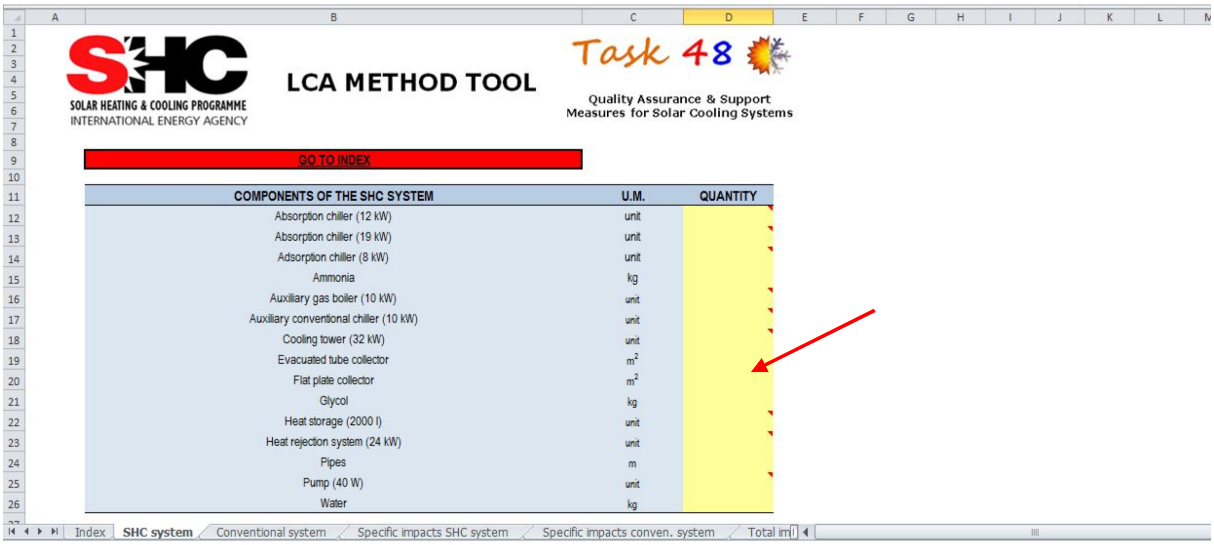


Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

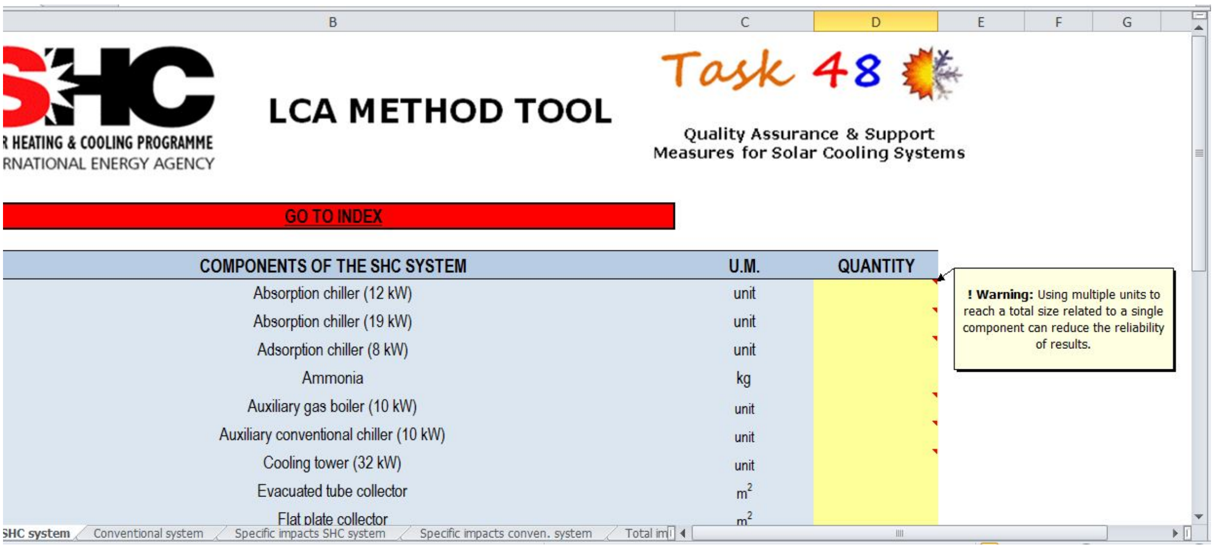
Worksheet No.1: SHC system

This worksheet contains input data and is constituted by three tables.

The first table is called "Components of the SHC system"; it shows a list of components that usually are part of a SHC system. For each component, the corresponding unit of measure is indicated. In the column "Quantity" the user have to insert input data on components that constitute the system to be examined.



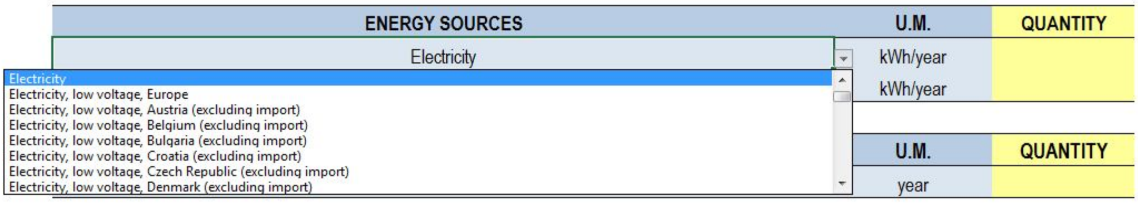
For components that have as unit of measure “unit”, the following warning message is shown in the “quantity” text box: “! Warning: Using multiple units to reach a total size related to a single component can reduce the reliability of results”. For example, let suppose that the examined system includes a 240 W pump and that the tool contains the impacts for a 40 W pump; in this case the user can only insert the value “6” in the row that correspond to the component “pump (40 W)” (240 W = 6 pumps * 40 W). This calculation is not exact; in fact to assume that the impact of a 240 W pump is the same that six 40 W pumps cannot true. Then, this assumption can introduce uncertainty in the analysis and reduce the reliability of the results.



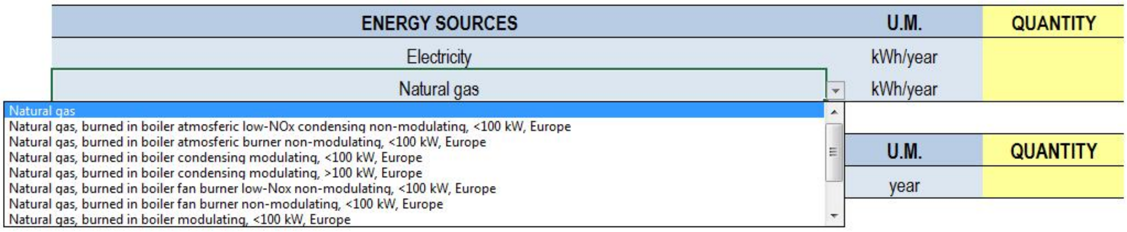
The second table is called “Energy sources”; it shows the two energy sources usually consumed during the operation step of a SHC system: electricity and natural gas. For each energy source, the corresponding unit of measure is indicated. In the column “Quantity” the user have to insert input data related on the yearly electricity and natural gas consumed by the system.

ENERGY SOURCES	U.M.	QUANTITY
Electricity	kWh/year	
Natural gas	kWh/year	

By clicking on “Electricity”, a drop-down menu is shown. It contains the reference to electricity mix for 25 localities (23 European countries, Switzerland and Europe), including and excluding import.



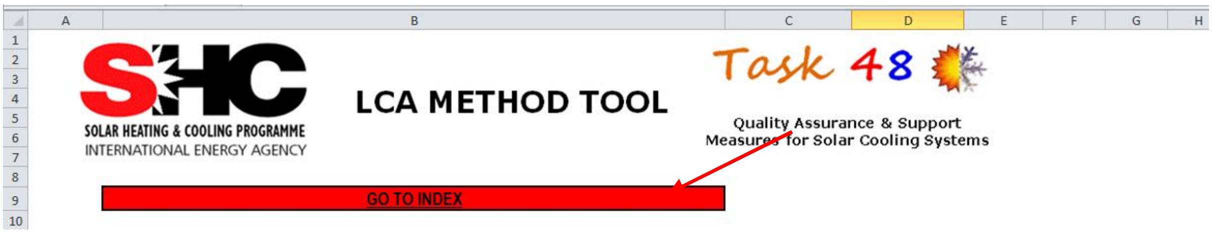
By clicking on “Natural gas”, a drop-down menu is shown. It contains the reference to natural gas burned in 10 different systems in the European context.



The third table is called “Other information”. In the column “Quantity” the user have to insert input data related on the useful life of the system. This information will be used to calculate the impacts caused by the system during the operation step and the payback indices.

	OTHER INFORMATION	U.M.	QUANTITY
32	OTHER INFORMATION	U.M.	QUANTITY
33	Useful life of the system	year	

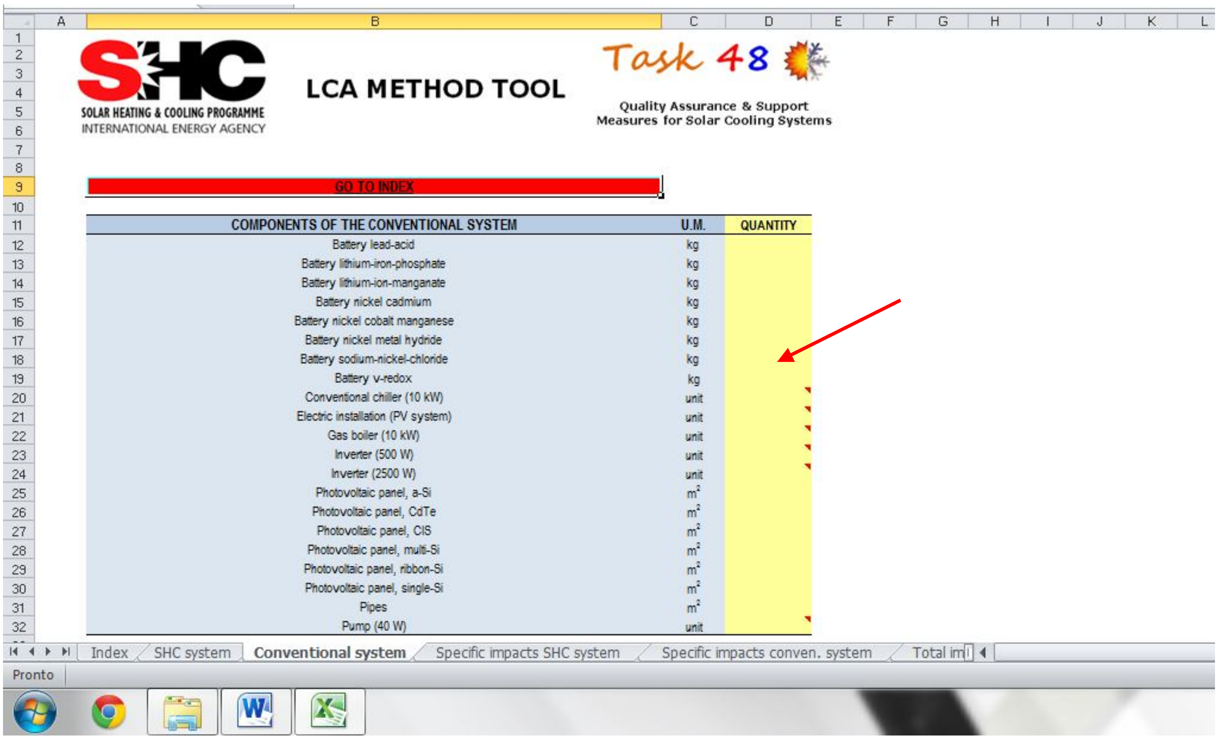
By clicking on the button “Go to index” the user can visualize the worksheet “index”.



Worksheet No.2: Conventional system

This worksheet contains input data and is constituted by three tables.

The first table is called "Components of the conventional system"; it shows a list of components that usually are part of a conventional system, eventually equipped with a photovoltaic system. For each component, the corresponding unit of measure is indicated. In the column "Quantity" the user have to insert input data on the components that constitute the system to be examined.

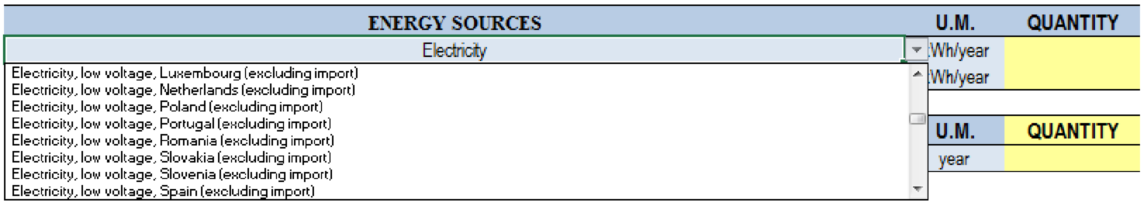


For components that have as unit of measure "unit", the following warning message is shown in the "quantity" text box: "! Warning: Using multiple units to reach a total size related to a single component can reduce the reliability of results" (see previous chapter).

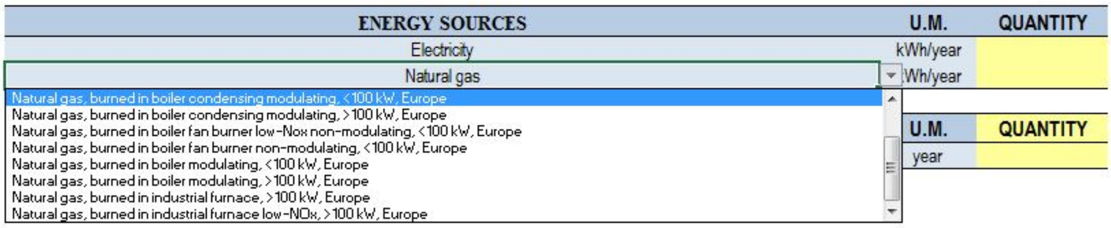
The second table is called "Energy sources"; it shows the two energy sources usually consumed during the operation step of a conventional system: electricity and natural gas. For each energy source, the corresponding unit of measure is indicated. In the column “Quantity” the user have to insert input data related on the yearly electricity and natural gas consumed by the system.

ENERGY SOURCES	U.M.	QUANTITY
Electricity	kWh/year	
Natural gas	kWh/year	

By clicking on “Electricity”, a drop-down menu is shown. It contains the reference to electricity mix for 25 localities (23 European countries, Switzerland and Europe), including and excluding import.



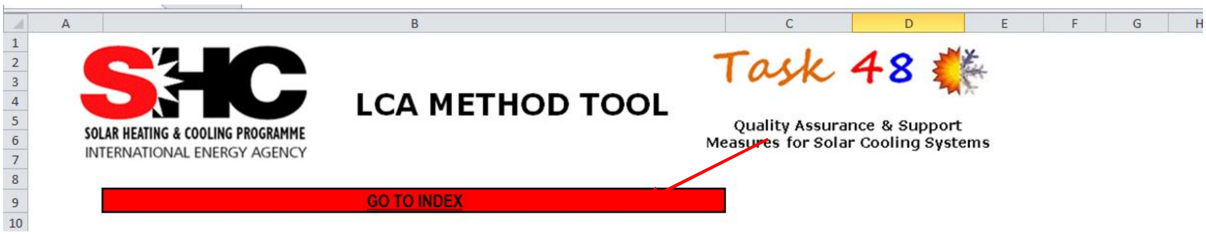
By clicking on “Natural gas”, a drop-down menu is shown. It contains the reference to natural gas burned in 10 different systems in the European context.



The third table is called “Other information”. In the column “Quantity” the user have to insert input data related on the useful life of the system. This information will be used to calculate the impacts caused by the system during the operation step.

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	

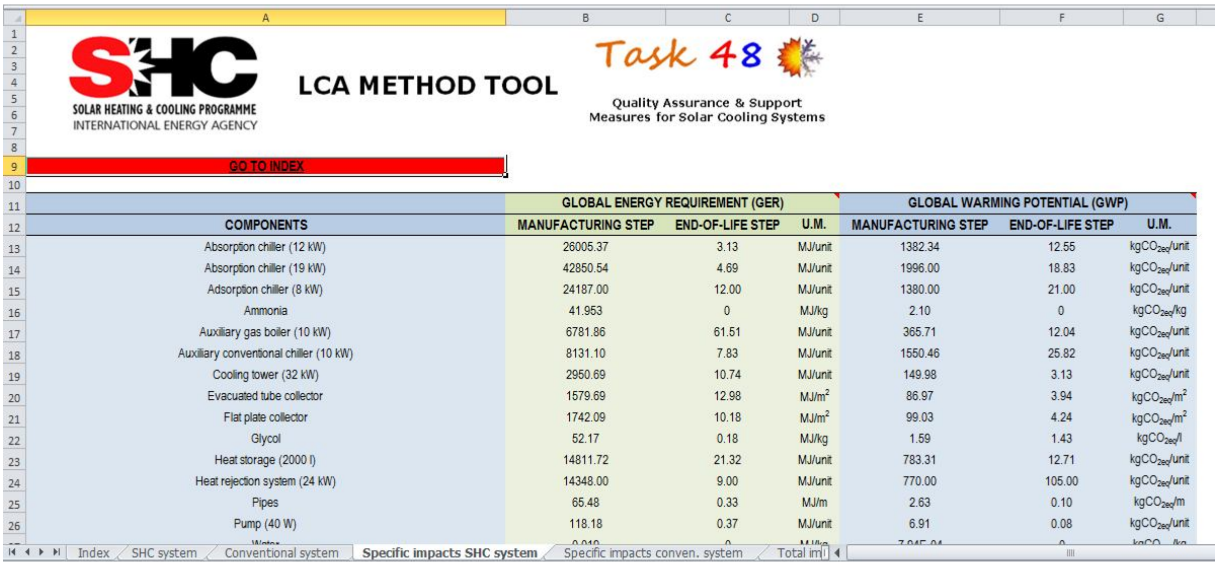
By clicking on the button “Go to index”, the user can visualize the worksheet “index”.



Worksheet No.3: Specific impact SHC system

This worksheet contains two tables.

The first table is called "Components"; for each component of the SHC system it shows the specific impacts (Global Energy Requirement and Global Warming Potential) for the manufacturing and end-of-life steps. For each impact the corresponding unit of measure is indicated.



	GLOBAL ENERGY REQUIREMENT (GER)			GLOBAL WARMING POTENTIAL (GWP)		
COMPONENTS	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.
Absorption chiller (12 kW)	26005.37	3.13	MJ/unit	1382.34	12.55	$kgCO_{2eq}$/unit
Absorption chiller (19 kW)	42850.54	4.69	MJ/unit	1996.00	18.83	$kgCO_{2eq}$/unit
Adsorption chiller (8 kW)	24187.00	12.00	MJ/unit	1380.00	21.00	$kgCO_{2eq}$/unit
Ammonia	41.953	0	MJ/kg	2.10	0	$kgCO_{2eq}$/kg
Auxiliary gas boiler (10 kW)	6781.86	61.51	MJ/unit	365.71	12.04	$kgCO_{2eq}$/unit
Auxiliary conventional chiller (10 kW)	8131.10	7.83	MJ/unit	1550.46	25.82	$kgCO_{2eq}$/unit
Cooling tower (32 kW)	2950.69	10.74	MJ/unit	149.98	3.13	$kgCO_{2eq}$/unit
Evacuated tube collector	1579.69	12.98	MJ/m^2	86.97	3.94	$kgCO_{2eq}/m^2$
Flat plate collector	1742.09	10.18	MJ/m^2	99.03	4.24	$kgCO_{2eq}/m^2$
Glycol	52.17	0.18	MJ/kg	1.59	1.43	$kgCO_{2eq}$/l
Heat storage (2000 l)	14811.72	21.32	MJ/unit	783.31	12.71	$kgCO_{2eq}$/unit
Heat rejection system (24 kW)	14348.00	9.00	MJ/unit	770.00	105.00	$kgCO_{2eq}$/unit
Pipes	65.48	0.33	MJ/m	2.63	0.10	$kgCO_{2eq}$/m
Pump (40 W)	118.18	0.37	MJ/unit	6.91	0.08	$kgCO_{2eq}$/unit

The second table is called "Energy sources"; for each energy source used in the operation step of the SHC system it shows the life cycle specific impacts (Global Energy Requirement and Global Warming Potential). For each impact the corresponding unit of measure is indicated.

ENERGY SOURCES	GLOBAL ENERGY REQUIREMENT (GER) QUANTITY	GLOBAL ENERGY REQUIREMENT (GER) U.M.	GLOBAL WARMING POTENTIAL (GWP) QUANTITY	GLOBAL WARMING POTENTIAL (GWP) U.M.
Electricity				
Electricity, low voltage, Europe	12.29	MJ/kWh	0.564	kg CO_{2eq}/kWh
Electricity, low voltage, Austria (excluding import)	8.07	MJ/kWh	0.358	kg CO_{2eq}/kWh
Electricity, low voltage, Belgium (excluding import)	12.51	MJ/kWh	0.364	kg CO_{2eq}/kWh
Electricity, low voltage, Bulgaria (excluding import)	15.52	MJ/kWh	0.789	kg CO_{2eq}/kWh
Electricity, low voltage, Croatia (excluding import)	10.84	MJ/kWh	0.425	kg CO_{2eq}/kWh
Electricity, low voltage, Czech Republic (excluding import)	13.19	MJ/kWh	0.885	kg CO_{2eq}/kWh
Electricity, low voltage, Denmark (excluding import)	10.74	MJ/kWh	0.698	kg CO_{2eq}/kWh
Electricity, low voltage, Finland (excluding import)	12.49	MJ/kWh	0.438	kg CO_{2eq}/kWh
Electricity, low voltage, France (excluding import)	13.63	MJ/kWh	0.105	kg CO_{2eq}/kWh
Electricity, low voltage, Germany (excluding import)	12.66	MJ/kWh	0.748	kg CO_{2eq}/kWh
Electricity, low voltage, Greece (excluding import)	18.66	MJ/kWh	1.18	kg CO_{2eq}/kWh
Electricity, low voltage, Hungary (excluding import)	17.05	MJ/kWh	0.835	kg CO_{2eq}/kWh
Electricity, low voltage, Ireland (excluding import)	13.06	MJ/kWh	0.902	kg CO_{2eq}/kWh
Electricity, low voltage, Italy (excluding import)	10.71	MJ/kWh	0.719	kg CO_{2eq}/kWh
Electricity, low voltage, Luxembourg (excluding import)	10.82	MJ/kWh	0.603	kg CO_{2eq}/kWh
Electricity, low voltage, Netherlands (excluding import)	11.85	MJ/kWh	0.743	kg CO_{2eq}/kWh
Electricity, low voltage, Poland (excluding import)	16.05	MJ/kWh	1.37	kg CO_{2eq}/kWh
Electricity, low voltage, Portugal (excluding import)	11.52	MJ/kWh	0.713	kg CO_{2eq}/kWh

Index | SHC system | Conventional system | **Specific impacts SHC system** | Specific impacts conven. system | Total im

By clicking on the buttons "Global Energy Requirement" and "Global Warming Potential" the methods used to calculate the impact are shown.

Task 48

OOL

Quality Assurance & Support
Measures for Solar Cooling Systems

GER is calculated using the impact assessment method "Cumulative Energy Demand".

	GLOBAL ENERGY REQUIREMENT (GER)			ARMING POTENTIAL (GWP)		
	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.	[illegible]	END-OF-LIFE STEP	U.M.
13	26005.37	3.13	MJ/unit	1382.34	12.55	$kgCO_{2eq}$/unit
14	42850.54	4.69	MJ/unit	1996.00	18.83	$kgCO_{2eq}$/unit
15	24187.00	12.00	MJ/unit	1380.00	21.00	$kgCO_{2eq}$/unit
16	41.953	0	MJ/kg	2.10	0	$kgCO_{2eq}$/kg
17	6781.86	61.51	MJ/unit	365.71	12.04	$kgCO_{2eq}$/unit
18	8131.10	7.83	MJ/unit	1550.46	25.82	$kgCO_{2eq}$/unit

Index | SHC system | Conventional system | **Specific impacts SHC system** | Specific impacts conven. system | Total im

	C	D	E	F	G
23	21.32	MJ/unit	783.31	12.71	$kgCO_{2eq}$/unit
24	9.00	MJ/unit	770.00	105.00	$kgCO_{2eq}$/unit
25	0.33	MJ/m	2.63	0.10	$kgCO_{2eq}$/m
26	0.37	MJ/unit	6.91	0.08	$kgCO_{2eq}$/unit
27	0	MJ/kg	7.94E-04	0	$kgCO_{2eq}$/kg
28					
29	REQUIREMENT (GER)		GLOBAL WARMING POTENTIAL (GWP)		
30	U.M.		QUANTITY	U.M.	
31					
32	MJ/kWh		0.564	kg CO_{2eq}/kWh	
33	MJ/kWh		0.358	kg CO_{2eq}/kWh	
34	MJ/kWh		0.364	kg CO_{2eq}/kWh	
35	MJ/kWh		0.789	kg CO_{2eq}/kWh	
36	MJ/kWh		0.425	kg CO_{2eq}/kWh	
37	MJ/kWh		0.885	kg CO_{2eq}/kWh	

GWP is calculated using the impact assessment method "IPCC 2013 GWP 100 year".

Index | SHC system | Conventional system | Specific impacts SHC system | Specific impacts conven. system | Total im

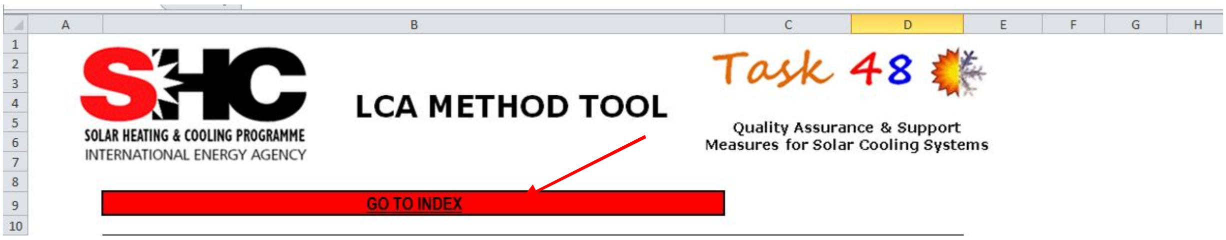
Data sources of energy and environmental impacts are following indicated:

- The impacts of absorption chiller (12 kW), adsorption chiller (8 kW), cooling tower (32 kW), and heat rejection system are referred to Beccali, M., Cellura, M., Ardente, F., Longo, S., Nocke, B., Finocchiaro, P., Kleijer, A., Hildbrand, C., Bony, J., 2010. Life Cycle Assessment of Solar Cooling Systems – A technical report of subtask D Subtask Activity D3, Task 38 Solar Air-Conditioning and Refrigeration, International Energy Agency. Solar Heating & Cooling Programme.

- The impacts of absorption chiller (19 kW) are referred to: Beccali, M., Cellura, M., Longo, S., 2014, Technical report of Subtask A2-B3, Task 48 Quality Assurance & Support Measures for Solar Cooling, International Energy Agency. Solar Heating & Cooling Programme.

- The impacts of electricity, natural gas, ammonia, auxiliary gas boiler, auxiliary conventional chiller, evacuated tube collectors, flat plate collectors, glycol, heat storage (2000 l), pipes, pump (40 W), water are referred to the Ecoinvent database.

By clicking on the button "Go to index" the user can visualize the worksheet "index".



Worksheet No.4: Specific impact conventional system

This worksheet contains two tables.

The first table is called "Components"; for each component of the conventional system it shows the specific impacts (Global Energy Requirement and Global Warming Potential) for the manufacturing and end-of-life steps. For each impact the corresponding unit of measure is indicated.

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

LCA METHOD TOOL

Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

GO TO INDEX

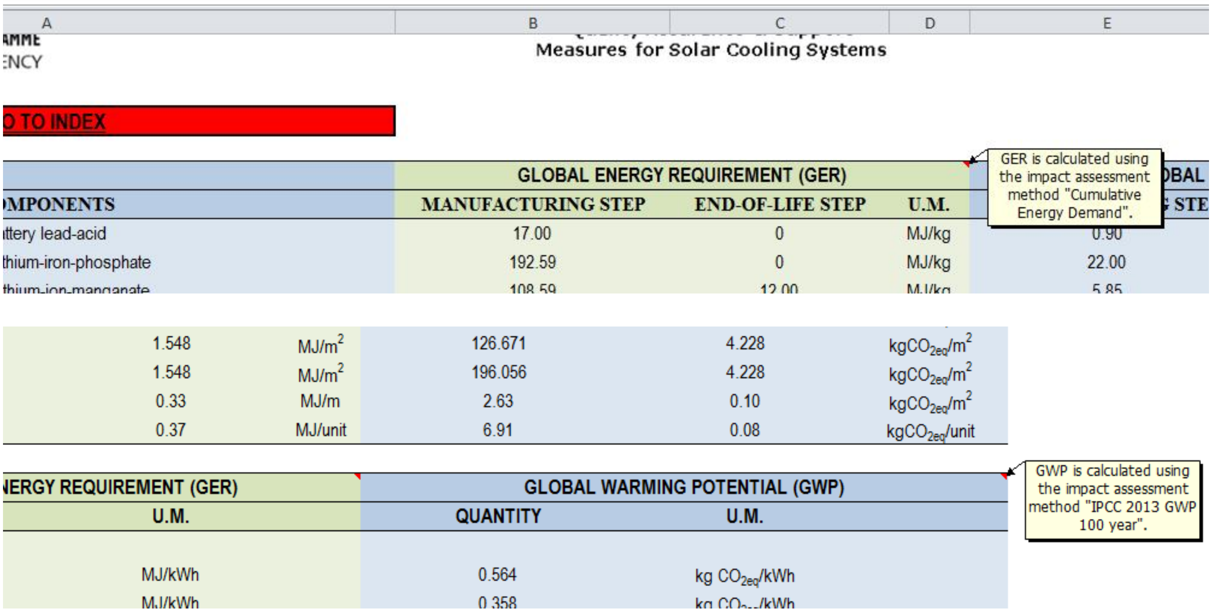
	GLOBAL ENERGY REQUIREMENT (GER)			GLOBAL WARMING POTENTIAL (GWP)		
COMPONENTS	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.
Battery lead-acid	17.00	0	MJ/kg	0.90	0	$kgCO_{2eq}/kg$
Battery lithium-iron-phosphate	192.59	0	MJ/kg	22.00	0	$kgCO_{2eq}/kg$
Battery lithium-ion-manganate	108.59	12.00	MJ/kg	5.85	0.93	$kgCO_{2eq}/kg$
Battery nickel cadmium	37.00	0	MJ/kg	2.1	0	$kgCO_{2eq}/kg$
Battery nickel cobalt manganese	196.78	0	MJ/kg	22.00	0	$kgCO_{2eq}/kg$
Battery nickel metal hydride	226.09	0	MJ/kg	20.00	0	$kgCO_{2eq}/kg$
Battery sodium-nickel-chloride	234.30	11.04	MJ/kg	14.32	0.77	$kgCO_{2eq}/kg$
Battery v-redox	67.79	9.88	MJ/kg	6.80	1.17	$kgCO_{2eq}/unit$
Conventional chiller (10 kW)	8131.10	7.83	MJ/unit	1550.46	25.82	$kgCO_{2eq}/unit$
Electric installation (PV system)	2221.35	11.159	MJ/unit	79.744	60.154	$kgCO_{2eq}/unit$
Gas boiler (10 kW)	6781.86	61.51	MJ/unit	365.71	12.04	$kgCO_{2eq}/unit$
Inverter (500 W)	685.25	1.675	MJ/unit	36.311	1.281	$kgCO_{2eq}/unit$
Inverter (2500 W)	3212.40	3.723	MJ/unit	173.72	1.373	$kgCO_{2eq}/unit$
Photovoltaic panel, a-Si	1181.70	1.548	MJ/m^2	72.961	4.228	$kgCO_{2eq}/m^2$
Photovoltaic panel, CdTe	1515.69	1.548	MJ/m^2	96.281	4.228	$kgCO_{2eq}/m^2$
Photovoltaic panel, CIS	2029.435	1.548	MJ/m^2	121.68	4.228	$kgCO_{2eq}/m^2$
Photovoltaic panel, multi-Si	3060.768	1.548	MJ/m^2	156.667	4.228	$kgCO_{2eq}/m^2$
Photovoltaic panel, ribbon-Si	2414.699	1.548	MJ/m^2	126.671	4.228	$kgCO_{2eq}/m^2$
Photovoltaic panel, single-Si	3854.796	1.548	MJ/m^2	196.056	4.228	$kgCO_{2eq}/m^2$
Pipes	65.48	0.33	MJ/m	2.63	0.10	$kgCO_{2eq}/m^2$
Pump (40 W)	118.18	0.37	MJ/unit	6.91	0.08	$kgCO_{2eq}/unit$

Index | SHC system | Conventional system | Specific impacts SHC system | **Specific impacts conven. system** | Total im

The second table is called "Energy sources"; for each energy source used in the operation step of the conventional system it shows the life-cycle specific impacts (Global Energy Requirement and Global Warming Potential).

Electricity, low voltage, Luxembourg (including import)	12.11	MJ/kWh	0.643	kg CO_{2eq}/kWh
Electricity, low voltage, Netherlands (including import)	11.92	MJ/kWh	0.727	kg CO_{2eq}/kWh
Electricity, low voltage, Poland (including import)	14.18	MJ/kWh	1.20	kg CO_{2eq}/kWh
Electricity, low voltage, Portugal (including import)	11.62	MJ/kWh	0.696	kg CO_{2eq}/kWh
Electricity, low voltage, Romania (including import)	12.50	MJ/kWh	0.810	kg CO_{2eq}/kWh
Electricity, low voltage, Slovakia (including import)	11.93	MJ/kWh	0.506	kg CO_{2eq}/kWh
Electricity, low voltage, Slovenia (including import)	9.95	MJ/kWh	0.487	kg CO_{2eq}/kWh
Electricity, low voltage, Spain (including import)	12.21	MJ/kWh	0.596	kg CO_{2eq}/kWh
Electricity, low voltage, Sweden (including import)	10.66	MJ/kWh	0.102	kg CO_{2eq}/kWh
Electricity, low voltage, Switzerland (including import)	10.98	MJ/kWh	0.149	kg CO_{2eq}/kWh
Electricity, low voltage, United Kingdom (including import)	12.41	MJ/kWh	0.688	kg CO_{2eq}/kWh
Natural gas				
Natural gas, burned in boiler atmosferic low-NOx condensing non-modulating, <100 kW, Europe	4.61	MJ/kWh	0.273	kg CO_{2eq}/kWh
Natural gas, burned in boiler atmosferic burner non-modulating, <100 kW, Europe	4.44	MJ/kWh	0.265	kg CO_{2eq}/kWh
Natural gas, burned in boiler condensing modulating, <100 kW, Europe	4.48	MJ/kWh	0.267	kg CO_{2eq}/kWh
Natural gas, burned in boiler condensing modulating, >100 kW, Europe	4.30	MJ/kWh	0.248	kg CO_{2eq}/kWh
Natural gas, burned in boiler fan burner low-Nox non-modulating, <100 kW, Europe	4.74	MJ/kWh	0.279	kg CO_{2eq}/kWh
Natural gas, burned in boiler fan burner non-modulating, <100 kW, Europe	4.48	MJ/kWh	0.267	kg CO_{2eq}/kWh
Natural gas, burned in boiler modulating, <100 kW, Europe	4.48	MJ/kWh	0.267	kg CO_{2eq}/kWh
Natural gas, burned in boiler modulating, >100 kW, Europe	4.30	MJ/kWh	0.248	kg CO_{2eq}/kWh
Natural gas, burned in industrial furnace, >100 kW, Europe	4.30	MJ/kWh	0.247	kg CO_{2eq}/kWh
Natural gas, burned in industrial furnace low-NOx, >100 kW, Europe	4.44	MJ/kWh	0.254	kg CO_{2eq}/kWh

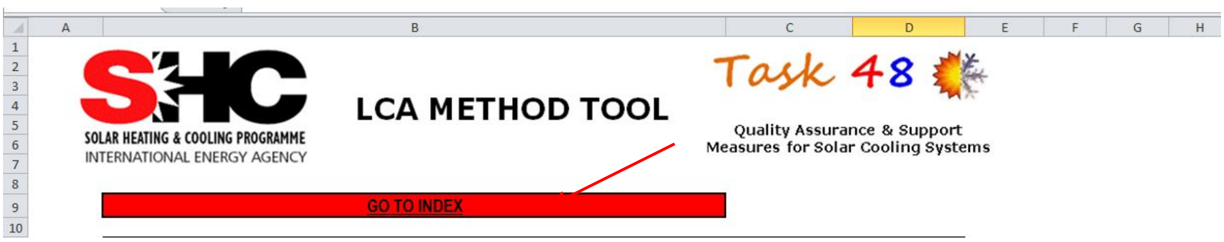
By clicking on the buttons "Global Energy Requirement" and "Global Warming Potential" the methods used to calculate the impact are shown.



Data sources of energy and environmental impacts are following indicated:

- The impacts of batteries are referred to literature studies;
- The impacts of electricity, natural gas, conventional chiller, electric installation, gas boiler, inverter (500 W), inverter (2500 W), photovoltaic panels, pipes, pump (40 W), are referred to the Ecoinvent database.

By clicking on the button "Go to index" the user can visualize the worksheet "index".



Worksheet No.5: Total impacts SHC system

The worksheet shows the results of the balance for the impact categories "Global Energy Requirement" and "Global Warming Potential".

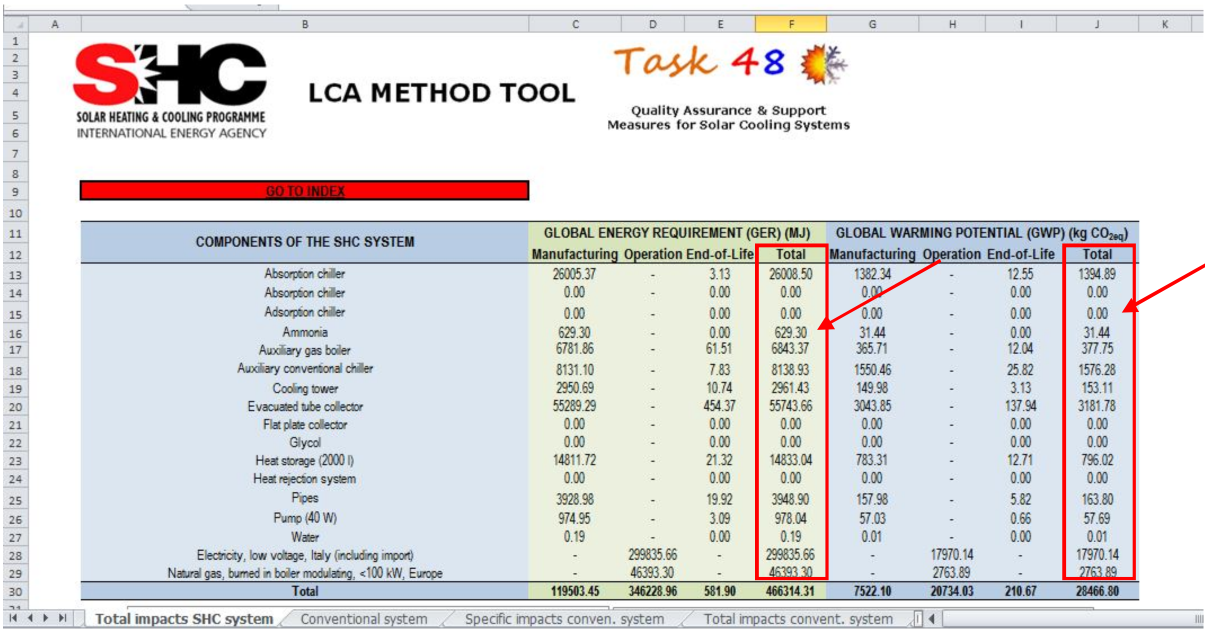
Balances are calculated with the following impact assessment methods:

- Cumulative Energy Demand for the Global Energy Requirement. The unit of measure is MJ;

- IPCC 2013 GWP 100 year for the Global Warming Potential. The unit of measure is kg CO_{2eq}.

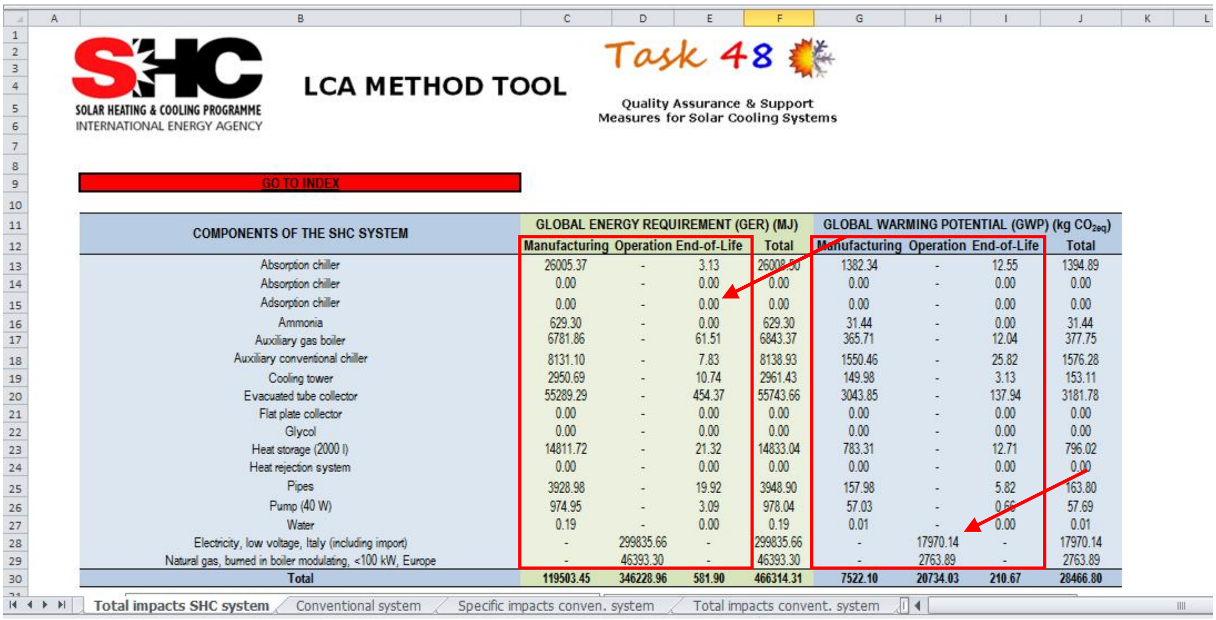
The worksheet shows:

- the total impact for each component/energy source;



COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage (2000 l)	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump (40 W)	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	**119503.45**	**346228.96**	**581.90**	**466314.31**	**7522.10**	**20734.03**	**210.67**	**28466.80**

- the impact for the manufacturing and end-of-life steps of each component of the SHC system and the impact for the operation step;



COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage (2000 l)	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump (40 W)	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	**119503.45**	**346228.96**	**581.90**	**466314.31**	**7522.10**	**20734.03**	**210.67**	**28466.80**

- the total impact for each life-cycle step (manufacturing, operation, end-of-life);

LCA METHOD TOOL

Quality Assurance & Support Measures for Solar Cooling Systems

GO TO INDEX

COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage (2000 l)	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump (40 W)	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80

Total impacts SHC system | Conventional system | Specific impacts conven. system | Total impacts convent. system

- the total impact for the life cycle of the SHC system.

LCA METHOD TOOL

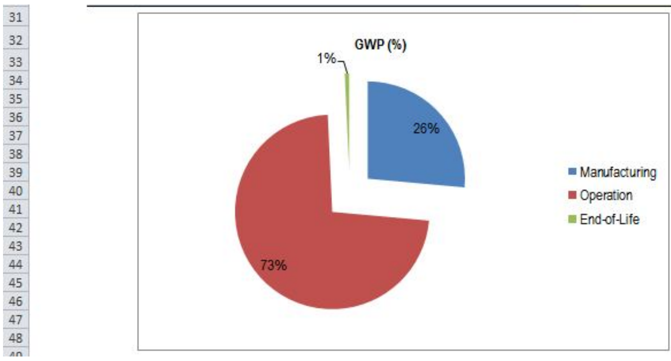
Quality Assurance & Support Measures for Solar Cooling Systems

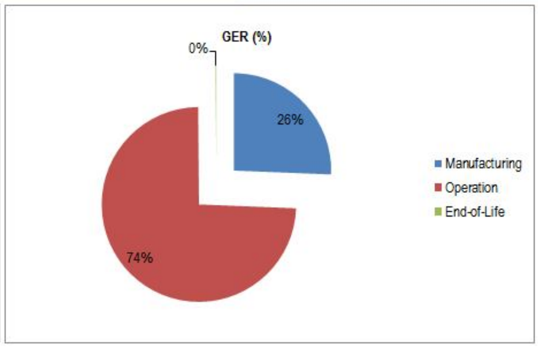
GO TO INDEX

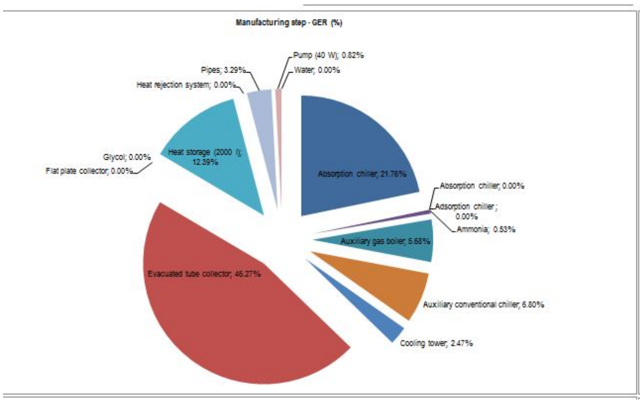
COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage (2000 l)	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump (40 W)	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80

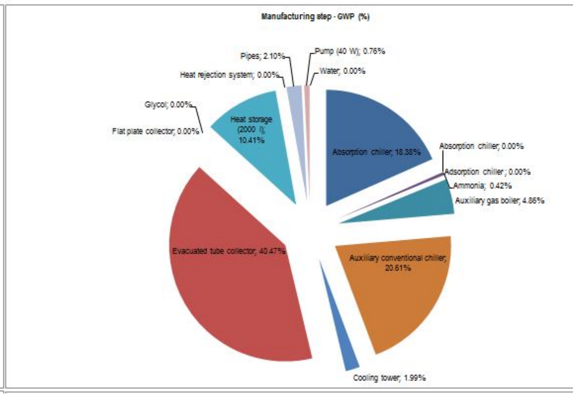
Total impacts SHC system | Conventional system | Specific impacts conven. system | Total impacts convent. system

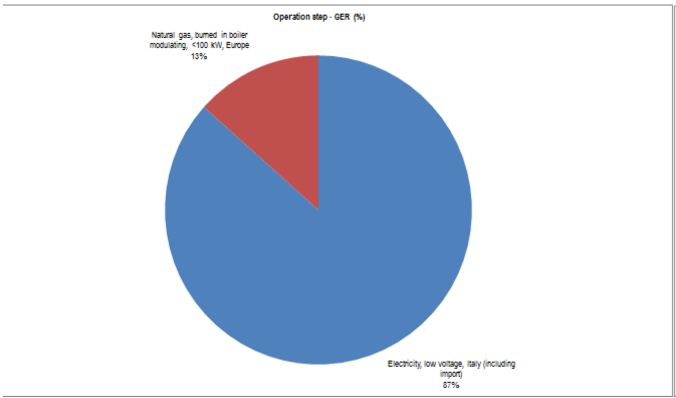
The results for the total life cycle and for each life-cycle step are also showed with graphs.

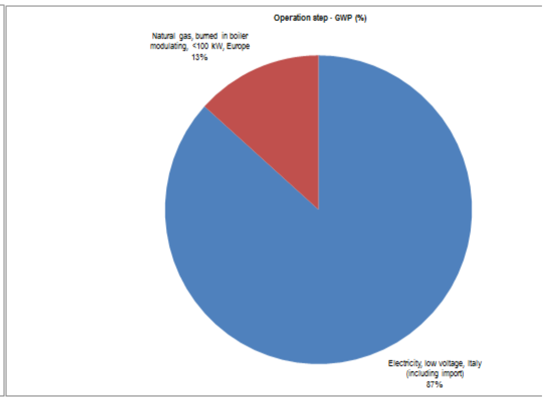

GWP (%)
1%
26%
73%
Manufacturing
Operation
End-of-Life

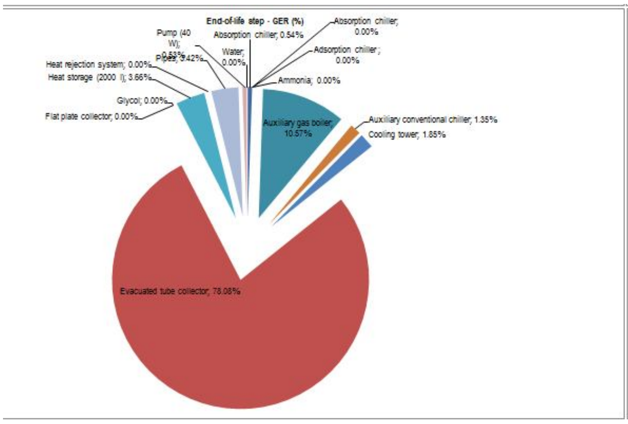

GER (%)
0%
26%
74%
Manufacturing
Operation
End-of-Life

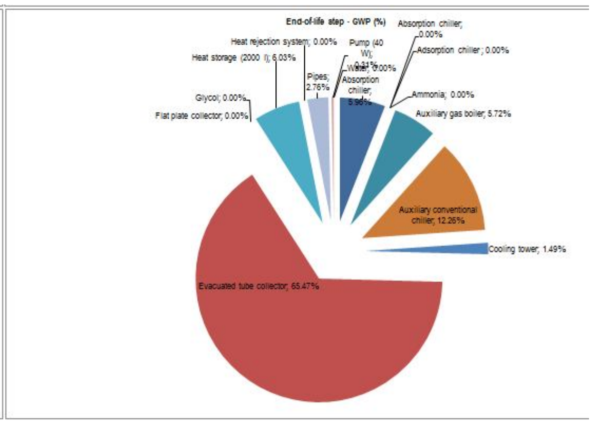

Manufacturing step - GER (%)
Pump (40 W); 0.82%
Water; 0.00%
Pipes; 3.29%
Heat rejection system; 0.00%
Glycol; 0.00%
Flat plate collector; 0.00%
Heat storage (2000 l); 12.39%
Absorption chiller; 21.76%
Absorption chiller; 0.00%
Adsorption chiller ; 0.00%
Ammonia; 0.53%
Auxiliary gas boiler; 5.68%
Auxiliary conventional chiller; 6.80%
Cooling tower; 2.47%
Evacuated tube collector; 46.27%


Manufacturing step - GWP (%)
Pipes; 2.10%
Pump (40 W); 0.76%
Heat rejection system; 0.00%
Water; 0.00%
Glycol; 0.00%
Flat plate collector; 0.00%
Heat storage (2000 l); 10.41%
Absorption chiller; 18.38%
Absorption chiller; 0.00%
Adsorption chiller ; 0.00%
Ammonia; 0.42%
Auxiliary gas boiler; 4.86%
Evacuated tube collector; 40.47%
Auxiliary conventional chiller; 20.61%
Cooling tower; 1.99%

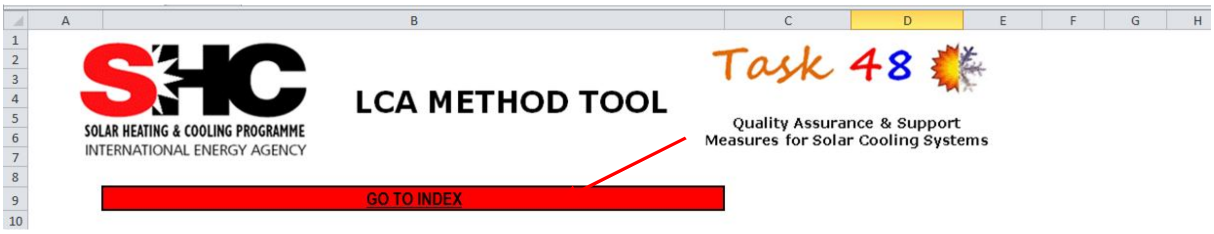

Operation step - GER (%)
Natural gas, burned in boiler modulating, <100 kW, Europe 13%
Electricity, low voltage, Italy (including import) 87%


Operation step - GWP (%)
Natural gas, burned in boiler modulating, <100 kW, Europe 13%
Electricity, low voltage, Italy (including import) 87%





By clicking on the button "Go to index" the user can visualize the worksheet "index".



Worksheet No.6: Total impacts conventional system

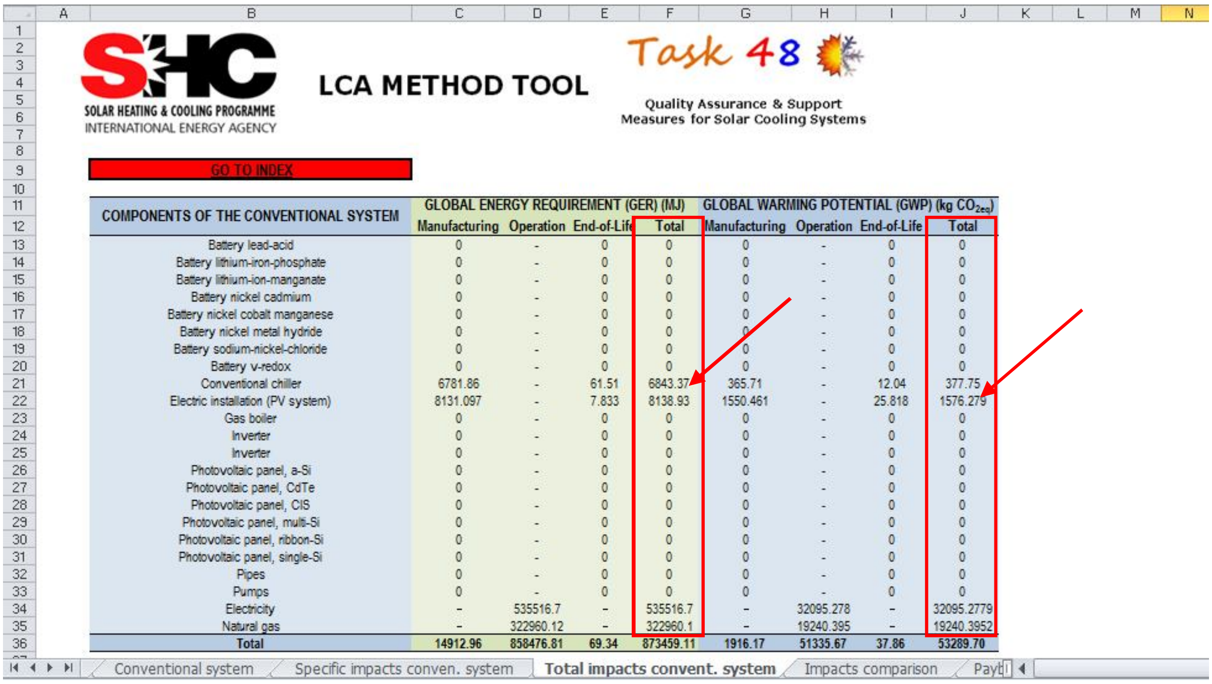
The worksheet shows the results of the balance for the impact categories "Global Energy Requirement" and "Global Warming Potential".

Balances are calculated with the following impact assessment methods:

- Cumulative Energy Demand for the Global Energy Requirement. The unit of measure is MJ;
- IPCC 2013 GWP 100 year for the Global Warming Potential. The unit of measure is kg CO_{2eq}.

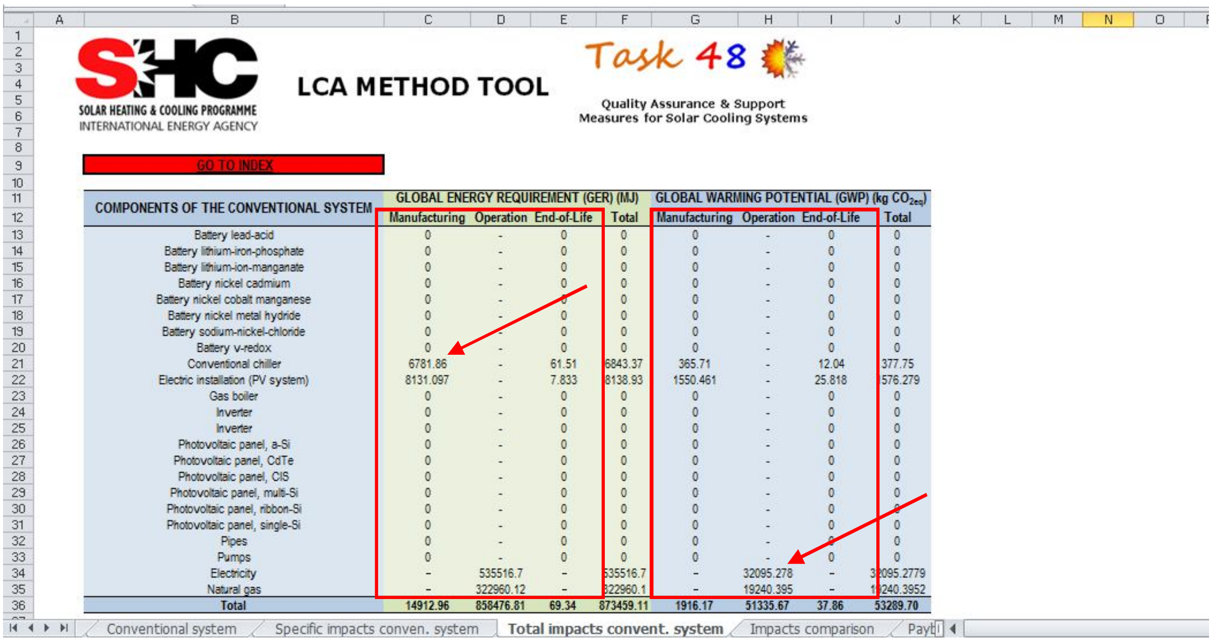
The worksheet shows:

- the total impact for each component/energy source;



COMPONENTS OF THE CONVENTIONAL SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Battery lead-acid	0	-	0	0	0	-	0	0
Battery lithium-iron-phosphate	0	-	0	0	0	-	0	0
Battery lithium-ion-manganate	0	-	0	0	0	-	0	0
Battery nickel cadmium	0	-	0	0	0	-	0	0
Battery nickel cobalt manganese	0	-	0	0	0	-	0	0
Battery nickel metal hydride	0	-	0	0	0	-	0	0
Battery sodium-nickel-chloride	0	-	0	0	0	-	0	0
Battery v-redox	0	-	0	0	0	-	0	0
Conventional chiller	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Electric installation (PV system)	8131.097	-	7.833	8138.93	1550.461	-	25.818	1576.279
Gas boiler	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Photovoltaic panel, a-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, CdTe	0	-	0	0	0	-	0	0
Photovoltaic panel, CIS	0	-	0	0	0	-	0	0
Photovoltaic panel, multi-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, ribbon-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, single-Si	0	-	0	0	0	-	0	0
Pipes	0	-	0	0	0	-	0	0
Pumps	0	-	0	0	0	-	0	0
Electricity	-	535516.7	-	535516.7	-	32095.278	-	32095.2779
Natural gas	-	322960.12	-	322960.1	-	19240.395	-	19240.3952
Total	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70

- the impact for the manufacturing and end-of-life steps of each component of the conventional system and the impact for the operation step;



COMPONENTS OF THE CONVENTIONAL SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Battery lead-acid	0	-	0	0	0	-	0	0
Battery lithium-iron-phosphate	0	-	0	0	0	-	0	0
Battery lithium-ion-manganate	0	-	0	0	0	-	0	0
Battery nickel cadmium	0	-	0	0	0	-	0	0
Battery nickel cobalt manganese	0	-	0	0	0	-	0	0
Battery nickel metal hydride	0	-	0	0	0	-	0	0
Battery sodium-nickel-chloride	0	-	0	0	0	-	0	0
Battery v-redox	0	-	0	0	0	-	0	0
Conventional chiller	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Electric installation (PV system)	8131.097	-	7.833	8138.93	1550.461	-	25.818	1576.279
Gas boiler	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Photovoltaic panel, a-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, CdTe	0	-	0	0	0	-	0	0
Photovoltaic panel, CIS	0	-	0	0	0	-	0	0
Photovoltaic panel, multi-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, ribbon-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, single-Si	0	-	0	0	0	-	0	0
Pipes	0	-	0	0	0	-	0	0
Pumps	0	-	0	0	0	-	0	0
Electricity	-	535516.7	-	535516.7	-	32095.278	-	32095.2779
Natural gas	-	322960.12	-	322960.1	-	19240.395	-	19240.3952
Total	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70

- the total impact for each life-cycle step (manufacturing, operation, end-of-life);

LCA METHOD TOOL

Task 48 Quality Assurance & Support Measures for Solar Cooling Systems

GO TO INDEX

COMPONENTS OF THE CONVENTIONAL SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Battery lead-acid	0	-	0	0	0	-	0	0
Battery lithium-iron-phosphate	0	-	0	0	0	-	0	0
Battery lithium-ion-manganate	0	-	0	0	0	-	0	0
Battery nickel cadmium	0	-	0	0	0	-	0	0
Battery nickel cobalt manganese	0	-	0	0	0	-	0	0
Battery nickel metal hydride	0	-	0	0	0	-	0	0
Battery sodium-nickel-chloride	0	-	0	0	0	-	0	0
Battery v-redox	0	-	0	0	0	-	0	0
Conventional chiller	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Electric installation (PV system)	8131.097	-	7.833	8138.93	1550.461	-	25.818	1576.279
Gas boiler	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Photovoltaic panel, a-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, CdTe	0	-	0	0	0	-	0	0
Photovoltaic panel, CIS	0	-	0	0	0	-	0	0
Photovoltaic panel, multi-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, ribbon-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, single-Si	0	-	0	0	0	-	0	0
Pipes	0	-	0	0	0	-	0	0
Pumps	0	-	0	0	0	-	0	0
Electricity	-	535516.7	-	535516.7	-	32095.278	-	32095.2779
Natural gas	-	322960.12	-	322960.1	-	19240.395	-	19240.3952
Total	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70

Conventional system | Specific impacts conven. system | Total impacts convent. system | Impacts comparison | Payb

- the total impact for the life cycle of the conventional system.

LCA METHOD TOOL

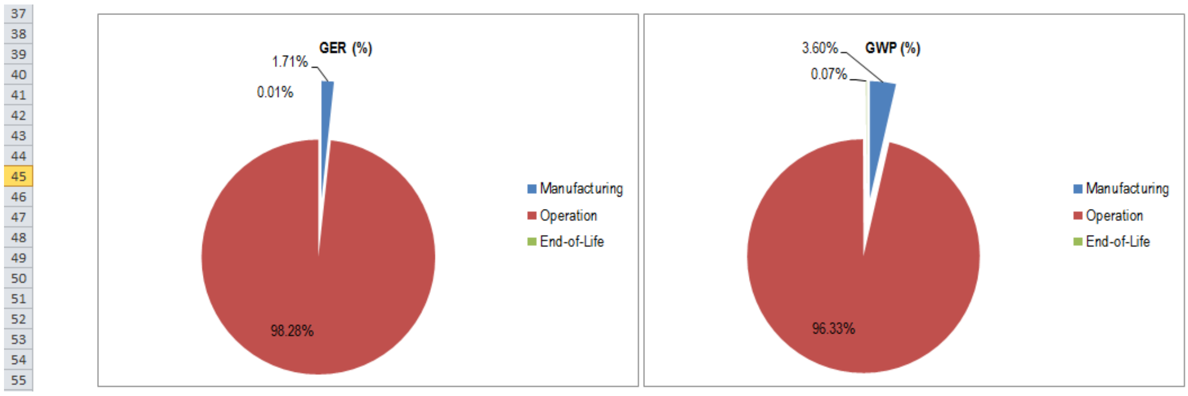
Task 48 Quality Assurance & Support Measures for Solar Cooling Systems

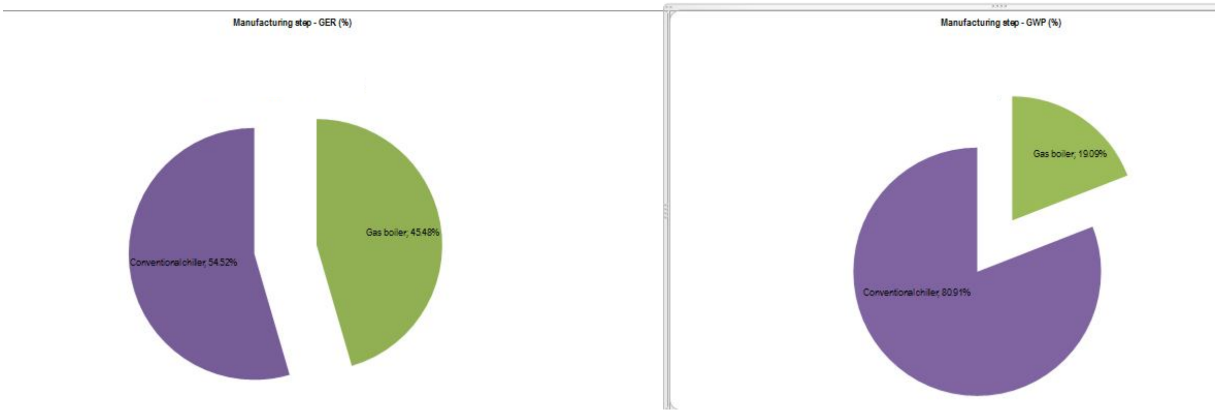
GO TO INDEX

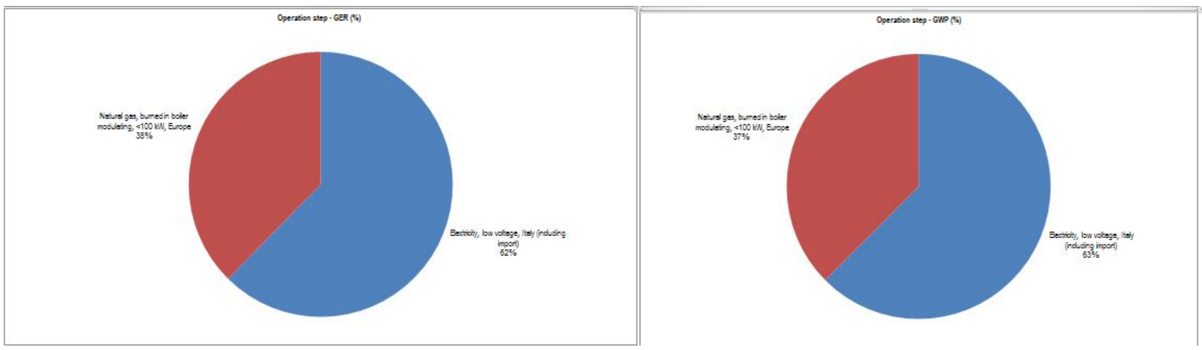
COMPONENTS OF THE CONVENTIONAL SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Battery lead-acid	0	-	0	0	0	-	0	0
Battery lithium-iron-phosphate	0	-	0	0	0	-	0	0
Battery lithium-ion-manganate	0	-	0	0	0	-	0	0
Battery nickel cadmium	0	-	0	0	0	-	0	0
Battery nickel cobalt manganese	0	-	0	0	0	-	0	0
Battery nickel metal hydride	0	-	0	0	0	-	0	0
Battery sodium-nickel-chloride	0	-	0	0	0	-	0	0
Battery v-redox	0	-	0	0	0	-	0	0
Conventional chiller	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Electric installation (PV system)	8131.097	-	7.833	8138.93	1550.461	-	25.818	1576.279
Gas boiler	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Photovoltaic panel, a-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, CdTe	0	-	0	0	0	-	0	0
Photovoltaic panel, CIS	0	-	0	0	0	-	0	0
Photovoltaic panel, multi-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, ribbon-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, single-Si	0	-	0	0	0	-	0	0
Pipes	0	-	0	0	0	-	0	0
Pumps	0	-	0	0	0	-	0	0
Electricity	-	535516.7	-	535516.7	-	32095.278	-	32095.2779
Natural gas	-	322960.12	-	322960.1	-	19240.395	-	19240.3952
Total	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70

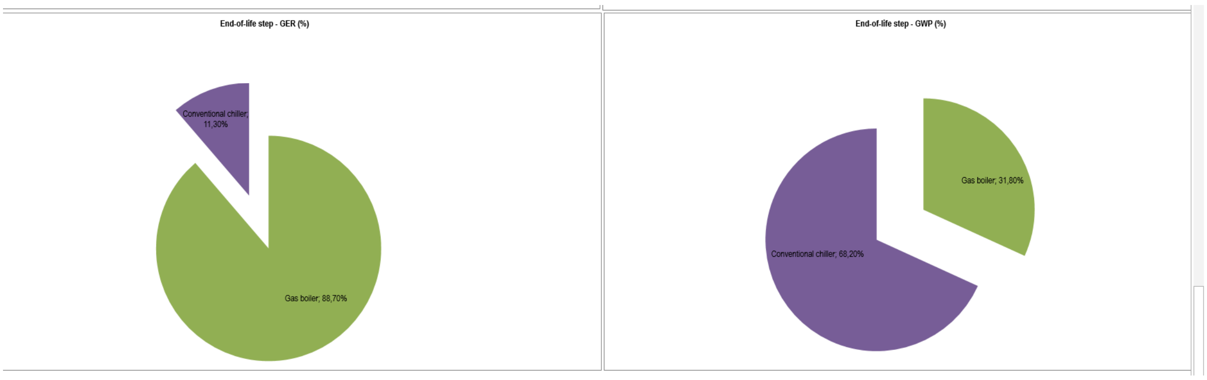
Conventional system | Specific impacts conven. system | Total impacts convent. system | Impacts comparison | Payb

The results for the total life cycle and for each life-cycle step are also showed with graphs.

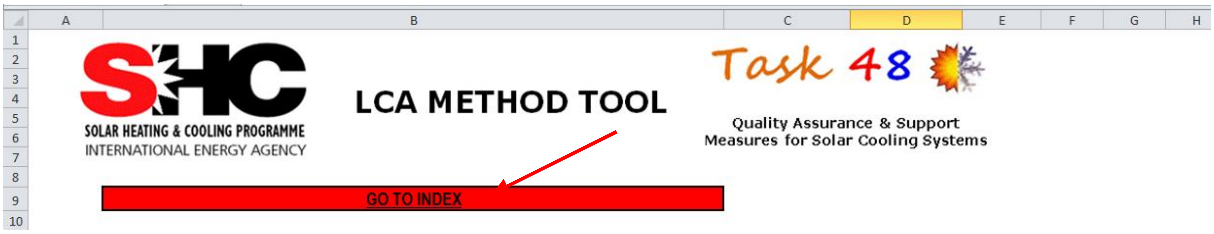

GER (%)
1.71%
0.01%
98.28%
Manufacturing
Operation
End-of-Life
GWP (%)
3.60%
0.07%
96.33%
Manufacturing
Operation
End-of-Life


Manufacturing step - GER (%)
Gas boiler; 45.48%
Conventional chiller; 54.52%
Manufacturing step - GWP (%)
Gas boiler; 19.09%
Conventional chiller; 80.91%


Operation step - GER (%)
Natural gas, burned in boiler modulating, <100 kW, Europe 38%
Electricity, low voltage, Italy (including import) 62%
Operation step - GWP (%)
Natural gas, burned in boiler modulating, <100 kW, Europe 37%
Electricity, low voltage, Italy (including import) 63%


End-of-life step - GER (%)
Conventional chiller; 11,30%
Gas boiler; 88,70%
End-of-life step - GWP (%)
Gas boiler; 31,80%
Conventional chiller; 68,20%

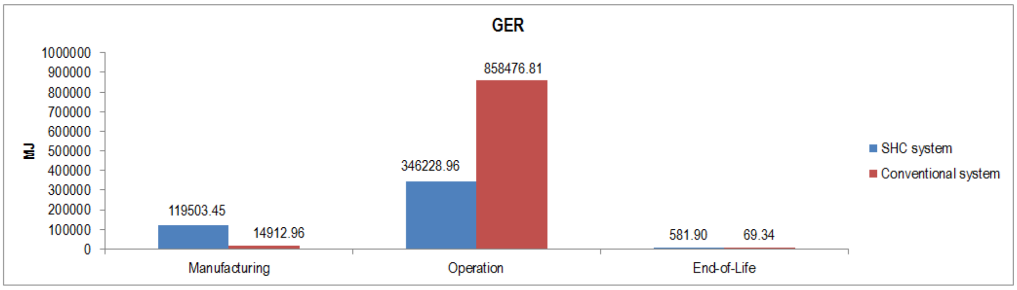
By clicking on the button “Go to index” the user can visualize the worksheet “index”.

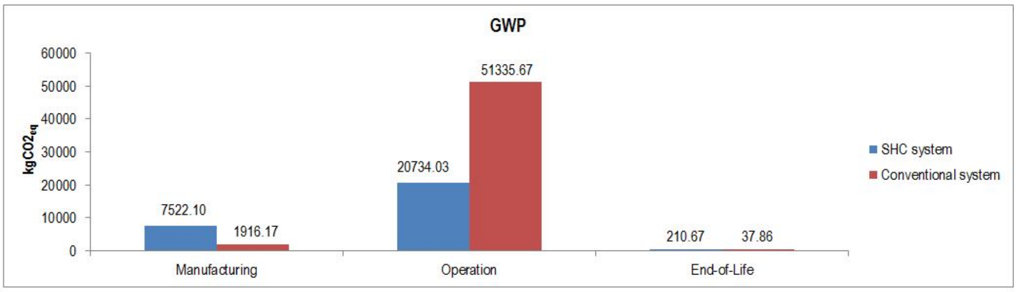


Worksheet No.7: Impacts comparison

This worksheet contains a table and two figures that show a comparison between the impacts of SHC system and those of the conventional one.

System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80
Conventional system	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70





By clicking on the button "Go to index" the user can visualize the worksheet "index".

Worksheet No.8: Payback indices

The use of SHC systems can cause additional environmental impacts in the production and end-of-life steps if compared with conventional systems. However, these impacts are usually balanced by the energy saving and avoidance of emissions during the operation step.

This worksheet allows calculating a set of indices useful to estimate the time needed to offset the energy consumption and environmental impacts due to the life cycle of a SHC system in substitution with a conventional one:

- Energy Payback Time, which is defined as the time during which the SHC system must work to harvest as much primary energy as it requires for its manufacture and disposal. The harvested energy is considered as net of the energy expenditure for system use. The Energy Payback Time can be calculated as:

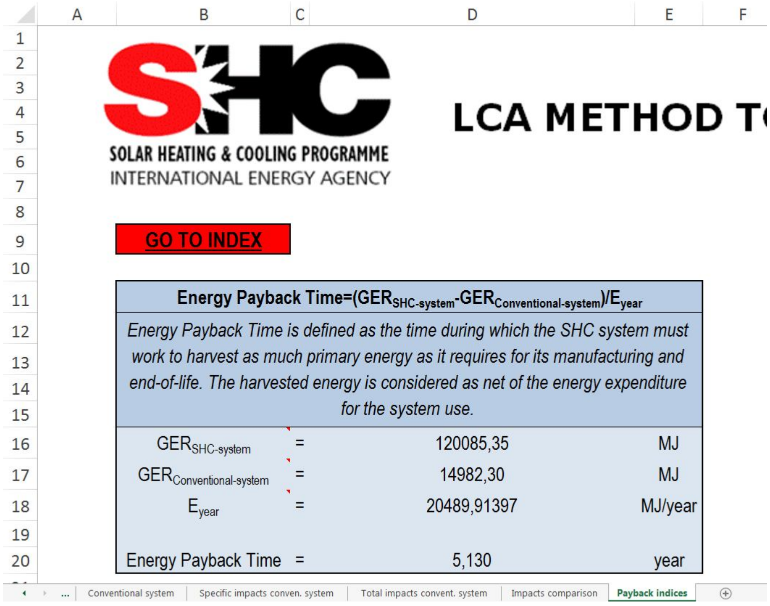
$$\text{Energy Payback Time} = (GER_{SHC\text{-}system} - GER_{Conventional\text{-}system})/E_{year}$$

where:

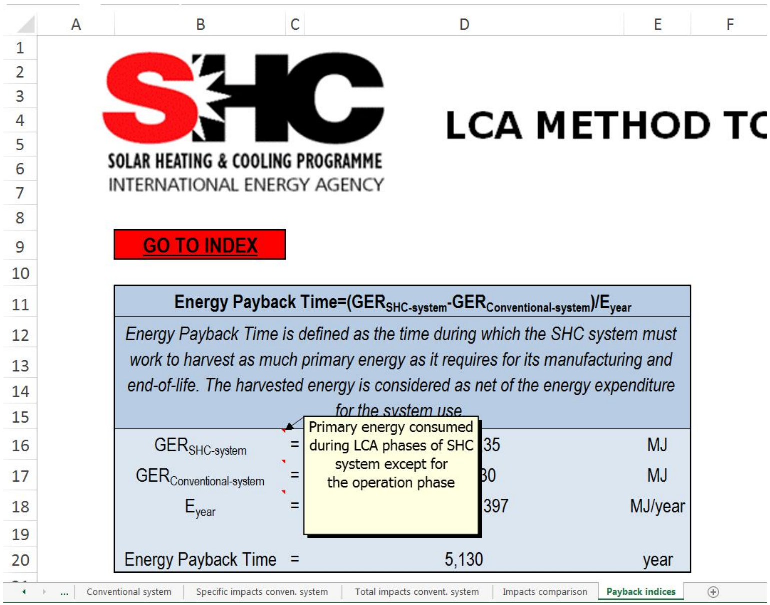
- $GER_{SHC\text{-}system}$ is the primary energy (MJ) consumed by the SHC system during the manufacturing and end-of-life steps (except for the operation step);
- $GER_{Conventional\text{-}system}$ is the primary energy (MJ) consumed by the conventional system during the manufacturing and end-of-life steps (except for the operation step);
- E_{year} is the net yearly primary energy saving due to the use of the SHC system (MJ per year).

The table related on the Energy Payback Time calculation contains the following information:

- Equation that allows the calculation of the index;
- Description of the index;
- The value of each item of equation above cited and the corresponding unit of measure.



By clicking on the symbol it is possible to display a brief description of each item.



- GWP Payback Time, which is defined as the time during which the avoided GWP impact due to the use of the SHC system is equal to GWP impact caused during its manufacturing and end-of-life steps The GWP Payback Time can be calculated as:

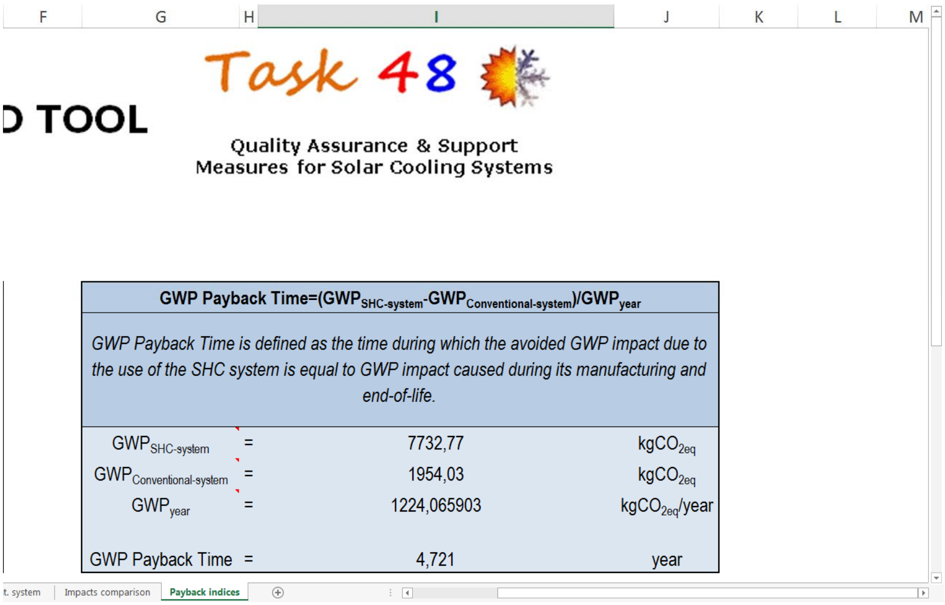
$$\text{GWP Payback Time} = (GWP_{SHC\text{-}system} - GWP_{Conventional\text{-}system}) / GWP_{year}$$

where:

- $GWP_{SHC\text{-}system}$ is the GWP (kg CO_{2eq}) generated by the SHC system during the manufacturing and end-of-life steps (except for the operation step);
- $GWP_{Conventional\text{-}system}$ is the GWP (kg CO_{2eq}) generated by the conventional system during the manufacturing and end-of-life steps (except for the operation step);
- GWP_{year} is the net yearly avoided GWP due to the use of the SHC system (kg CO_{2eq} per year).

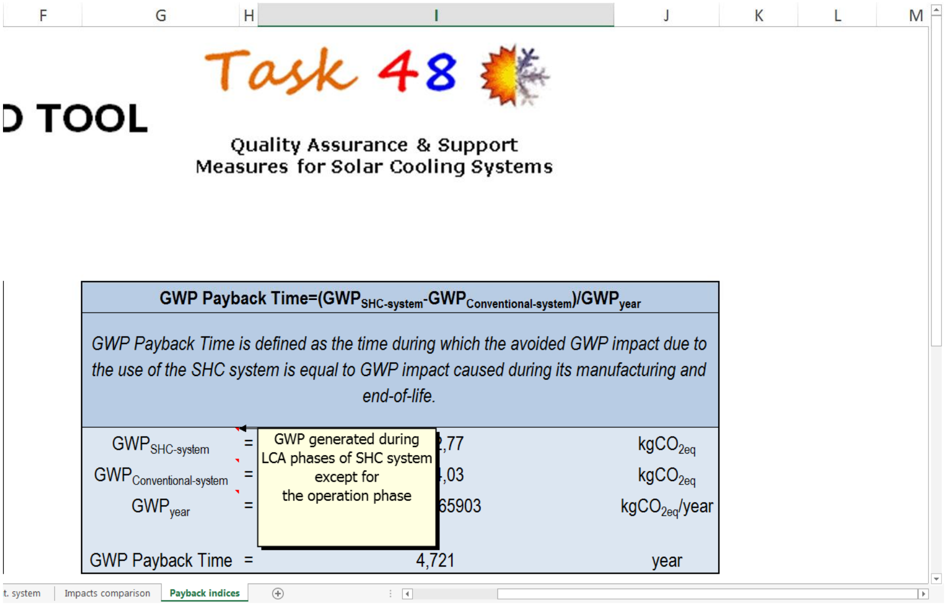
The table related on the GWP Payback Time calculation contains the following information:

- Equation that allows the calculation of the index;
- Description of the index;
- The value of each item of equation above cited and the corresponding unit of measure.



GWP Payback Time=($GWP_{SHC\text{-}system}$-$GWP_{Conventional\text{-}system}$)/$GWP_{year}$			
GWP Payback Time is defined as the time during which the avoided GWP impact due to the use of the SHC system is equal to GWP impact caused during its manufacturing and end-of-life.			
$GWP_{SHC\text{-}system}$	=	7732,77	$kgCO_{2eq}$
$GWP_{Conventional\text{-}system}$	=	1954,03	$kgCO_{2eq}$
GWP_{year}	=	1224,065903	$kgCO_{2eq}$/year
GWP Payback Time	=	4,721	year

By clicking on the ◥ symbol it is possible to display a brief description of each item.



- Energy Return Ratio, which represents how many times the primary energy saving overcomes the value of Global Energy Requirement caused by the SHC system. The Energy Return Ratio can be calculated as:

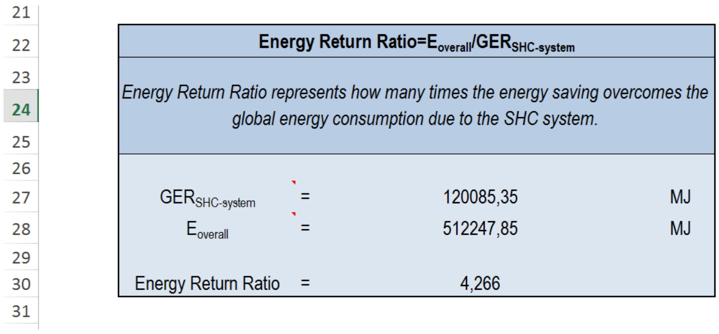
$$\text{Energy Return Ratio} = E_{overall} / GER_{SHC\text{-}system}$$

where:

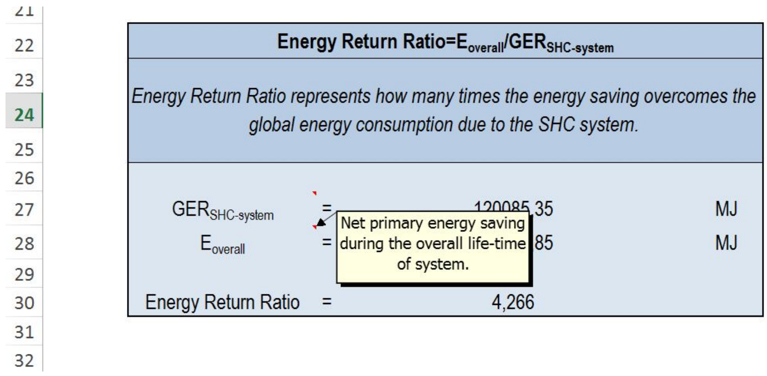
- $E_{Overall}$ is the net primary energy saving during the overall lifetime of the SHC system (MJ). This index is particularly significant because it considers both the Global Energy Requirement and the primary energy saved during the overall useful life of the SHC system; it provides a global view of the energy benefits related to the use of the examined technology;
- $GER_{SHC\text{-}system}$ is the primary energy (MJ) consumed by the SHC system during the manufacturing and end-of-life steps (except for the operation step).

The table related on the Energy Return Ratio calculation contains the following information:

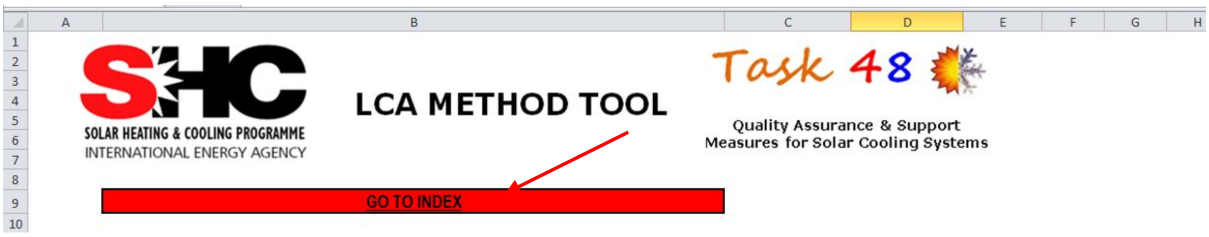
- Equation that allows the calculation of the index;
- Description of the index;
- The value of each item of equation above cited and the corresponding unit of measure.



By clicking on the symbol it is possible to display a brief description of each item.



By clicking on the button “Go to index” the user can visualize the worksheet “index”.



2.1.2.2 Example 1: SHC system with a cold backup, installed in Italy, in substitution of a conventional system

This example describes the application of the LCA Method Tool to carry out a LCA of a SHC system that works with a cold backup configuration, installed in Italy, in substitution of a conventional system. The corresponding example is available in the LCA Method Tool format with the name "Case study 1".

There are four basic steps in this modeling exercise:

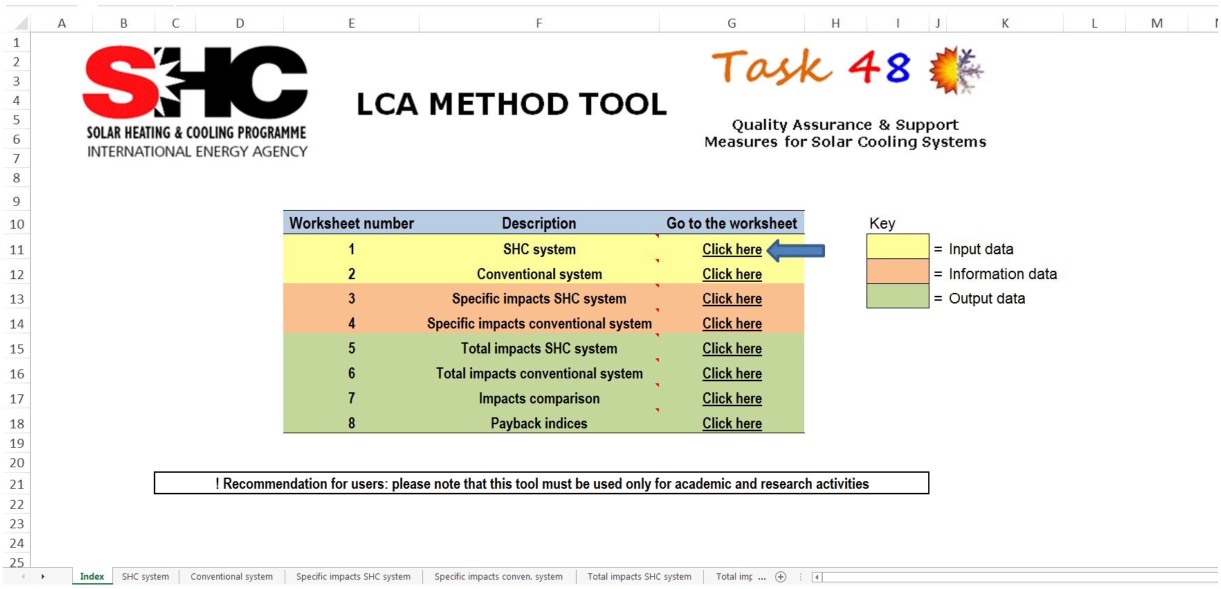
- Step 1: Entering data of SHC system;
- Step 2: Entering data of conventional system;
- Step 3: Examining data of specific energy and environmental impacts
- Step 4: Examining the results.

Starting the project

Opening the LCA Method Tool the worksheet “index” is showed.

Step 1: Entering data of SHC system

In the “index” worksheet, click on the button “Click here” that correspond to the row “SHC system”.



Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

The worksheet “SHC system” will be showed.

Before entering the data, we will have to collect them. In this example, the SHC system is located in Palermo (Italy), has a useful life of 25 years, and is constituted by the following components:

- an absorption chiller (12 kW);
- evacuated solar collectors (35 m^2);
- a heat storage (2000 l);
- a cooling tower (32 kW);
- an auxiliary gas boiler (10 kW);
- an auxiliary conventional chiller (10 kW);
- pipes (60 m);
- one pump (80 W);
- one pump (250 W).

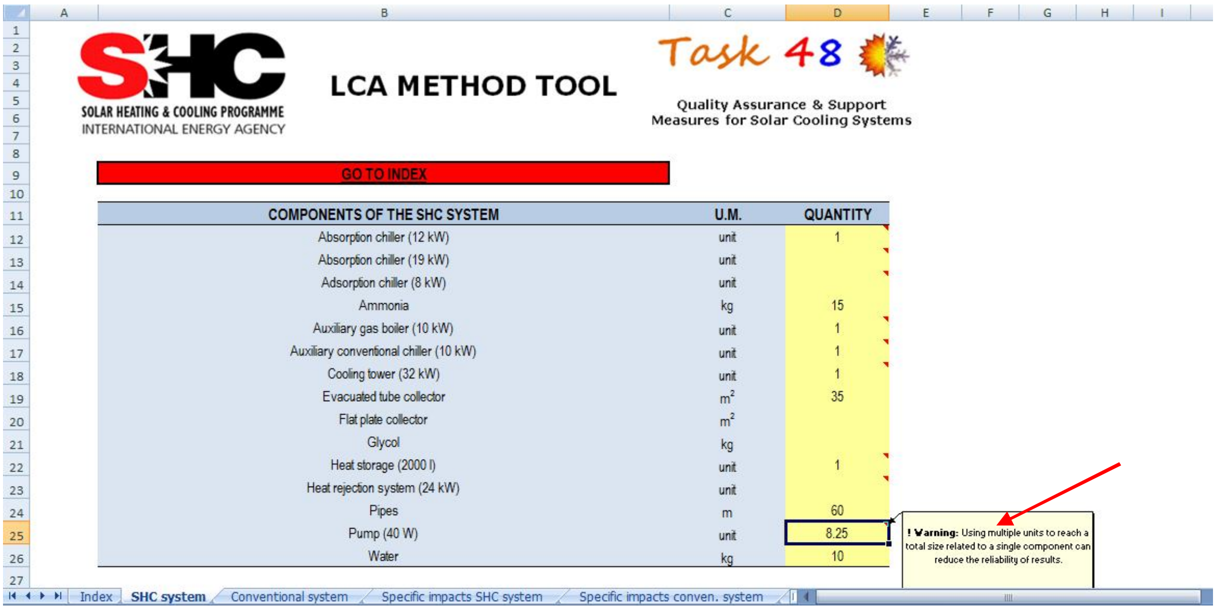
The system uses a water/ammonia solution (15 kg of ammonia and 10 kg of water). During the operation step, the SHC system consumes 1,117 kWh/year of electricity and 414/year kWh of natural gas.

Now we can create the process, as follows:

- in the "quantity" field corresponding to the component "absorption chiller (12 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "ammonia", we enter the value "15";
- in the "quantity" field corresponding to the component "auxiliary gas boiler (10 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "auxiliary conventional chiller (10 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "cooling tower (32 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "evacuated tube collector", we enter the value "35";
- in the "quantity" field corresponding to the component "heat storage (2000 l)", we enter the value "1";
- in the "quantity" field corresponding to the component "pipes", we enter the value "60";
- in the "quantity" field corresponding to the component "water", we enter the value "10".

Referring to the pumps, we have to calculate the correct value to be entered. The tool shows the impacts for a 40 W pump, but the SHC system uses one 80 W pump and one 250 W pump. We can assimilate the pump (80 W) to two pumps (40 W) and the pump (250 W) to 6.25 pumps (40 W). Thus, in the "quantity" field corresponding to the component "pump (40 W)", we enter the value "6.25". This assumption can reduce the reliability of the results, as outlined in the warning message showed in the worksheet "! Warning: Using multiple units to reach a total size related to a single component can reduce the reliability of results". However, due to the unavailability of data on pumps with different sizes, this assumption is the only feasible choice.

The following picture shows the table "components of SHC system" completed with all input data.



COMPONENTS OF THE SHC SYSTEM	U.M.	QUANTITY
Absorption chiller (12 kW)	unit	1
Absorption chiller (19 kW)	unit	
Adsorption chiller (8 kW)	unit	
Ammonia	kg	15
Auxiliary gas boiler (10 kW)	unit	1
Auxiliary conventional chiller (10 kW)	unit	1
Cooling tower (32 kW)	unit	1
Evacuated tube collector	m^2	35
Flat plate collector	m^2	
Glycol	kg	
Heat storage (2000 l)	unit	1
Heat rejection system (24 kW)	unit	
Pipes	m	60
Pump (40 W)	unit	8.25
Water	kg	10

The next step is the indication of energy sources used by the system during the operation step.

In the Table "Energy sources", in the "quantity" field corresponding to the energy source "electricity" we enter the electricity consumption (1,117 kWh/year). By clicking on the box "electricity" a drop-box menu opens. We can select the electricity mix of the country where the system is located.

In this example, considering that the system is installed in Palermo (Italy) we choice the electricity mix for Italy. We can choice if include of not imports fro other countries. Let suppose to include the imports. In the drop-box menu we select "Electricity, low voltage, Italy (including import)".

Pump (40 W)	unit	8,25
Water	kg	10

ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1117
	kWh/year	

- Electricity, low voltage, Greece (including import)
- Electricity, low voltage, Hungary (including import)
- Electricity, low voltage, Ireland (including import)
- Electricity, low voltage, Italy (including import)
- Electricity, low voltage, Luxembourg (including import)
- Electricity, low voltage, Netherlands (including import)
- Electricity, low voltage, Poland (including import)
- Electricity, low voltage, Portugal (including import)

	U.M.	QUANTITY
	year	

Now in the Table “Energy sources”, in the “quantity” field corresponding to the energy source “natural gas” we enter the natural gas consumption (414 kWh/year). By clicking on the box “natural gas” a drop-box menu opens. We can select the system where the natural gas is burned.

In this example, we choice to assimilate our gas boiler to a boiler modulating (< 100 kW). In the drop-box menu we select “Natural gas, burned in boiler modulating, <100 kW, Europe”.

ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1117
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	414

- Natural gas, burned in boiler condensing modulating, <100 kW, Europe
- Natural gas, burned in boiler condensing modulating, >100 kW, Europe
- Natural gas, burned in boiler fan burner low-Nox non-modulating, <100 kW, Europe
- Natural gas, burned in boiler fan burner non-modulating, <100 kW, Europe
- Natural gas, burned in boiler modulating, <100 kW, Europe
- Natural gas, burned in boiler modulating, >100 kW, Europe
- Natural gas, burned in industrial furnace, >100 kW, Europe
- Natural gas, burned in industrial furnace low-NOx, >100 kW, Europe

	U.M.	QUANTITY
	year	--

Then, we can complete the table “other information” by adding the useful life of the system.

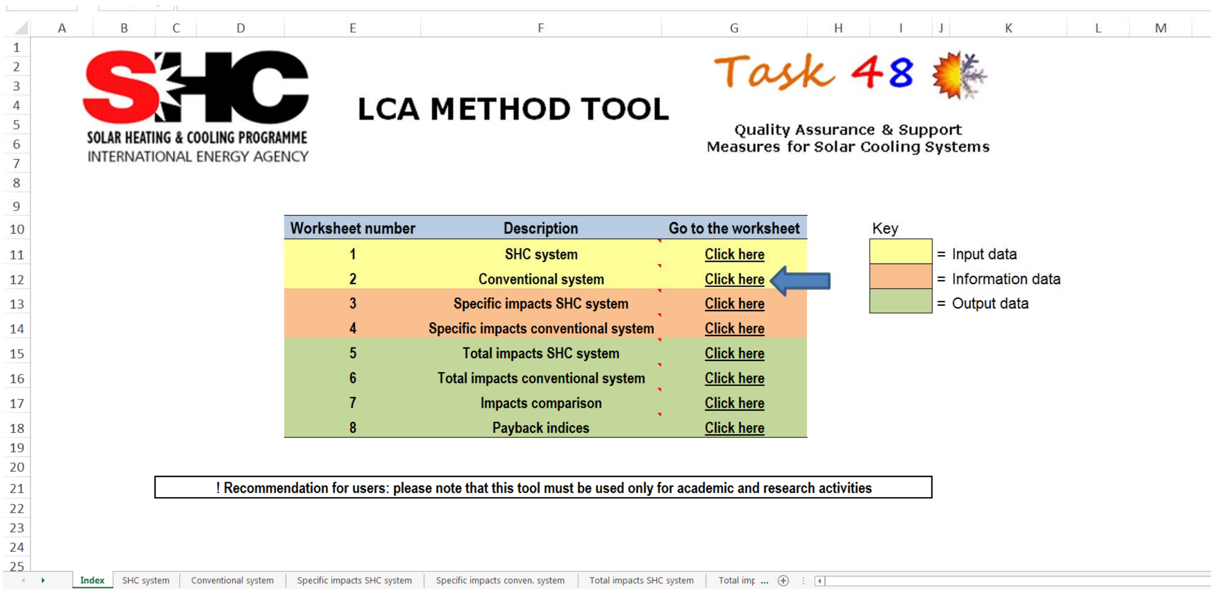
ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1117
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	414

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

After this, the worksheet is completed and we can return to the worksheet “index” by clicking on the button “Go to index”.

Step 2: Entering data of conventional system

Now, let us go to insert data on the conventional system. In the "index" worksheet, click on the button "Click here" that correspond to the row "Conventional system". The worksheet "Conventional system" will be showed.



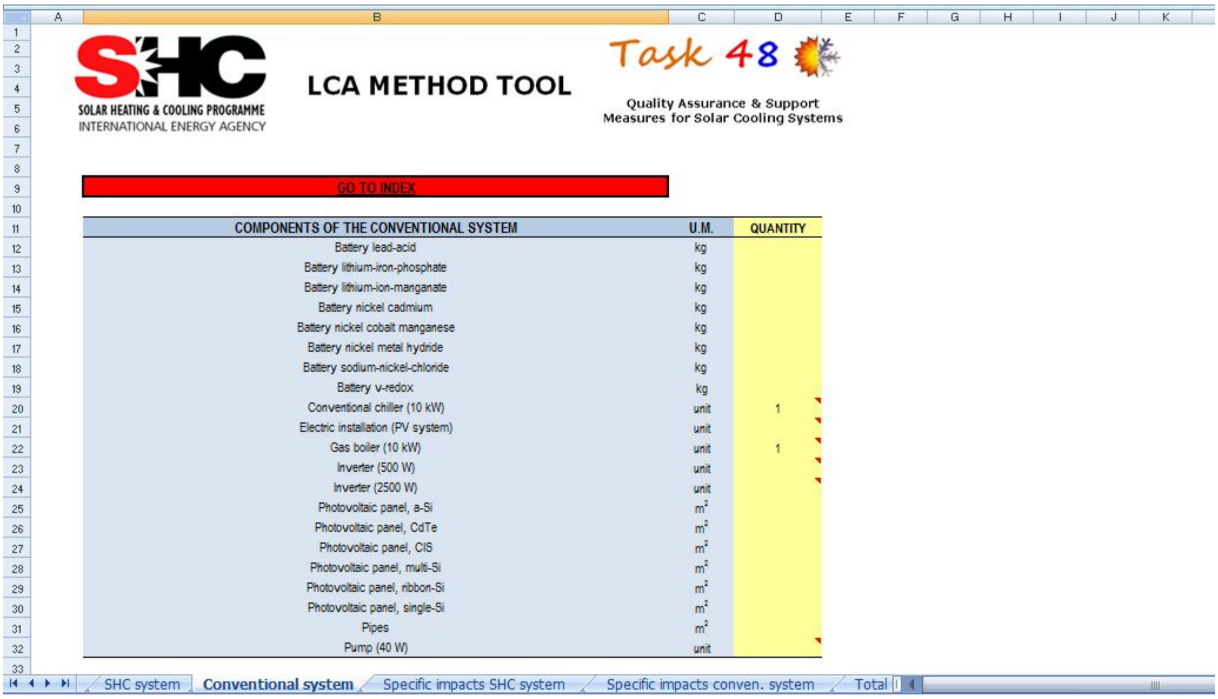
The conventional system is constituted by the following components: a conventional chiller (10 kW) and a gas boiler (10 kW). During the operation step (25 years), it consumes 1,995 kWh/year of electricity and 2,882/year kWh of natural gas.

We can create the process, as follows:

- in the "quantity" field corresponding to the component "conventional chiller (10 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "gas boiler (10 kW)", we enter the value "1".

There are no multiple units in the conventional system. Thus, no assumption on the size of components is made.

The following picture shows the table "Components of conventional system" completed with all input data.



COMPONENTS OF THE CONVENTIONAL SYSTEM	U.M.	QUANTITY
Battery lead-acid	kg	
Battery lithium-iron-phosphate	kg	
Battery lithium-ion-manganate	kg	
Battery nickel cadmium	kg	
Battery nickel cobalt manganese	kg	
Battery nickel metal hydride	kg	
Battery sodium-nickel-chloride	kg	
Battery v-redox	kg	
Conventional chiller (10 kW)	unit	1
Electric installation (PV system)	unit	
Gas boiler (10 kW)	unit	1
Inverter (500 W)	unit	
Inverter (2500 W)	unit	
Photovoltaic panel, a-Si	m^2	
Photovoltaic panel, CdTe	m^2	
Photovoltaic panel, CIS	m^2	
Photovoltaic panel, multi-Si	m^2	
Photovoltaic panel, ribbon-Si	m^2	
Photovoltaic panel, single-Si	m^2	
Pipes	m^2	
Pump (40 W)	unit	

The next step is the indication of energy sources used by the system during the operation step.

Similarly to the SHC system, in the Table "Energy sources", we enter the electricity and natural gas consumption, and the useful life of the system.

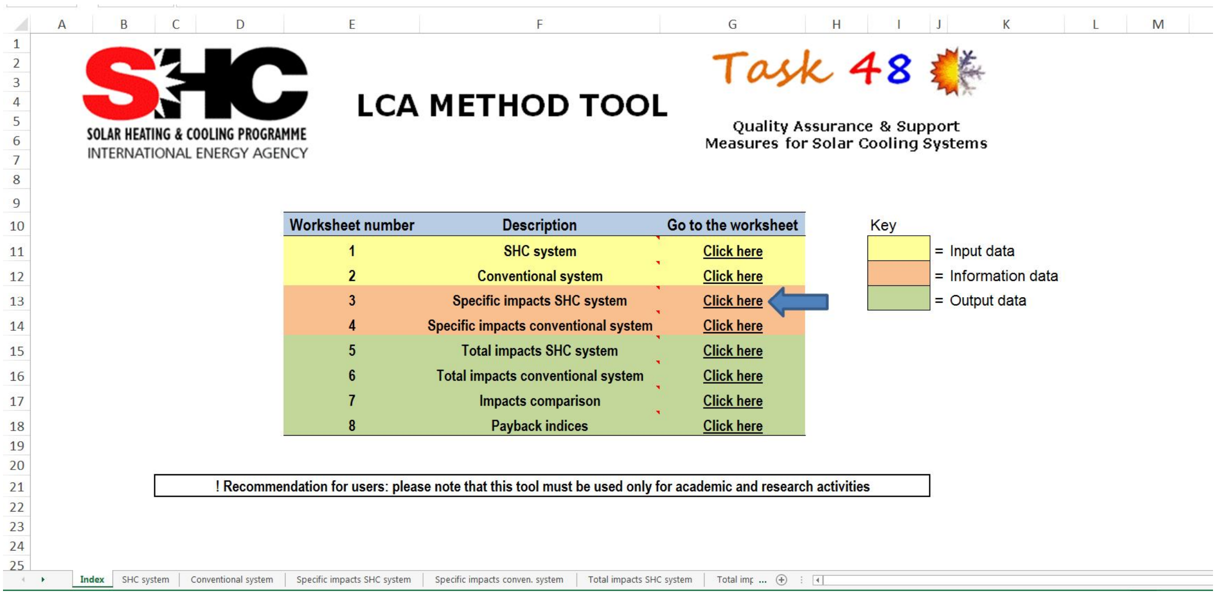
ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1995
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	2882

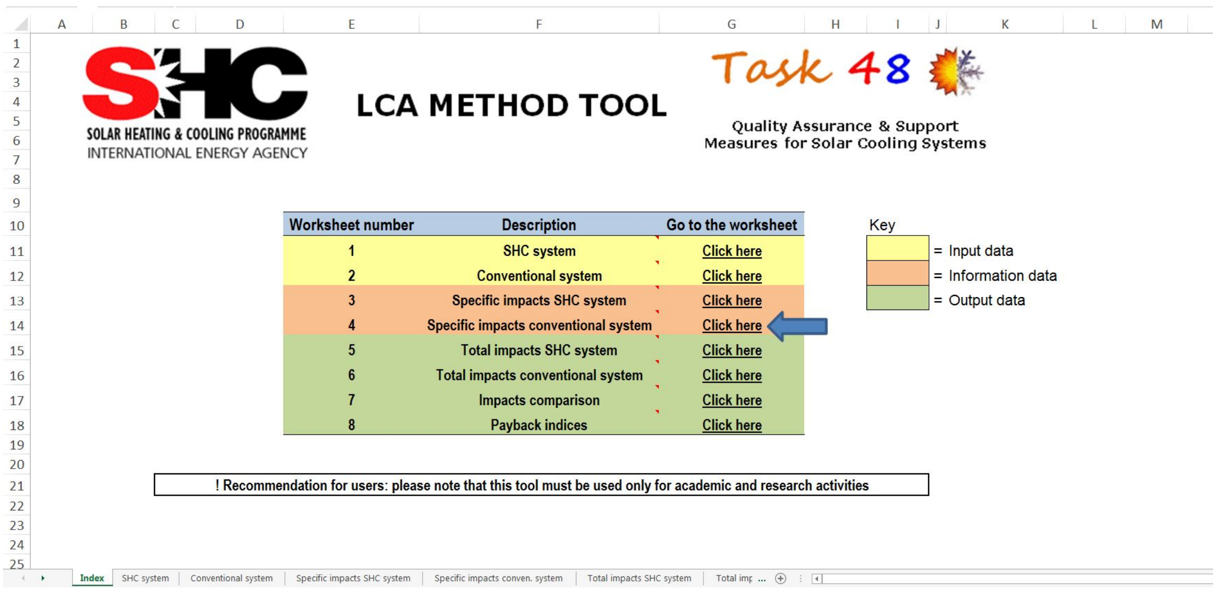
OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

After this, the worksheet is completed and we can return to the worksheet "index" by clicking on the button "Go to index".

Step 3: Examining data of specific energy and environmental impacts

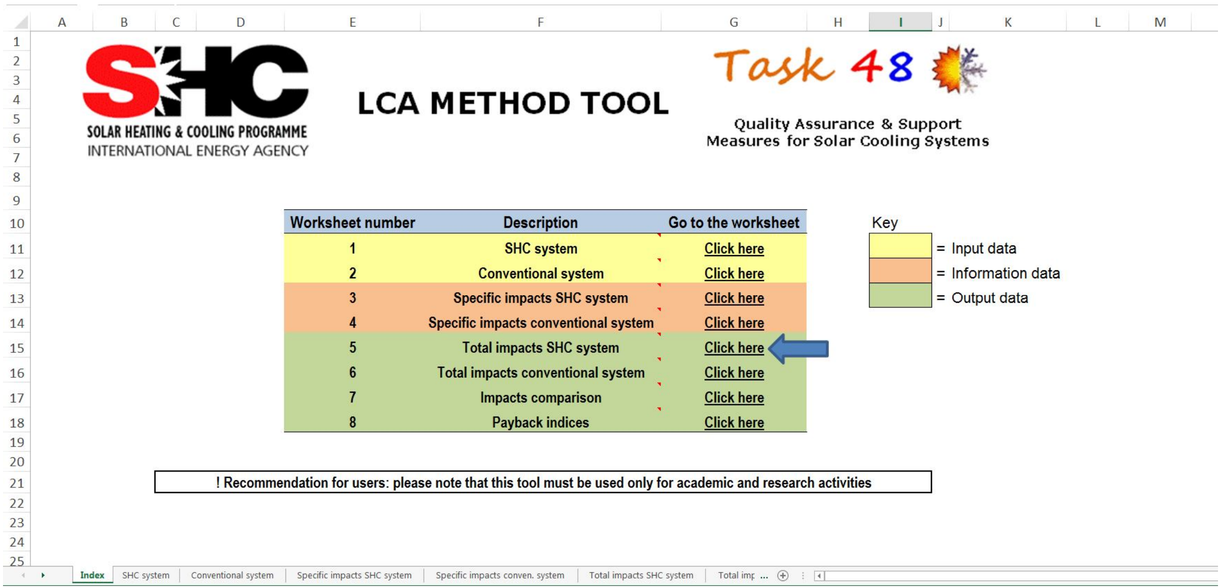
Now it is possible to visualize the specific impacts of the SHC system by clicking on the button "Click here" that correspond to the row "Specific impacts SHC system" or the specific impacts of the conventional system by clicking on the button "Click here" that correspond to the row "Specific impacts Conventional system".





Step 4: Examining the results

In the “index” worksheet, by clicking on the button “Click here” that correspond to the row “Total impacts SHC system” it is possible to go to the worksheet showing the LCA results for the SHC system.


LCA METHOD TOOL

Quality Assurance & Support Measures for Solar Cooling Systems

Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

Key
= Input data
= Information data
= Output data

! Recommendation for users: please note that this tool must be used only for academic and research activities

Index | SHC system | Conventional system | Specific impacts SHC system | Specific impacts conven. system | Total impacts SHC system | Total imp ...

As described in the previous chapters, the tool shows the total results and the results for each component and life-cycle step, both in tables and graphs.

Looking at the following table, it is possible to visualize the total GER and GWP of the system, that are about 466 GJ and about 28.5 tons of CO_{2eq}, respectively.

The energy and environmental impacts for each life cycle step and for each component/energy source can also be examined.

Note that a null impact is allocated to the components that are not part of the system (as flat plate collectors, glycol, etc.)

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

LCA METHOD TOOL

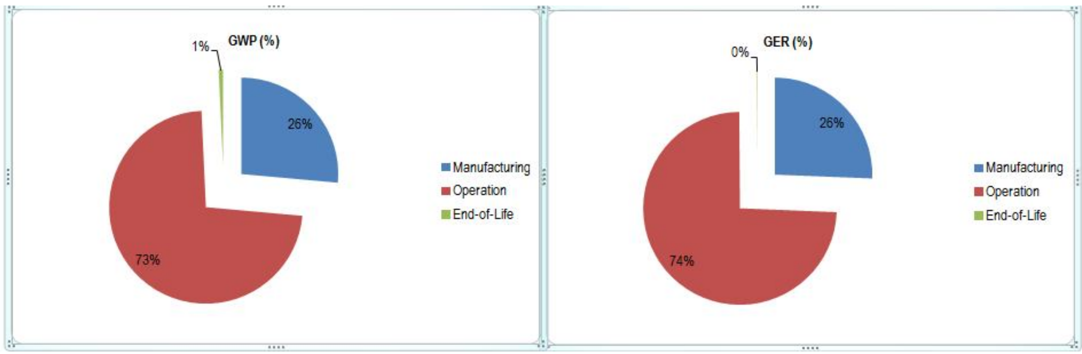
Task 48
Quality Assurance & Support Measures for Solar Cooling Systems

GO TO INDEX

COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	**119503.45**	**346228.96**	**581.90**	**466314.31**	**7522.10**	**20734.03**	**210.67**	**28466.80**

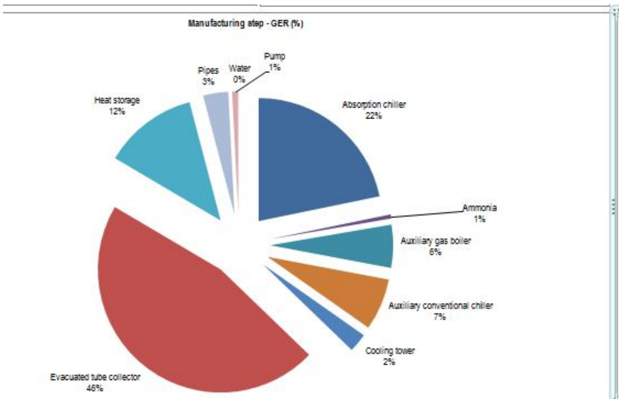
Specific impacts SHC system | Specific impacts conven. system | Total impacts SHC system | Total impacts co

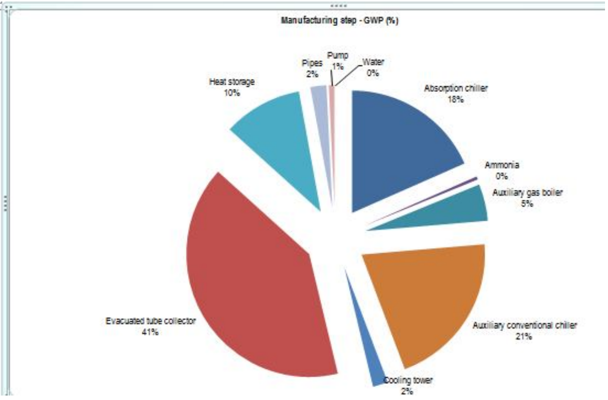
By analysing the picture below, it is possible to visualize the contribution of the different life cycle steps to the total impact. It can be noted that the operation step is the main contributor towards the GER (73%) and GWP (74%) and that the contribution of the end-of-life step is negligible (lower than 1%).

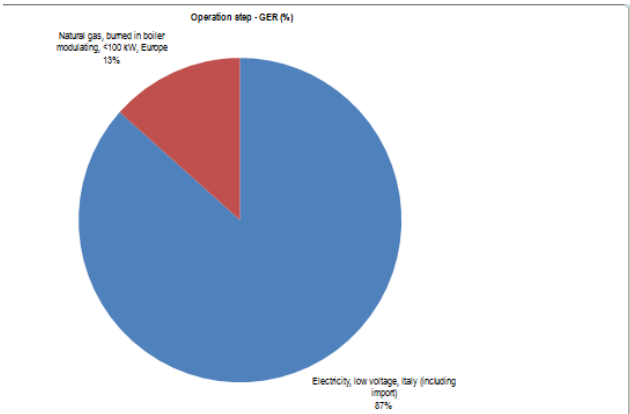


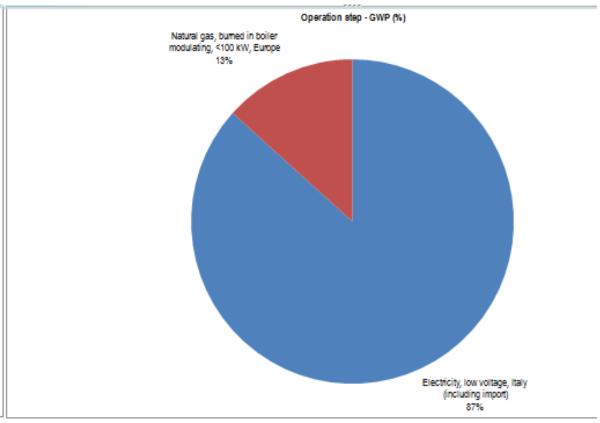
A detailed contribution analysis of each life cycle step shows that:

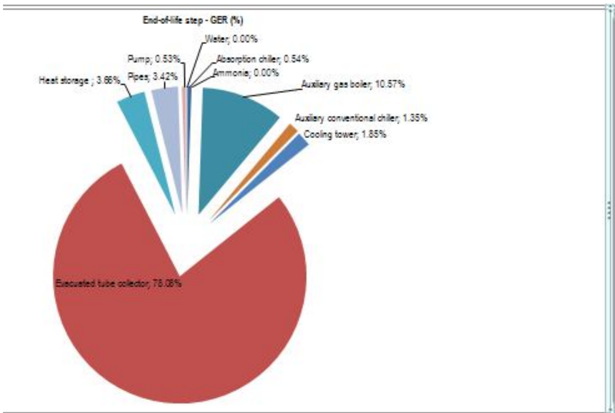
- during the production and end-of-life steps the main impacts are caused by the evacuated tube collectors and the absorption chiller;
- electricity is the energy source responsible of the main impacts during the operation step.

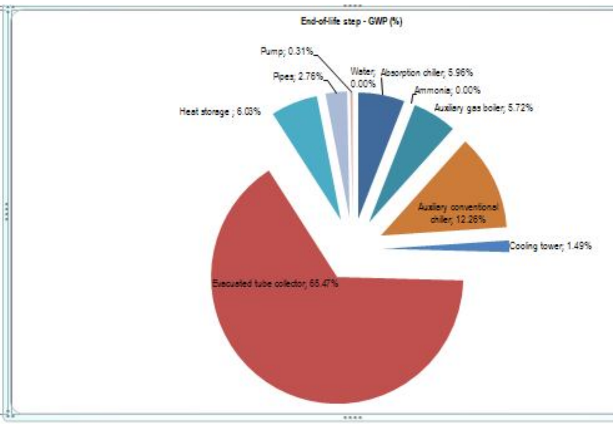






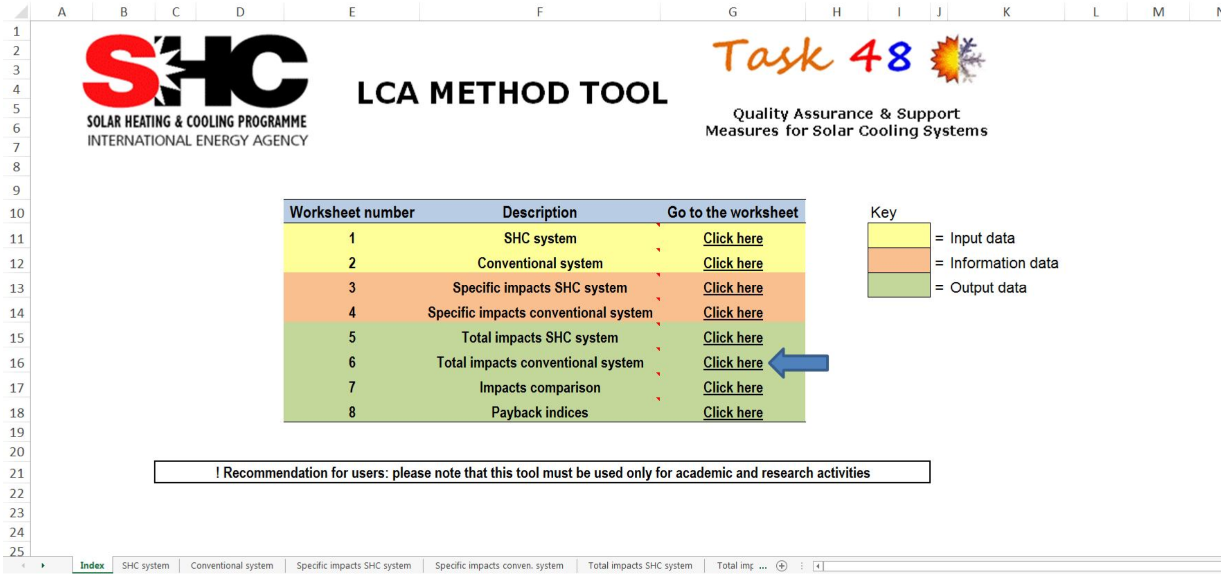






When the analysis is completed we can return to the worksheet “index” by clicking on the button “Go to index”.

Now, by clicking on the button “Click here” that correspond to the row “Total impacts Conventional system” it is possible to visualize the results of the life cycle of the conventional system.



Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

As for the SHC system, the tables and pictures below show the total impacts of the conventional system, the incidence of each life cycle step and of each component/energy source.

For this system, the incidence of the operation step on the total impacts is about 96-98%.

A detailed contribution analysis of each life cycle step shows that:

- the main contributor to the impacts of the production step is the conventional chiller (about 54.5% of GER and about 81% of GWP);
- electricity is the energy source responsible of the main impacts during the operation step;
- during the end-of-life step the main impact to GER is caused by the gas boiler (about 89%), while the main contribution to GWP is attributable to the conventional chiller (about 68%)

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

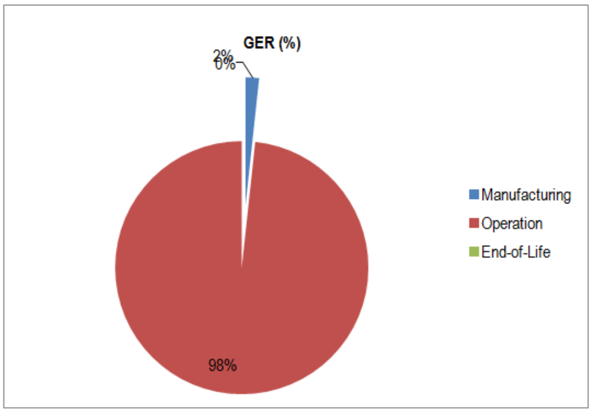
LCA METHOD TOOL

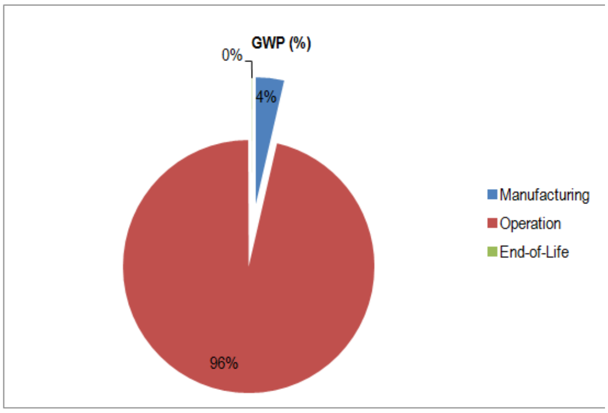
Task 48
Quality Assurance & Support Measures for Solar Cooling Systems

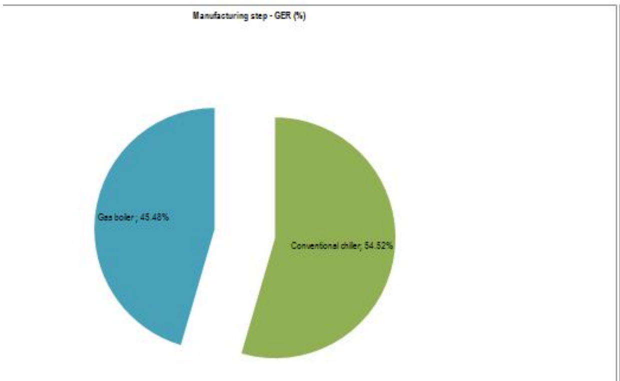
GO TO INDEX

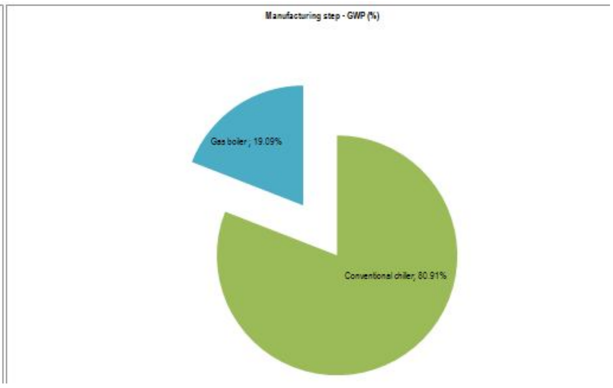
COMPONENTS OF THE CONVENTIONAL SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Battery lead-acid	0	-	0	0	0	-	0	0
Battery lithium-iron-phosphate	0	-	0	0	0	-	0	0
Battery lithium-ion-manganate	0	-	0	0	0	-	0	0
Battery nickel cadmium	0	-	0	0	0	-	0	0
Battery nickel cobalt manganese	0	-	0	0	0	-	0	0
Battery nickel metal hydride	0	-	0	0	0	-	0	0
Battery sodium-nickel-chloride	0	-	0	0	0	-	0	0
Battery v-redox	0	-	0	0	0	-	0	0
Conventional chiller	8131.097	-	7.833	8138.93	1550.461	-	25.818	1576.279
Electric installation (PV system)	0	-	0	0	0	-	0	0
Gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Inverter	0	-	0	0	0	-	0	0
Inverter	0	-	0	0	0	-	0	0
Photovoltaic panel, a-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, CdTe	0	-	0	0	0	-	0	0
Photovoltaic panel, CIS	0	-	0	0	0	-	0	0
Photovoltaic panel, multi-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, ribbon-Si	0	-	0	0	0	-	0	0
Photovoltaic panel, single-Si	0	-	0	0	0	-	0	0
Pipes	0	-	0	0	0	-	0	0
Pumps	0	-	0	0	0	-	0	0
Electricity, low voltage, Italy (including import)	-	535516.7	-	535516.7	-	32095.278	-	32095.2779
Natural gas, burned in boiler modulating, <100 kW, Europe	-	322960.12	-	322960.1	-	19240.395	-	19240.3952
Total	**14912.96**	**858476.81**	**69.34**	**873459.11**	**1916.17**	**51335.67**	**37.86**	**53289.70**

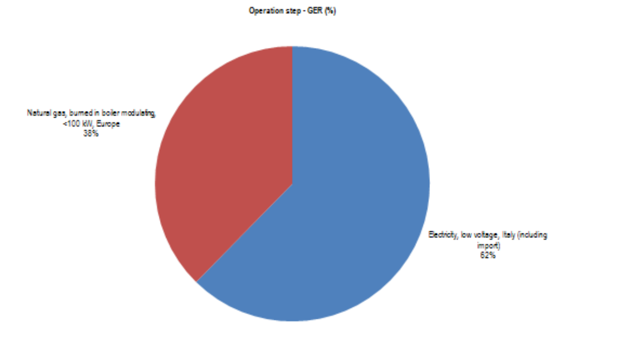
Specific impacts conven. system | Total impacts SHC system | **Total impacts convent. system** | Impacts comp

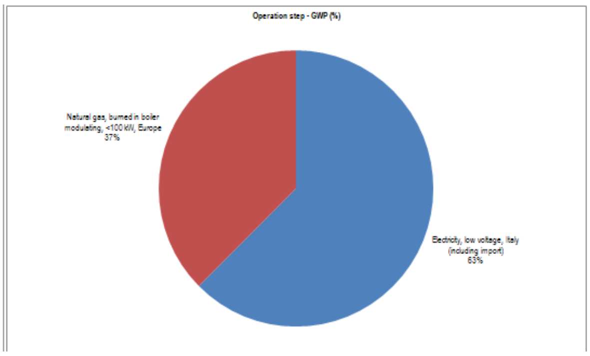


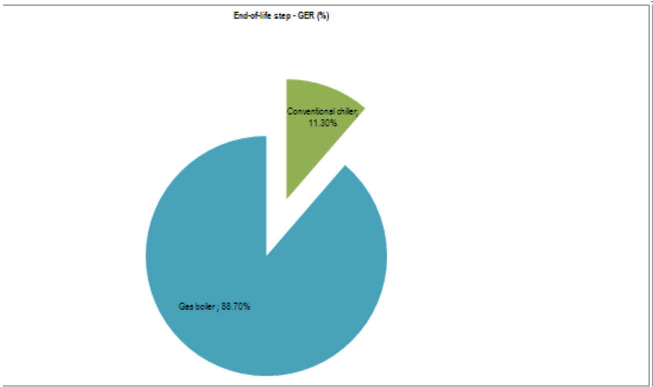


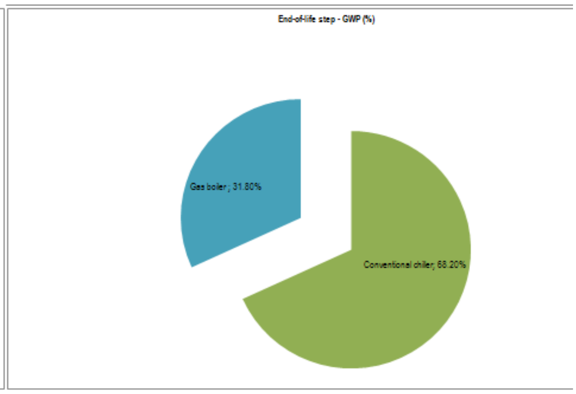






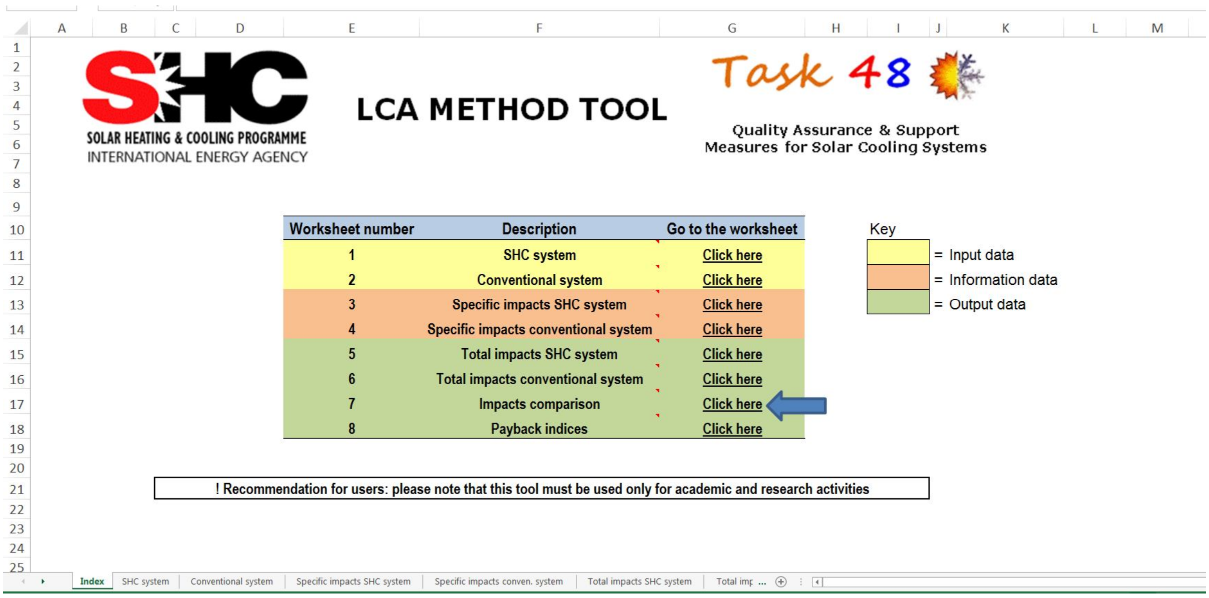






When the analysis is completed we can return to the worksheet “index” by clicking on the button “Go to index”.

In the “index” worksheet, by clicking on the button “Click here” that correspond to the row “Impacts comparison” it is possible to compare the impacts of the two examined systems.



LCA METHOD TOOL

SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Task 48 Quality Assurance & Support Measures for Solar Cooling Systems

Worksheet number	Description	Go to the worksheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

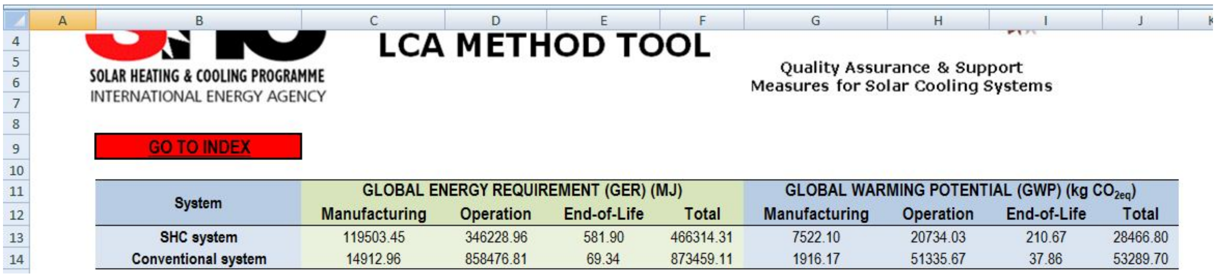
Key
= Input data
= Information data
= Output data

! Recommendation for users: please note that this tool must be used only for academic and research activities

Index | SHC system | Conventional system | Specific impacts SHC system | Specific impacts conven. system | Total impacts SHC system | Total imp ...

A comparison of the GER and the GWP of the SHC system with those of the conventional system is shown in the following table and graphs. The comparison shows that the SHC system is better than the conventional system in terms of energy and environmental performances. In detail, the values of GER and GWP for SHC system are about 45% lower than those for the conventional system. In particular, the higher impacts caused by the SHC system during the manufacturing and end-of-life steps are balanced by the energy savings and avoided emissions during the operation step.

Thus, the results of the comparison show the advantages due to the use of SHC systems in substitution of conventional ones.



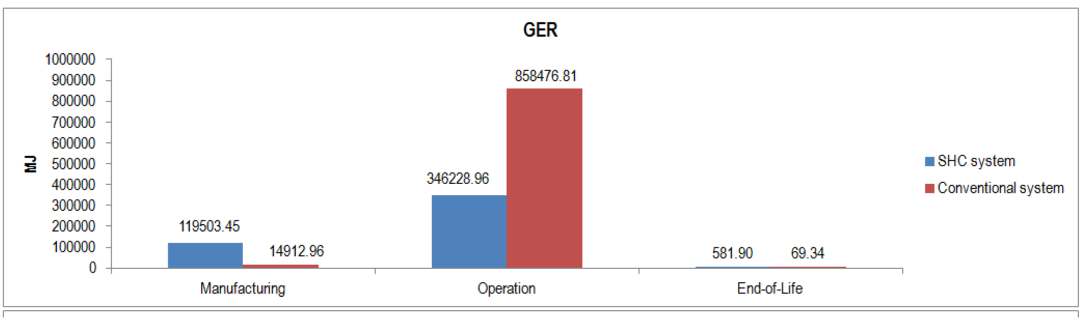
LCA METHOD TOOL

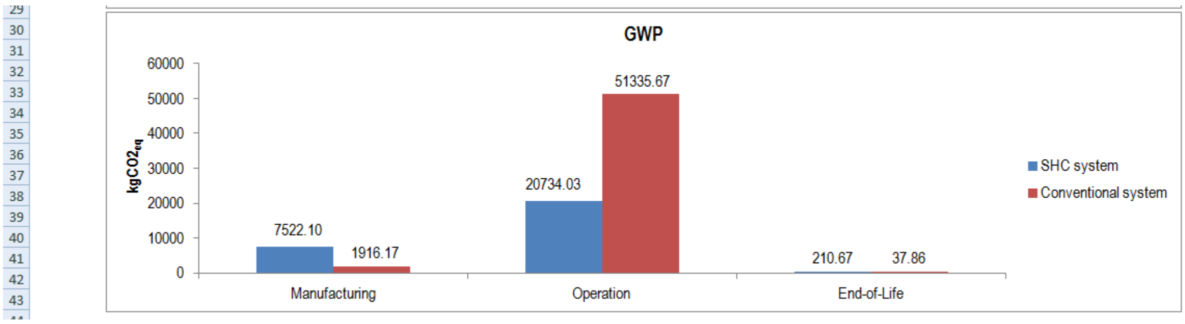
SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Quality Assurance & Support Measures for Solar Cooling Systems

GO TO INDEX

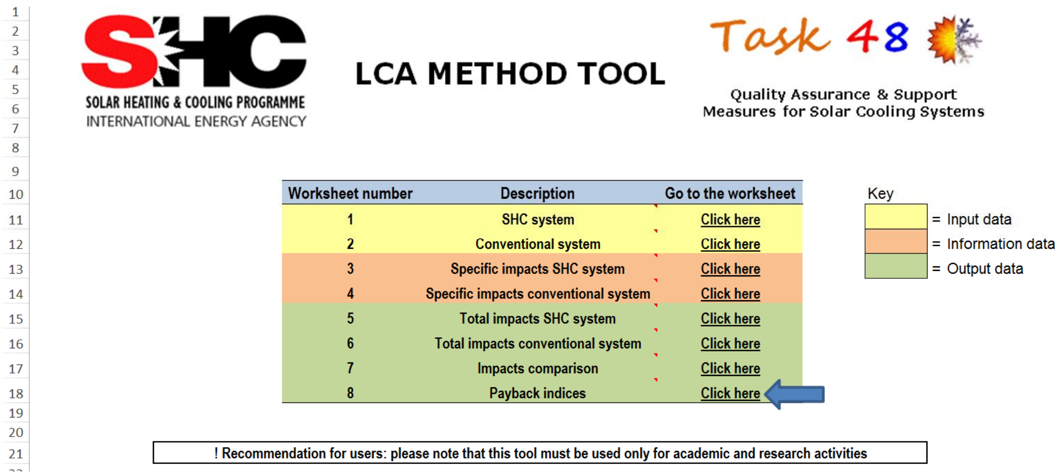
System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80
Conventional system	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70





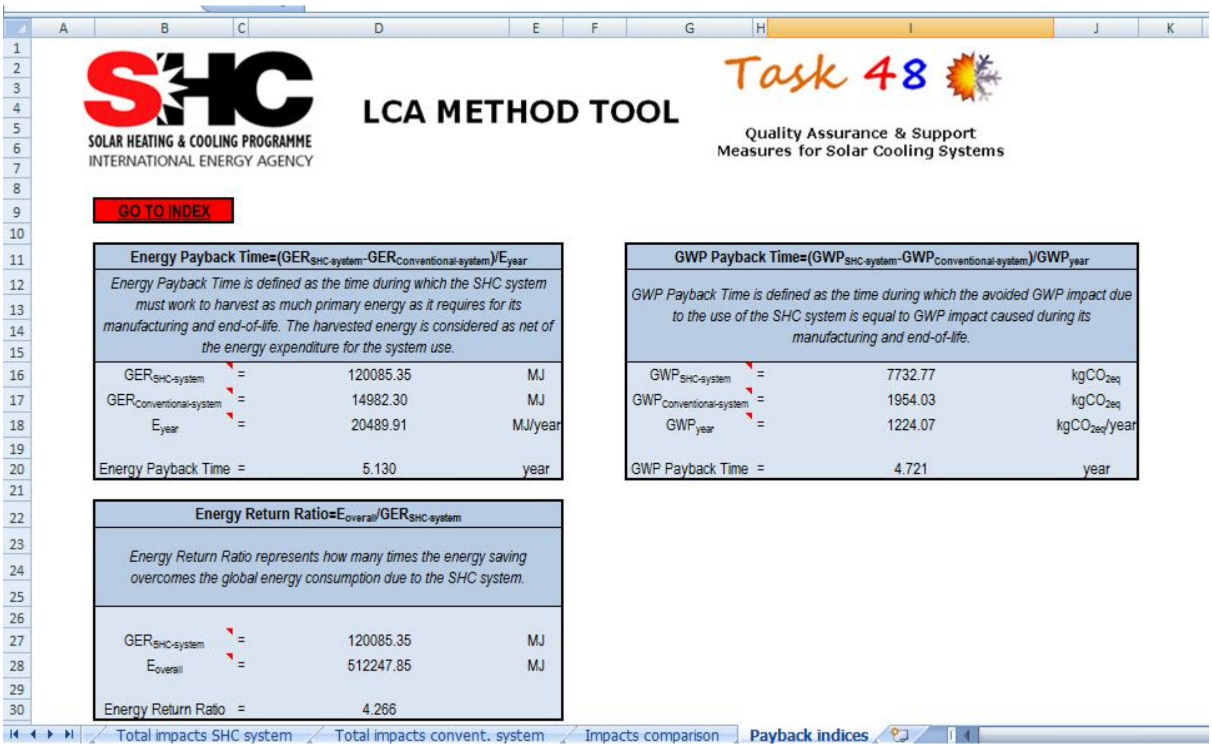
When the analysis is completed we can return to the worksheet “index” by clicking on the button “Go to index”.

In the “index” worksheet, by clicking on the button “Click here” that correspond to the row “Payback indices” it is possible to compare the impacts of the two examined systems.



The Energy and GWP Payback Times are about 5.1 years and 4.7 years, respectively. This highlight that the additional impacts caused for the manufacturing and end-of-life steps of the SHC system are annulled from the generated yearly energy saving and avoided GWP impact in a time lower than 5 years.

The value of Energy Return Ratio is about 4.2. This means that the energy saved during the useful life of the SHC system overcomes the global energy consumption due to its manufacture and end-of-life of about four times.



Note: The payback indices values are strongly dependent on the national electricity mix.
For example, by changing the electricity mix of Italy (including import), characterized by specif impact to GER of 10.74 MJ/kWh and to GWP of 0.644 kg $CO_{2e}q$/kWh, with the electricity mix of Austria (including import), characterized by lower specif impacts to GER (9.06 MJ/kWh) and GWP (0.446 kg $CO_{2e}q$/kWh), the Energy Payback Time rises from 5.1 years to 5.5 years and the GWP Payback Time goes from about 4.7 years to about 5.5 years.

2.1.2.3 Example 2: SHC system with a cold backup, installed in Italy, in substitution of a conventional system assisted by a grid-connected PV system

This example describes the application of the LCA Method Tool to carry out a LCA of a SHC system that works with a cold backup configuration, installed in Italy, in substitution of a conventional system assisted by a grid-connected PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 2".

The procedure to carry out Step 1 (entering data of SHC system) is the same of that of Example 1. Thus, let us go to Step 2.

Step 2: Entering data of conventional system

The conventional system is constituted by the following components: a conventional chiller (10 kW), a gas boiler (10 kW), a PV system constituted by the electric installation, 14.5 m^2 of multi-Si photovoltaic panels, and an inverter (750 W). During the operation step (25 years), the system consumes 2,882 kWh/year of natural gas. The electricity consumed during the life cycle of the system is produced by the photovoltaic system.

The life cycle of each system component is estimated to be 25 years, except for the inverter (12.5 years). Thus, during the life cycle of the system two inverters are installed.

We can create the process, as follows:

- in the “quantity” field corresponding to the component “conventional chiller (10 kW)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “gas boiler (10 kW)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “electric installation (PV system)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “photovoltaic panel, multi-Si”, we enter the value “14.5”.

Referring to the inverters, we have to calculate the correct value to be entered. The tool shows the impacts for a 500 W inverter, but the system uses two 750 W inverters. We can assimilate the inverters of 750 W to three inverters of 500 W. Thus, in the “quantity” field corresponding to the component “inverter (500 W)”, we enter the value “3”. As outlined in the previous chapters, this assumption can reduce the reliability of the results.

In the Table “Energy sources”, we enter the natural gas consumption. In the Table “Other information”, we enter information about the life cycle of the system.

The following picture shows the table “Components of conventional system” completed with all input data.

COMPONENTS OF THE CONVENTIONAL SYSTEM	U.M.	QUANTITY
Battery lead-acid	kg	
Battery lithium-iron-phosphate	kg	
Battery lithium-ion-manganate	kg	
Battery nickel cadmium	kg	
Battery nickel cobalt manganese	kg	
Battery nickel metal hydride	kg	
Battery sodium-nickel-chloride	kg	
Battery v-redox	kg	
Conventional chiller (10 kW)	unit	1
Electric installation (PV system)	unit	1
Gas boiler (10 kW)	unit	1
Inverter (500 W)	unit	3
Inverter (2500 W)	unit	
Photovoltaic panel, a-Si	m^2	
Photovoltaic panel, CdTe	m^2	
Photovoltaic panel, CIS	m^2	
Photovoltaic panel, multi-Si	m^2	14,5
Photovoltaic panel, ribbon-Si	m^2	
Photovoltaic panel, single-Si	m^2	
Pipes	m^2	
Pump (40 W)	unit	

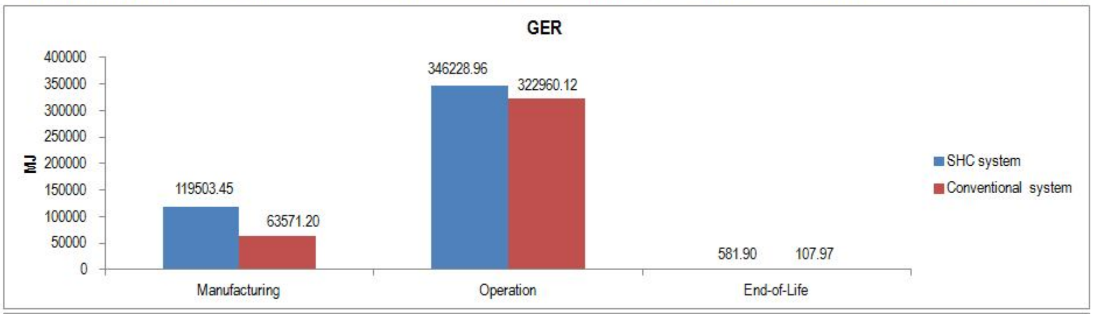
ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh	
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh	2882

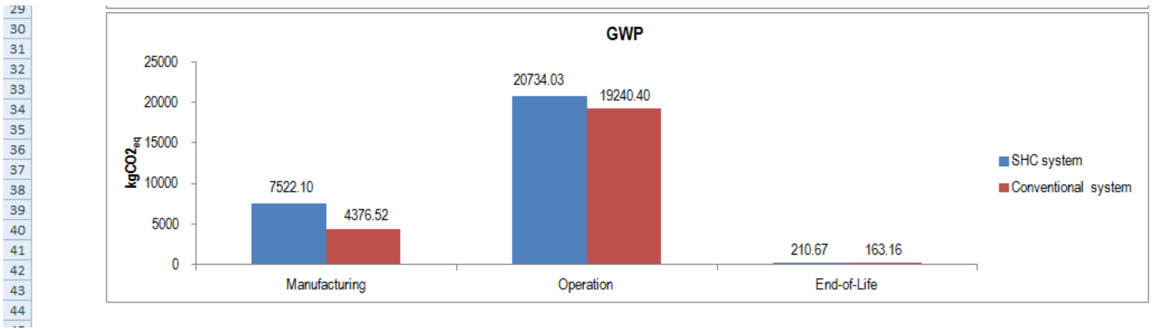
OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

Considering that Step 3 is the same than that in Example 1 and that the analysis of the results can be made in a similar way than Example 1, let us go to the impact comparison, shown below.

A comparison of the impacts calculated for the SHC system and the conventional one shows that the conventional system is the best system with the lowest global energy requirement and global warming potential for each examined life cycle step.

System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80
Conventional system	63571.20	322960.12	107.97	386639.29	4376.52	19240.40	163.16	23780.08





Thus, in this case there are no energy and environmental advantages arising from the substitution of the conventional system with a SHC system.

Furthermore, negative values are obtained for Energy Payback Time, GWP Payback Time and Energy Return Ratio. This is due to GER and GWP values for the operation step of the SHC system higher than that of the conventional system, which uses electricity produced by renewable energy sources.

2.1.2.4 Example 3: SHC system with a cold backup, installed in Italy, in substitution of a conventional system assisted by a stand-alone PV system

This example describes the application of the LCA Method Tool to carry out a LCA of a SHC system that works with a cold backup configuration, installed in Italy, in substitution of a conventional system assisted by a stand-alone PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 3".

Being the procedure to carry out Step 1 (entering data of SHC system) the same than that of Example 1. Thus, let us go to Step 2.

Step 2: Entering data of conventional system

The conventional system is constituted by the following components: a conventional chiller (10 kW), a gas boiler (10 kW), a PV system constituted by the electric installation, 33 m^2 of multi-Si photovoltaic panel, and an inverter (2500 W), a lithium-ion-manganate battery (150 kg). During the operation step (25 years), the system consumes 2,882 kWh/year of natural gas. The electricity consumed by the system is produced by the photovoltaic system.

The life cycle of each system component is estimated to be 25 years, except for the inverter (12.5 years) and the battery (8.3 years). Thus, during the life cycle of the system two inverters and three batteries are installed.

We can create the process, as follows:

- in the “quantity” field corresponding to the component “battery lithium-ion-manganate”, we enter the value “450”, that is the mass of three batteries;
- in the “quantity” field corresponding to the component “conventional chiller (10 kW)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “gas boiler (10 kW)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “electric installation (PV system)”, we enter the value “1”;
- in the “quantity” field corresponding to the component “inverter (2500 W)”, we enter the value “2”;
- in the “quantity” field corresponding to the component “photovoltaic panel, multi-Si”, we enter the value “33”.

In the Table “Energy sources”, we enter the natural gas consumption. In the Table “Other information”, we enter information about the life cycle of the system.

The following picture shows the table “Components of conventional system” completed with all input data.

COMPONENTS OF THE CONVENTIONAL SYSTEM	U.M.	QUANTITY
Battery lead-acid	kg	
Battery lithium-iron-phosphate	kg	
Battery lithium-ion-manganate	kg	450
Battery nickel cadmium	kg	
Battery nickel cobalt manganese	kg	
Battery nickel metal hydride	kg	
Battery sodium-nickel-chloride	kg	
Battery v-redox	kg	
Conventional chiller (10 kW)	unit	1
Electric installation (PV system)	unit	1
Gas boiler (10 kW)	unit	1
Inverter (500 W)	unit	
Inverter (2500 W)	unit	2
Photovoltaic panel, a-Si	m^2	
Photovoltaic panel, CdTe	m^2	
Photovoltaic panel, CIS	m^2	
Photovoltaic panel, multi-Si	m^2	33
Photovoltaic panel, ribbon-Si	m^2	
Photovoltaic panel, single-Si	m^2	
Pipes	m^2	
Pump (40 W)	unit	

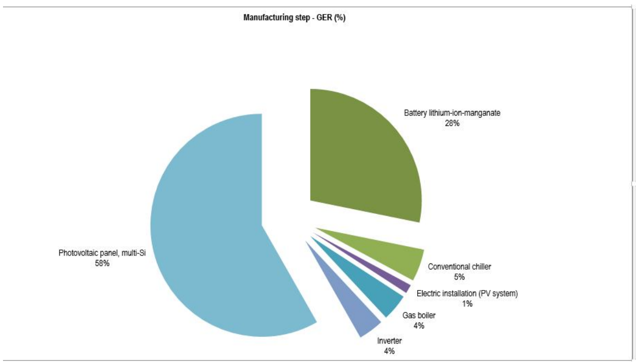
ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	2882

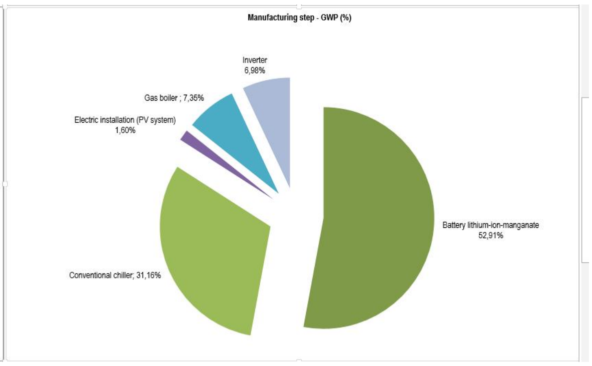
OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

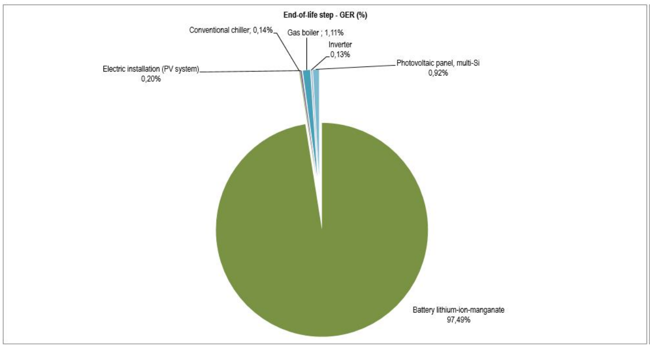
Step 3 is the same than that of Example 1 and the analysis of the results can be made in a similar way than Example 1.

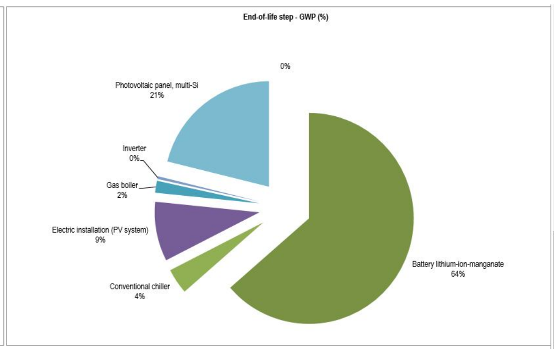
However, it is interesting to analyze the contribution to the total impacts due to the manufacturing and end-of-life of battery (see graphs below). In detail:

- during the manufacturing step the battery gives a contribution of about 28% on GER and of about 53% on GWP;
- during the end-of-life step the battery is the main contributor to GER (about 97.5%) and is responsible of about 64% of the impact on GWP.





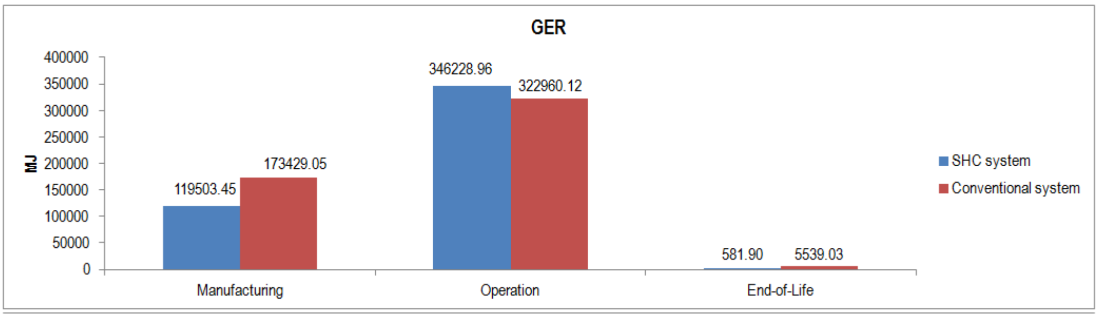


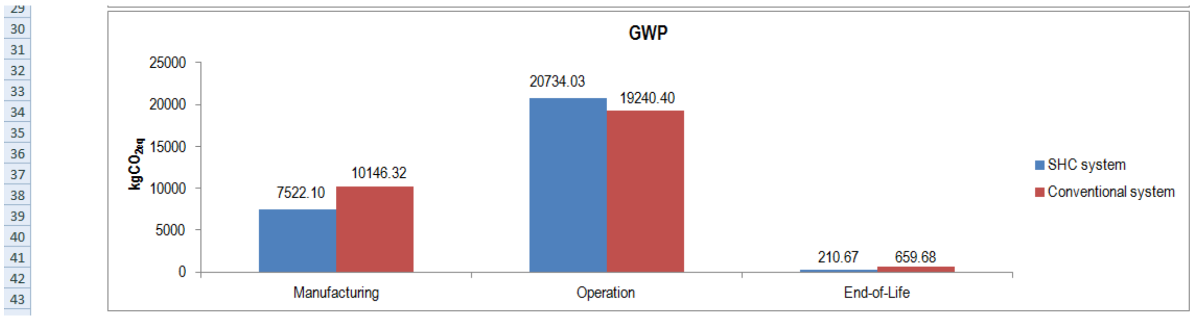


Now, let us go to the impact comparison, shown below.

A comparison of GER and GWP shows that the SHC system has the lowest global energy requirement and global warming potential. However, referring to the operation step, the conventional system shows lower impacts.

System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80
Conventional system	173429.05	322960.12	5539.03	501928.19	10146.32	19240.40	659.68	30046.39





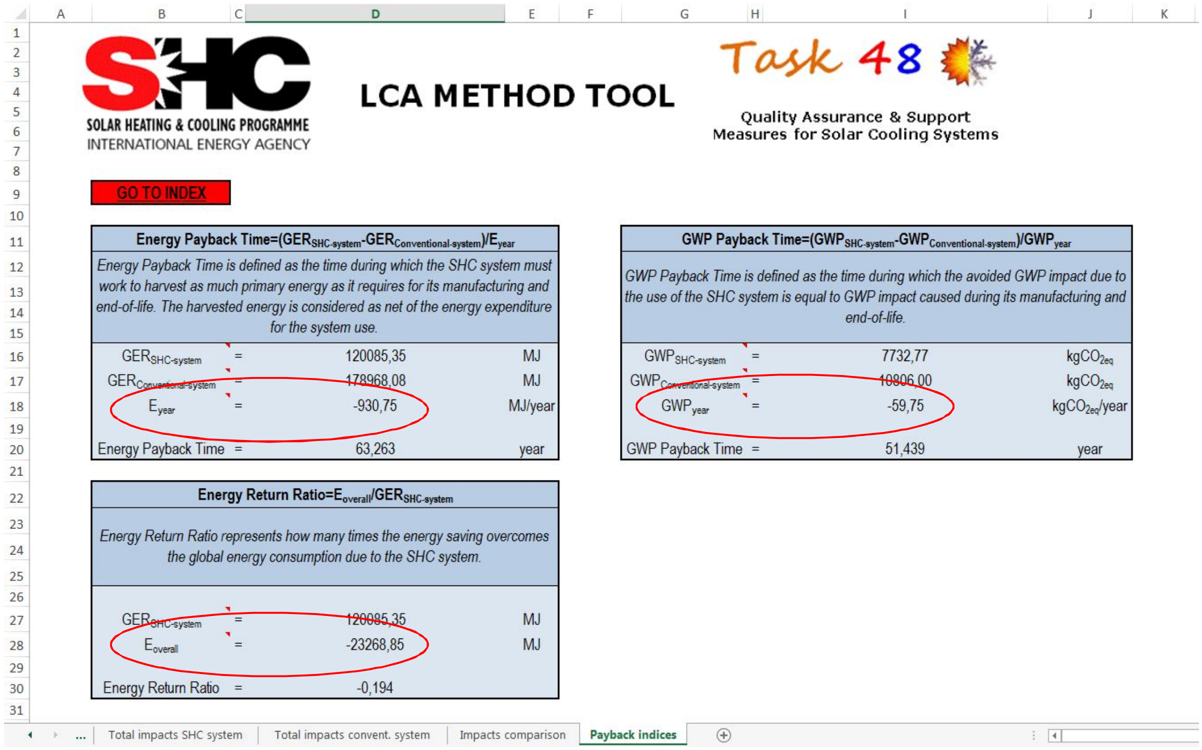
An analysis of the “payback indices” worksheet show that the following items, related on the use of the SHC system in substitution with the conventional one, have negative values:

- net yearly primary energy saving;
- net yearly avoided GWP;
- net primary energy saving during the overall life cycle of the SHC system.

This means that during the operation step the impacts of the SHC system are higher than that of the conventional one, which uses electricity produced by renewable energy sources.

Thus, even if the total energy and environmental impacts due to the conventional system are higher than the one of the SHC system, the last one has worse performances during the operation step.

In this case, the calculation of the payback time indices cannot be carried out.



Note: The payback time indices obtained for Example 2 and 3 highlight that the values of these indices have to be analysed in detail to avoid misunderstanding and wrong considerations.

If negative values are obtained for E_{year}, GWP_{year} and $E_{overall}$, the calculation of the payback indices must not be carried out.

2.1.2.5 Example 4: SHC system with a cold backup, installed in Switzerland, in substitution of a conventional system assisted by a stand-alone PV system

This example describes the application of the LCA Method Tool to carry out a LCA of a SHC system that works with a cold backup configuration, installed in Switzerland, in substitution of a conventional system assisted by a stand-alone PV system. The corresponding example is available in the LCA Method Tool format with the name "Case study 4".

Being the examined SHC system different from the system examined in the previous examples, in the following the procedure to carry out Step 1 (entering data of SHC system) is briefly described.

Step 2: Entering data of conventional system

The SHC system is located in Zurich (Switzerland), has a useful life of 25 years, and is constituted by the same elements that the system of example 1.

The system uses a water/ammonia solution (15 kg of ammonia and 10 kg of water) and 15.5 kg of glycol. During the operation step, the SHC system consumes 767 kWh/year of electricity and 10,165 kWh/year of natural gas.

The following picture shows the table "components of SHC system" completed with all input data.

COMPONENTS OF THE SHC SYSTEM	U.M.	QUANTITY
Absorption chiller (12 kW)	unit	1
Absorption chiller (19 kW)	unit	
Adsorption chiller (8 kW)	unit	
Ammonia	kg	15
Auxiliary gas boiler (10 kW)	unit	1
Auxiliary conventional chiller (10 kW)	unit	1
Cooling tower (32 kW)	unit	1
Evacuated tube collector	m²	35
Flat plate collector	m²	
Glycol	kg	15,5
Heat storage (2000 l)	unit	1
Heat rejection system (24 kW)	unit	
Pipes	m	60
Pump (40 W)	unit	8,25
Water	kg	10

ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Switzerland (including import)	kWh/year	767
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	10165

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

Step 2: Entering data of conventional system

The conventional system is constituted by the following components: a conventional chiller (10 kW), a gas boiler (10 kW), a PV system composed by the electric system, 23.6 m^2 of multi-Si photovoltaic panel, and an inverter (1800 W), a lithium-ion-manganate battery (90 kg). During the operation step

(25 years), the system consumes 14,951 kWh/year of natural gas. The electricity consumed by the system is produced by the photovoltaic system.

The life cycle of each system component is estimated to be 25 years, except for the inverter (12.5 years) and the battery (8.3 years). Thus, during the life cycle of the system two inverters and three batteries are installed.

We can create the process, as follows:

- in the "quantity" field corresponding to the component "battery lithium-ion-manganate", we enter the value "270", that is the mass of three batteries;
- in the "quantity" field corresponding to the component "conventional chiller (10 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "gas boiler (10 kW)", we enter the value "1";
- in the "quantity" field corresponding to the component "electric installation (PV system)", we enter the value "1";
- in the "quantity" field corresponding to the component "photovoltaic panel, multi-Si", we enter the value "23.6";

in the "quantity" field corresponding to the component "inverter (2500 W)", we enter the value "2";

Referring to the inverters, we have to calculate the correct value to be entered. The tool shows the impacts for a 2500 W inverter, but the system uses a 1800 W inverter. We can assimilate the inverter of 1800 W to 0.72 inverters of 2500 W. Thus, in the "quantity" field corresponding to the component "inverter (2500 W)", we enter the value "0.72". As outlined in the previous chapters, this assumption can reduce the reliability of the results.

In the Table "Energy sources", we enter the natural gas consumption. In the Table "Other information", we enter information about the life cycle of the system.

The following picture shows the table "Components of conventional system" completed with all input data.

COMPONENTS OF THE CONVENTIONAL SYSTEM	U.M.	QUANTITY
Battery lead-acid	kg	
Battery lithium-iron-phosphate	kg	
Battery lithium-ion-manganate	kg	270
Battery nickel cadmium	kg	
Battery nickel cobalt manganese	kg	
Battery nickel metal hydride	kg	
Battery sodium-nickel-chloride	kg	
Battery v-redox	kg	
Conventional chiller (10 kW)	unit	1
Electric installation (PV system)	unit	1
Gas boiler (10 kW)	unit	1
Inverter (500 W)	unit	
Inverter (2500 W)	unit	0,72
Photovoltaic panel, a-Si	m^2	
Photovoltaic panel, CdTe	m^2	
Photovoltaic panel, CIS	m^2	
Photovoltaic panel, multi-Si	m^2	23,6
Photovoltaic panel, ribbon-Si	m^2	
Photovoltaic panel, single-Si	m^2	
Pipes	m^2	
Pump (40 W)	unit	

ENERGY SOURCES	U.M.	QUANTITY
Electricity	kWh/year	
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	14951

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

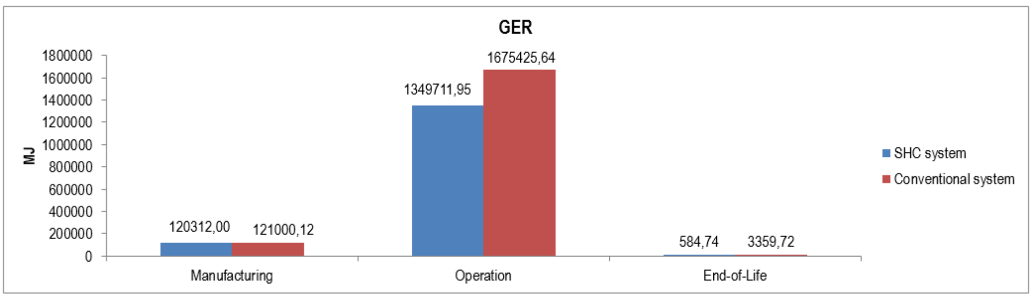
Step 3 is the same than that of Example 1 and the analysis of the results can be made in a similar way than Example 1.

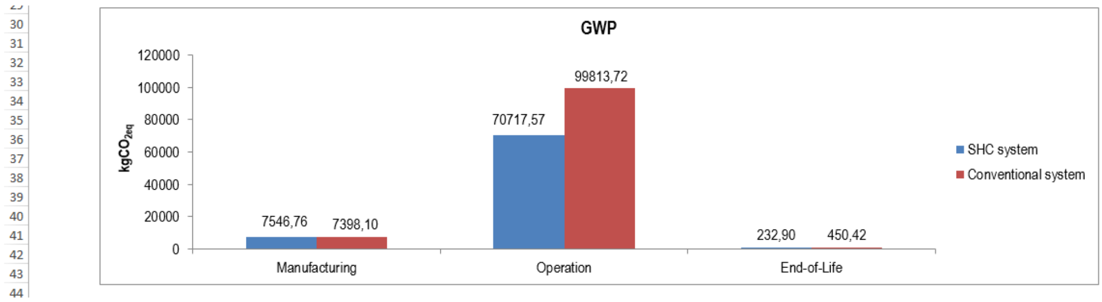
Now, let us go to the impact comparison, shown below.

A comparison of GER and GWP shows that the SHC system has the lowest global energy requirement and global warming potential for each life-cycle step.

Compared with the results of Example 3, in this case the operation step of conventional system has a higher impact than that of SHC system.

System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	120312,00	1349711,95	584,74	1470608,70	7546,76	70717,57	232,90	78497,23
Conventional system	121000,12	1675425,64	3359,72	1799785,48	7398,10	99813,72	450,42	107662,25



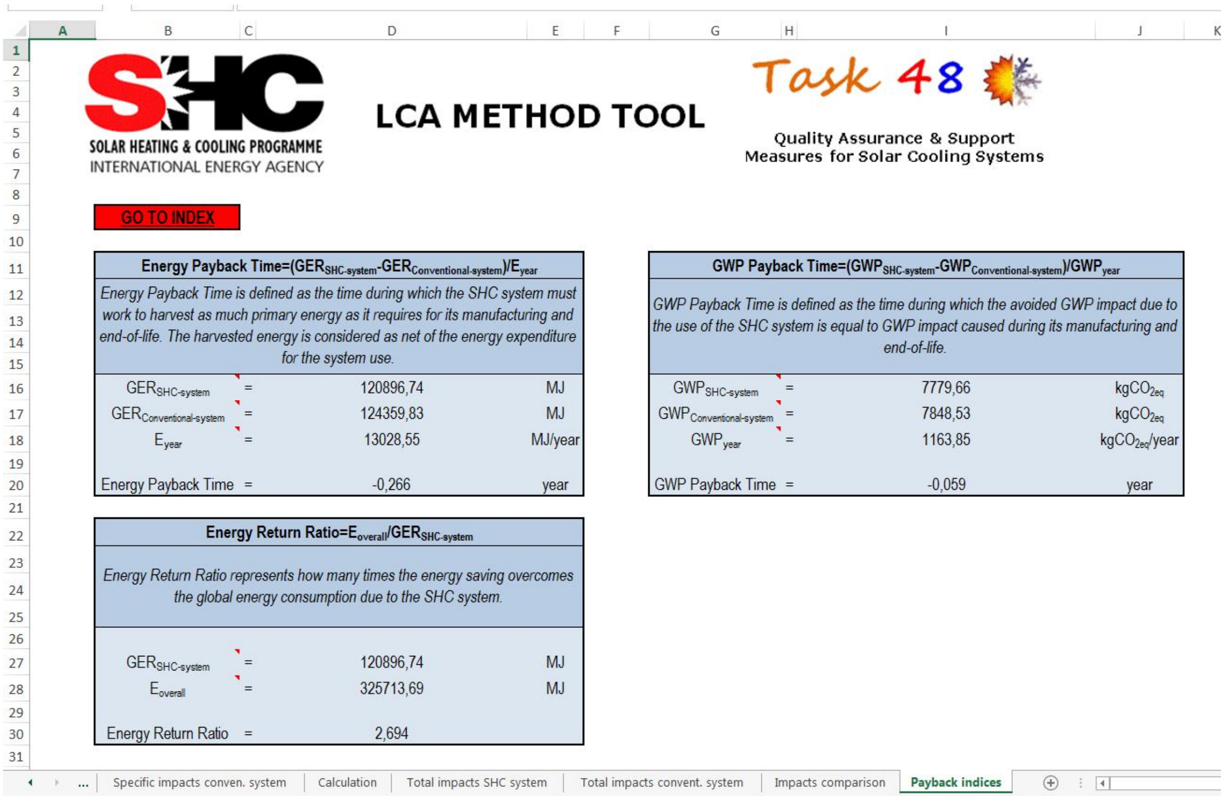


An analysis of the “payback indices” worksheet show that the net yearly primary energy saving, net yearly avoided GWP and net primary energy saving during the overall life cycle of the SHC system have positive values, showing the advantages due to the use of SHC systems in substitution with conventional ones.

However, even in this case, the Energy Payback Time and GWP Payback Time have negative values.

During the manufacturing and end-of-life step the impacts of the conventional system are higher than the one of the SHC one, due to the high incidence of battery manufacturing and dismalting on the total impacts.

The Energy Return Ratio has a value of about 2.7. This means that the primary energy saved by using the SHC system instead of the conventional one is 2.7 times higher than the primary energy consumed for the manufacturing and end-of-life of the SHC system.



2.1.2.6 Case studies: main conclusions

The case studies described above show a comparison of SHC systems with conventional ones. The results of the case studies provide a comprehensive investigation of the energy and environmental performance of solar assisted cooling systems during their life cycle. For some configurations, the primary energy savings and avoided greenhouse gases emissions related to the use of SHC systems instead of conventional ones are also showed.

Different system configurations have been investigated, and different results have been obtained for each configuration.

The comparison of a SHC system located in Palermo (Italy) with a cold backup configuration with a conventional system (Case study 1) shows the energy and environmental advantages due to the use of SHC systems in substitution of conventional ones. In particular, the values of GER and GWP for SHC system result about 45% lower than the impacts for the conventional one. Thus, the higher impacts caused by the SHC system during the manufacturing and end-of-life steps are balanced by the energy savings and avoided emissions during the operation step. An analysis of the Energy and GWP Payback Time indices shows that the yearly energy saving and avoided GWP impact during the operational step of the SHC system annul the additional impacts caused for its manufacturing and end-of-life in a time lower than 5 years. In addition, the energy saved during the useful life of the SHC system overcomes the global energy consumption due to its manufacture and end-of-life of about four times (Energy Return Ratio about 4.2).

Case study 2 shows a comparison between a SHC system located in Palermo (Italy) with a cold backup configuration and a conventional system assisted by a grid-connected PV system. In this case, the conventional system is the best one, with the lowest global energy requirement and global warming potential for each examined life cycle step. Thus, in this case there are no energy and environmental advantages arising from the substitution of the conventional system with a SHC system. Furthermore, the operation step of the SHC system shows higher impacts if compared with the operation of the conventional system, which uses electricity produced by renewable energy sources. Consequently, negative values are obtained for Energy Payback Time, GWP Payback Time and Energy Return Ratio.

The comparison of a SHC system located in Palermo (Italy) with a cold backup configuration compared with a conventional system assisted by a stand-alone PV system (Case study 3) shows that the SHC system has the lowest global energy requirement and global warming potential. However, referring to the operation step, the conventional system, which uses electricity produced by renewable energy sources, is characterized by lower impacts. Therefore, negative values are obtained for net yearly primary energy saving, net yearly avoided GWP, and net primary energy saving during the overall life cycle of the SHC system. This indicates that during the operation step the impacts of the SHC system are higher than that of the conventional one. Thus, even if the total energy and environmental impacts of the conventional system are higher than that of the SHC system, the last one has worse performances during the operation step. In this case, the calculation of the payback time indices cannot be carried out.

Case study 4 compares a SHC system located in Zurich (Switzerland) with a cold backup configuration and a conventional system assisted by a stand-alone PV system. SHC system has the lowest global energy requirement and global warming potential for each life-cycle step. Positive values of net yearly avoided GWP and net primary energy saving during the overall life cycle of the SHC system show the advantages due to the use of SHC systems in substitution with conventional ones.

In this specific case study, the impacts for manufacturing and end-of-life steps of the conventional system are higher than that of the SHC one, due to the high incidence of battery manufacturing and dismantling on the total impacts. Consequently, there is no additional energy for the manufacturing and end-of-life step of SHC system if compared with the conventional system and negative values are obtained for the Energy and GWP Payback Time indices. The primary energy saved by using the SHC system instead of the conventional one is 2.7 times higher than the primary energy consumed for the manufacturing and end-of-life of the SHC system.

An interesting and more comprehensive comparison among SHC systems and different configurations of conventional systems (including PV assisted) can be found in: Marco Beccali, Maurizio Cellura, Pietro Finocchiaro, Francesco Guarino, Sonia Longo, Bettina Nocke. Life cycle performance assessment of small solar thermal cooling systems and conventional plants assisted with photovoltaics, Solar Energy Volume 104, June 2014, Pages 93–102.

2.2 LCA from SolarCoolingOpt Project

The objective of the life cycle analysis (Life Cycle Assessment, LCA) is to assess optimized solar heat driven cooling systems developed in the Austrian research project 'SOLAR COOLING OPT' with regard to the reduction of the non-renewable primary energy use and greenhouse gas emissions.

2.2.1 Investigated systems

The LCA is performed based on two case studies:

1. Absorption chiller (ABKM) H_2O-LiBr, refrigeration capacity 1.470 kW (large scale)
2. Absorption chiller (ABKM) NH_3-H_2O, refrigeration capacity 19 kW ()

For each case study a "baseline" and an "optimized version" are examined for the solar thermal cooling system (Table 6). Based on results from the optimization of system configurations and control strategies, the optimized version was defined. The solar thermal cooling systems are compared with reference systems with a compression chiller (CCH), a natural gas boiler and photovoltaics (PV). The competitive systems deliver energy to cover the same required cooling, heating and hot water demand as the solar cooling system. The electricity derived from photovoltaic system partially operates the compression chiller and other electric consumers of the energy systems.

Table 6: Overview of the variants studied

<table>
<tr><th>Variante</th><th>Bezeichnung</th><th>Eckdaten</th></tr>
<tr><td colspan="3">Fallbeispiel „Absorptionskältemaschine H_2O-LiBr, Kälteleistung 1470 kW"</td></tr>
<tr><td colspan="2">Solarthermisches Kühlung</td><td rowspan="7">Standort: Singapur
Kälteleistung: 1470 kW
Kühlen und Warmwasser für College Campus</td></tr>
<tr><td>Basisvariante</td><td>ABKM + Kollektor (3870m²)</td></tr>
<tr><td>Optimierte Variante</td><td>ABKM+ Kollektor (5808m²)</td></tr>
<tr><td colspan="2">Referenz</td></tr>
<tr><td>Kompressionskältemaschine mit Gaskessel</td><td>KKM + Gaskessel</td></tr>
<tr><td rowspan="2">Kompressionskältemaschine mit Gaskessel und PV</td><td>KKM + Gaskessel + PV (1000m²)</td></tr>
<tr><td>KKM + Gaskessel + PV (2000m²)</td></tr>
<tr><td colspan="3">Fallbeispiel „Absorptionskältemaschine NH_3-H_2O, Kälteleistung 19 kW"</td></tr>
<tr><td colspan="2">Solarthermisches Kühlung</td><td rowspan="8">Standort: Wien
Kälteleistung: 19 kW
Kühlen, Heizen, Warmwasser für Bürogebäude</td></tr>
<tr><td>Basisvariante</td><td>ABKM + Kollektor + Kaltwassertank + Gaskessel</td></tr>
<tr><td>Optimierte Variante</td><td>ABKM + Kollektor + Backup KKM + Gaskessel</td></tr>
<tr><td colspan="2">Referenz</td></tr>
<tr><td>Kompressionskältemaschine mit Gaskessel</td><td>KKM + Gaskessel</td></tr>
<tr><td rowspan="3">Kompressionskältemaschine mit Gaskessel und PV</td><td>KKM + Gaskessel + PV (20m²)</td></tr>
<tr><td>KKM + Gaskessel + PV (40m²)</td></tr>
<tr><td>KKM + Gaskessel + PV (60m²)</td></tr>
</table>

2.2.2 Methodology

The method of life cycle analysis is applied to determine the non-renewable primary energy demand and the greenhouse gas emissions of solar thermal cooling systems and reference systems. Therefore environmental effects during the life cycle, e.g. production phase, use phase and disposal phase, are examined. Figure 10 shows schematically the considered processes during the production, use and disposal phase of the cooling systems.

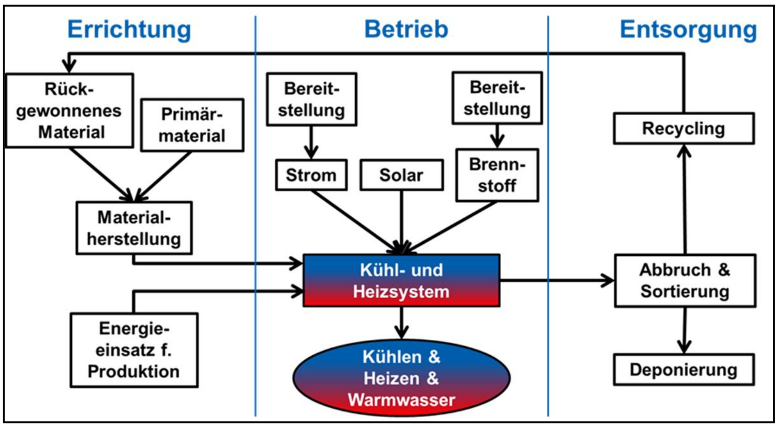


Figure 10: System boundaries in construction, operation and disposal

The following environmental effects are examined:

- Greenhouse gas emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorocarbons (HFCs), fully halogenated chlorofluorohydrocarbons (CFCs), partially halogenated chlorofluorohydrocarbons (HCFCs) and chlorocarbons are measured via carbon dioxide equivalent (CO_2e) during an observation period of 100 years (Global Warming Potential 100)
- Cumulative non-renewable primary energy demand

For these environmental effects absolute values based on the entire life span of the cooling system (e.g. xt CO_2e) and specific values based on 1 kWh of usable energy (e.g. 73g CO_2e/ (0.94 kWh Cooling + 0.06kWh hot water)) were determined.

PV power which is not used in the local energy system (for cooling, heating and domestic hot water preparation) it is assumed that 80% of this electricity (storage efficiency for the storage of PV electricity in the grid) replaces the typical power mix in the grid (depending on the installation location).

2.2.3 Results

The LCA results for the two investigated case studies indicate that the greenhouse gas emissions, which are emitted during the construction and disposal phase, are 2 to 3 times as high as the reference system "compression chiller + gas boiler". In addition, the non-renewable energy demand is 3 to 10 times as high as the reference system. For the reference systems additionally equipped with PV-modules, the greenhouse gas emissions and the non-renewable primary energy demand of the construction and disposal phase is quite similar to the values of the solar thermal cooling systems, depending on the size of the PV-system. The greenhouse gas with the largest contribution (70-90%) in the construction and disposal phase of solar thermal cooling systems is CO_2, which comes primarily from the fossil energy input for production of the technical components. For systems with a compression chiller also HFCs, CFCs, HCFCs and CHCs have a relevant contribution to greenhouse gas emissions, mainly due to losses of the refrigerant R410A in the production and disposal phase of the compression chiller. For example, the results for the greenhouse gas emissions of the production and disposal phase of the case study "Absorption chiller H2O-LiBr, refrigeration capacity 1470 kW" are shown in Figure 11.

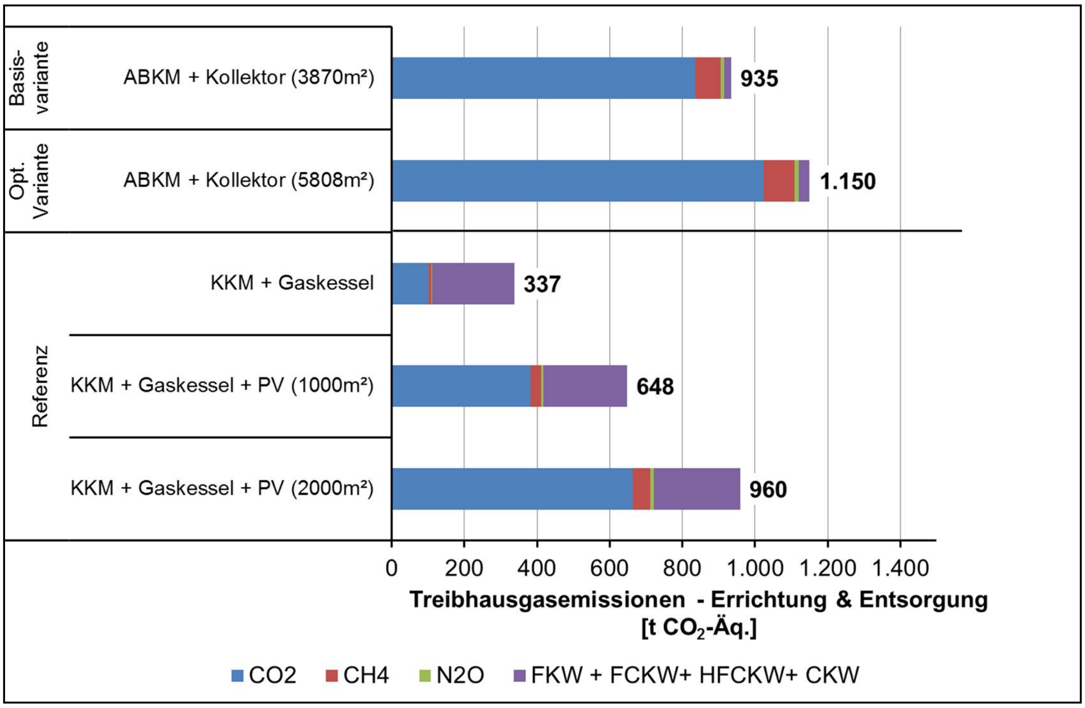


Figure 11: Case study " Absorption chiller H_2O-LiBr, refrigeration capacity 1470 kW": greenhouse gas emissions from construction and waste disposal for the base variant, the optimized version and the reference systems divided into the type of greenhouse gas emissions; refrigerant of the compression chiller: R410A

Considering the entire life cycle, the results of the LCA must be interpreted separately, because the case studies differ greatly in location, size, operation and supply of useful energy.

Especially the higher greenhouse gas emissions and the higher non-renewable primary energy demand of the production and disposal phase of case study "Absorption chiller H_2O-LiBr, refrigeration capacity 1470 kW" can be compensated by the use of solar thermal energy for cooling and hot water supply in the use phase. Over the entire life cycle the baseline reduces greenhouse gas emissions and the non-renewable primary energy demand by about 35% compared to the conventional reference system "compression chiller + gas boiler". In the optimized scenario of the large-scale solar cooling system, the energy savings potential with approx. 50% is significantly higher. Figure 12 indicates the absolute greenhouse gas emissions of both the optimized scenario and the reference systems with a life cycle of 20 years.

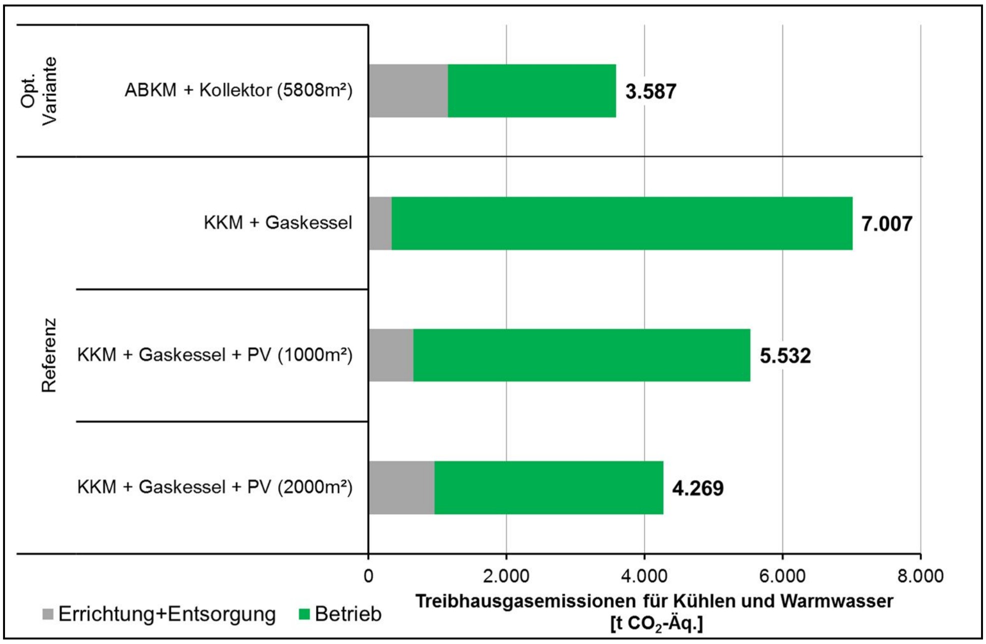


Figure 12: Case study „Absorption chiller H_2O-LiBr, refrigeration capacity 1470 kW": greenhouse gas emissions of the solar thermal optimized variant "Absorption chiller + collector (5808m²)" and the reference systems for cooling and hot water at a life cycle of 20 years

In the case study "Absorption chiller NH_3-H_2O, refrigeration capacity 19 kW" in addition to cooling and hot water supply also heating energy is provided. The focus of the study, however, was placed on the cooling mode, since optimization measures were made. For the cooling operation (including hot water supply at that time) the solar thermal base variant shows no savings compared to the reference system "compression chiller + gas boiler" when looking at the entire life cycle. Because of optimization measures in the system configuration and control, significant savings of greenhouse gas emissions and non-renewable energy demand can be achieved. In comparison to the reference system "compression chiller + gas boiler" the solar-thermal optimized variant reduces the greenhouse gas emissions and non-renewable primary energy demand by about 30%. As examples of the results for this case, the specific greenhouse gas emissions and the specific non-renewable primary energy demand are shown in Table 7 and Table 8.

The variation of the calculation parameters life cycle, refrigerant losses during operation and disposal shows that especially the refrigerant losses during the operational phase can have a high impact on the overall result. In the solar-thermal optimized version of the case study “Absorption chiller NH_3-H_2O, refrigeration capacity 19 kW” a compression chiller is used as a backup. Looking at the annual refrigerant loss the advantage of the optimization measure in terms of the greenhouse gas reduction potential is annulled when reaching 10%/a (Figure 13). In this case, also the solar thermal base variant with a thermal backup has lower greenhouse gas emissions than the reference system "compression chiller + gas boiler".

A detailed description of the work of the life cycle analysis of selected solar thermal systems is given in Annex 6 "Bewertung der Primärenergieeffizienz und der Treibhausgasreduktion im Lebenszyklus".

Table 7: Case study Absorption chiller NH_3-H_2O, refrigeration capacity 19 kW: Specific greenhouse gas emissions of solar thermal variations and the reference systems (lifetime 20 years)

		Treibhausgasemissionen					
		Basisvariante	*optimierte Variante*	*Referenzsystem*			
		ABKM + Kollektor + Kaltwassertank + Gaskessel	ABKM + Kollektor + Backup KKM + Gaskessel	KKM + Gaskessel	KKM + Gaskessel + PV(20m²)	KKM + Gaskessel + PV(40m²)	KKM + Gaskessel + PV(60m²)
Kühlen + Warmwasser	[g CO_2-Äq./(0,8 $kWh_{Kühlen}$ + 0,2 $kWh_{Warmwasser}$)]	260	141	209	nicht untersucht		
Heizen + Warmwasser	[g CO_2-Äq./(0,9 kWh_{Heizen} + 0,1 $kWh_{Warmwasser}$)]	271	271	280	nicht untersucht		
Kühlen + Heizen + Warmwasser	[g CO_2-Äq./ (0,2 $kWh_{Kühlen}$ + 0,7 kWh_{Heizen} + 0,1 $kWh_{Warmwasser}$)]	268	248	269	253	238	223

Table 8: Case study Absorption chiller NH_3-H_2O, refrigeration capacity 19 kW: Specific accumulated non-renewable primary energy demand of solar thermal variations and the reference systems (lifetime 20 years)

		Kumulierter nicht erneuerbarer Primärenergiebedarf					
		Basisvariante	*optimierte Variante*	*Referenzsystem*			
		ABKM + Kollektor + Kaltwassertank + Gaskessel	ABKM + Kollektor + Backup KKM + Gaskessel	KKM + Gaskessel	KKM + Gaskessel + PV(20m²)	KKM + Gaskessel + PV(40m²)	KKM + Gaskessel + PV(60m²)
Kühlen + Warmwasser	[kWh/(0,8 $kWh_{Kühlen}$ + 0,2 $kWh_{Warmwasser}$)]	1,14	0,49	0,78	nicht untersucht		
Heizen + Warmwasser	[kWh/(0,9 kWh_{Heizen} + 0,1 $kWh_{Warmwasser}$)]	1,26	1,26	1,31	nicht untersucht		
Kühlen + Heizen + Warmwasser	[kWh/ (0,2 $kWh_{Kühlen}$ + 0,7 kWh_{Heizen} + 0,1 $kWh_{Warmwasser}$)]	1,24	1,10	1,20	1,13	1,06	0,99

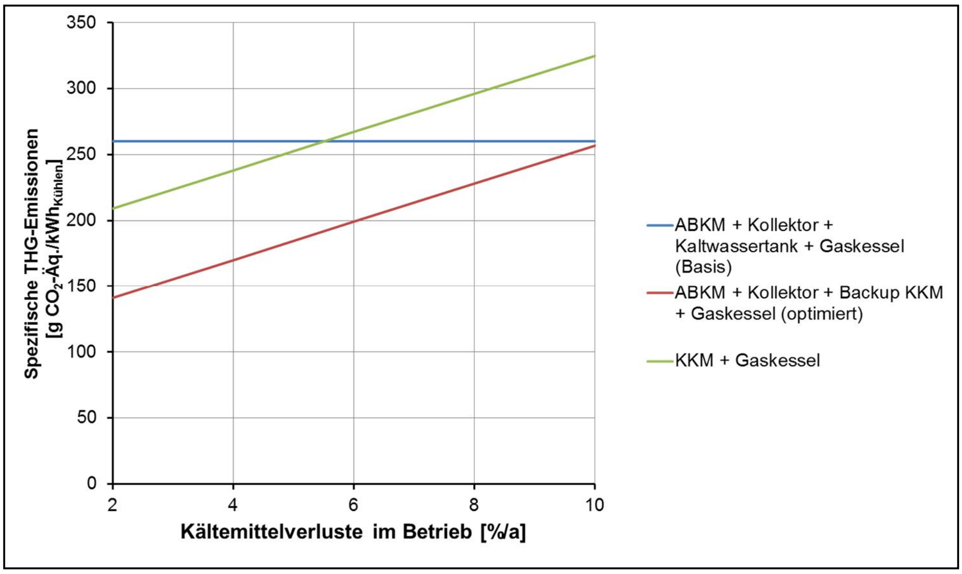


Figure 13: Greenhouse gas emissions of solar thermal variant and the reference system "compression chiller + gas boiler" with a refrigerant emission factor of 10% during the operational phase (lifetime 20 years)

2.2.4 Conclusions

To investigate the greenhouse gas reduction potential and the potential for the reduction of non-renewable primary energy demand of solar thermal cooling systems, a life cycle analysis was performed for two case studies. Therefore, a basic version and an optimized version of the solar thermal cooling system were studied in each system. They are also compared with the reference systems, which are equipped with compression chillers and a natural gas boiler for the heat and hot water supply. The results of this life-cycle analysis for the two investigated case studies show that the greenhouse gas emissions are 2 to 3 times as high and the primary energy demand is 3 to 10 times as high as the reference system "compression chiller + gas boiler". For the reference system with a PV plant, the greenhouse gas emissions and the non-renewable primary energy demand of the construction and disposal is in a similar range as for the solar thermal cooling systems, depending on the size of the PV plant.

The greenhouse gas with the largest contribution (70-90%) in the construction and disposal of solar thermal cooling systems is CO_2, which comes primarily from the fossil energy input for production of plant components. For systems with a compression chiller also HFCs, CFCs, HCFCs and CHCs have a relevant contribution to greenhouse gas emissions, mainly due to losses of the refrigerant R410A in the manufacture and disposal of the compression chiller.

When considering the whole life cycle, the results of the life cycle analysis must be interpreted separately, as the case studies differs greatly in location, size, operation and supply of useful energy.

In the case study "Absorption chiller H2O-LiBr, refrigeration capacity 1470 kW" the higher greenhouse gas emissions and the higher non-renewable primary energy demand in the operational phase can be compensated by the use of solar thermal energy for cooling and hot water supply.

The base variant reduces greenhouse gas emissions and the non-renewable primary energy demand by about 35% compared to the conventional reference system "compression chiller + gas boiler". In the solar thermal optimized variant, the energy savings potential with approx. 50% is significantly higher.

In the case study “Absorption chiller NH3-H2O, refrigeration capacity 19 kW” in addition to cooling and hot water supply also heating energy is provided. The focus of the study, however, was placed on the cooling mode, since optimization measures were made. For the cooling operation (including hot water supply at that time) the solar thermal base variant shows no savings compared to the reference system “compression chiller + gas boiler” when looking at the entire life cycle. Because of optimization measures in the system configuration and control, significant savings of greenhouse gas emissions and non-renewable energy demand can be achieved. In comparison to the reference system "compression chiller + gas boiler" the solar-thermal optimized variant reduces the greenhouse gas emissions and non-renewable primary energy demand by about 30%.

The variation of the parameters life cycle, refrigerant losses during operation and disposal shows that especially the refrigerant losses during the operational phase can have a high impact on the overall result. In the solar-thermal optimized version of the case study “Absorption chiller NH_3-H_2O, refrigeration capacity 19 kW” a compression chiller is used as a backup. Looking at the annual refrigerant loss the advantage of the optimization measure in terms of the greenhouse gas reduction potential is annulled when reaching 10%/a. In this case also the solar thermal base variant with a thermal backup has lower greenhouse gas emissions than the reference system "compression chiller + gas boiler". Based on these combined results, the following conclusions can be drawn:

- Solar thermal cooling systems have higher greenhouse gas emissions and a higher non-renewable primary energy demand than systems with a compression chiller and a gas boiler.
- In an optimized operation, solar thermal cooling systems can compensate those higher emissions and the higher energy demand for construction and disposal. In the investigated case studies the greenhouse gas emissions and the non-renewable primary energy demand in cooling mode can be decreased by 35% to 50% when they are compared with systems with a compression chiller and a gas boiler.
- Cooling systems based on a compression chiller in combination with PV systems have potential savings of a similar magnitude as solar thermal cooling systems. A major factor is the sizing of the PV system and the evaluation of the excess electricity produced when feeding into the grid.
- Due to the greater share of construction and disposal phases on the emissions and the non-renewable primary energy demand over the entire life cycle in solar thermal cooling systems, a long system life cycle had a positive effect. When using compression chillers with refrigerants with a high GWP (e.g. R410A) refrigerant losses during the operational phase and

disposal should be kept as low as possible. For these reasons, a professional maintenance and servicing of the cooling systems is of great importance.

3. Conclusions

This technical report describes the research activities of Subtasks A2 "Life cycle analysis at component level" and B3 "Life cycle analysis at system level".

With reference to Subtask A2, a complete update and upgrade of the database of life cycle inventories for components of SHC systems, developed within IEA-SHC Task 38, has been done. Life cycle assessment of a Pink PC19 Ammonia Chiller and of a Packed Adsorption Bed have been completed. The LCAs of other components has been set up but not completed due to the lack of complete and reliable data. The results of the LCA studies have been used to create the LCA method tool of Subtask B3.

With reference to Subtask B, a LCA method tool for SHC systems has been created, equipped with a guide for users. Some practical examples have been developed to show how the tool can be used.

The tool allows calculating:

- The global warming potential and the primary energy consumption of a specific SHC system and of a conventional system that has the same function of the SHC one;
- The life-cycle steps of the SHC and conventional systems that cause the main energy and environmental impacts;
- For the production step of the SHC system and conventional system, the components that are responsible of the main energy and environmental impacts;
- The net yearly impact savings due the use of the SHC system instead of the conventional one;
- The energy payback time, the GWP payback time, and the energy return ratio of the SHC system, in comparison with a conventional plant.

Within Subtask B the results of the SolarCoolingOpt project have been also illustrated.

4. References

European Commission, DG Joint Research Centre, Institute for Environment and Sustainability, 2011. ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European context – based on existing environmental impact assessment models and factors. Available on http://lct.jrc.ec.europa.eu/.

European Commission, DG Joint Research Centre - Institute for Environment and Sustainability, 2012. Characterization factors of the ILCD Recommended Life Cycle Impact Assessment methods. Database and supporting information. First Edition EUR 25167. Luxembourg Publications Office of the European Union.

Frischknecht, R., Jungbluth, N., Althaus, H.J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., Spielmann, M., 2007a. Overview and Methodology. Ecoinvent Report No. 1, ver.2.0, Swiss Centre for Life Cycle Inventories. Dübendorf (CH).

Frischknecht, R., Jungbluth, N., Althaus, H.J., Bauer, C., Doka, G., Dones, R., Hischier, R., Hellweg, S., Humbert, S., Köllner, T., Loerincik, Y., Margni, M., Nemecek T., 2007b. Implementation of Life Cycle Impact Assessment Methods. Ecoinvent report No. 3, v2.0. Swiss Centre for Life Cycle Inventories. Dübendorf.

ISO 14040, 2006. Environmental management - Life cycle assessment - Principles and framework.

ISO 14044, 2006. Environmental management - Life cycle assessment - Requirements and guidelines.

Krügher,U., 1994. Arc Welding Processes: TIG, Plasma Arc, MIG. TALAT lecturer 4201. EEA-European Aluminum Association.

Prè - Product Ecology Consultants, 2012. Software SimaPro7.

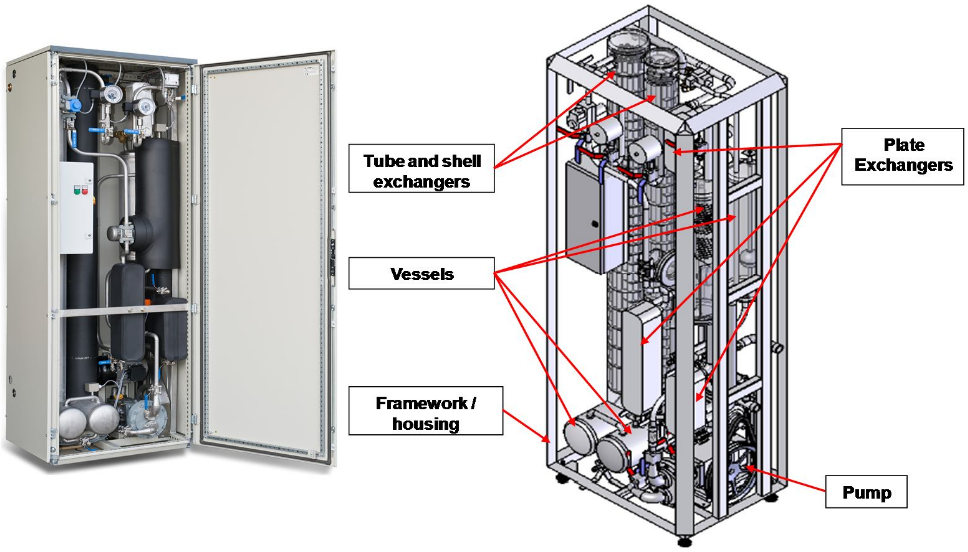
Annex 1

A.1 Absorption chiller (12 kW)

1. **Product:** Absorption chiller (F.U. 1 unit)

2. **Authors and reference:** data published by Beccali, M., Cellura, M., Ardente, F., Longo, S., Nocke, B., Finocchiaro, P., Kleijer, A., Hildbrand, C., Bony, J., 2010. Life Cycle Assessment of Solar Cooling Systems – A technical report of subtask D Subtask Activity D3, Task 38 Solar Air-Conditioning and Refrigeration, IEA. Solar Heating & Cooling Programme.

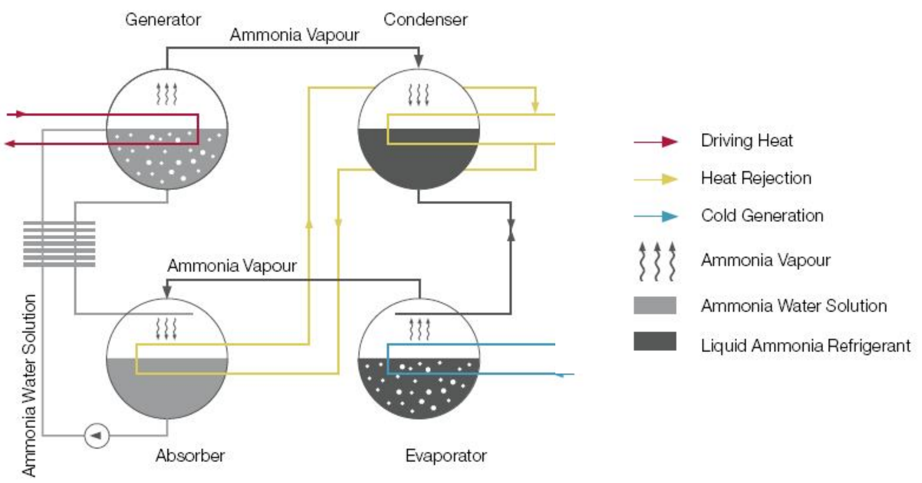
3. **Description of the product** Absorption chiller SolarNext/Pink chilli®PSC12



The SolarNext/Pink Absorption Chiller

4. **Characteristics of the product**

Nominal power/surface/other: power 12 kW
Measured/estimated yearly energy production and/or consumption:
Information about the use phase: The absorption chiller, filled with ammonia/water solution, generates cold through a closed, continuous cycle. The absorption chiller consists of four main components: the generator (also named boiler or expeller), the condenser, the evaporator and the absorber. Inside the generator (Figure below), hot water is supplied to the chiller through a heat exchanger. A part of the ammonia is being expelled from the ammonia / water solution and condensed again inside the condenser. The ammonia condensate is fed to the evaporator where it is evaporated. During this process, heat energy is discharged from the cooling cycle, which cools it down. Inside the absorber, the ammonia is absorbed from the low concentrated refrigerant ammonia/water solution and the cycle starts over again.



Ammonia cycle into Absorption Chiller

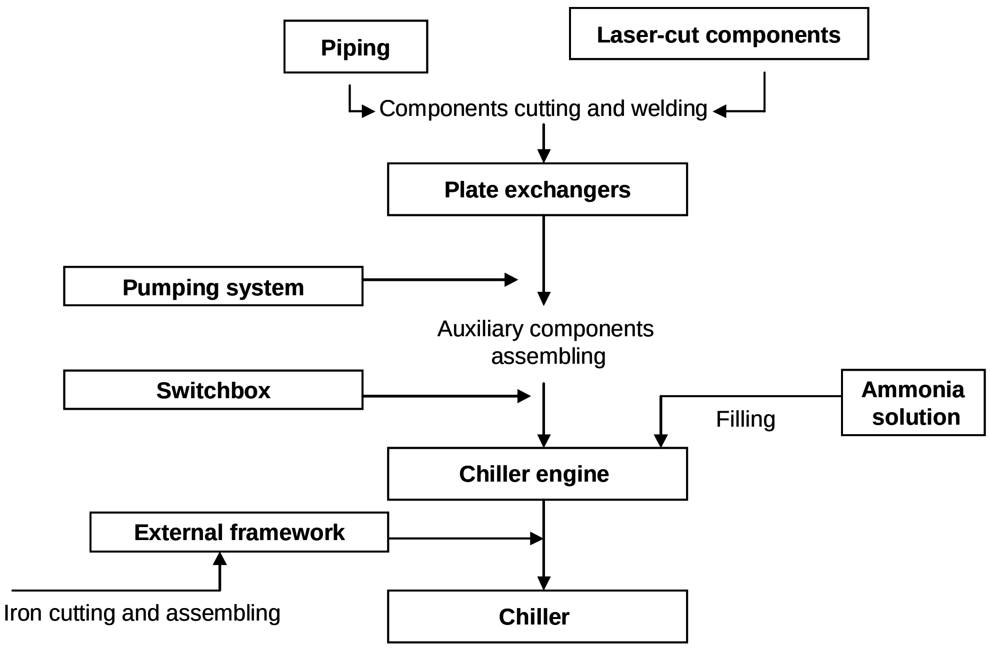
Information about the end-of-life phase:

5. Metadata

Age of the study: Materials and energy data have been investigated in 2009.

System boundaries: production and delivery of raw materials, production process in the factory and disposal of production wastes at the end-of-life.

The production of the chiller consists mainly in the cutting, TIG welding (Tungsten Inert Gas welding with argon gas) and assembling of semi-manufactured components.



Production diagram flow

The supplying of raw metal materials comes mainly from North Italy, France and North Europe. Few components are locally purchased. Almost all the transportations occur by road, except a short shipping from Sweden to Denmark. Total transportations amount to 266 tkm by large capacity trucks and 2 tkm by ship.

Useful life-time:25 years

Cut-off rules: a cut off rule of 5% has been adopted. Electronic components (electric cables, sensors, manometers and motor parts), that represent the 4.1% of the overall system mass, have been neglected.

Allocation rules: Concerning the assessment of the specific consumption of electricity and production of wastes per functional unit, allocation has been undergone with a mass criterion. In particular, the yearly consumption of electricity (50,000 kWh/year), the heat consumption (155,000 kWh/year from biomass district heating) and the disposed wastes (metal scraps 10,000 kg/year) have been allocated considering that the produced absorption chiller represent about 4% of the yearly company's production.

Further details:

Data Quality Assessment: the absorption chiller is produced in the plant of the "Pink" company, sited in Austria. Impacts related to the use of electricity refer to the Austrian energy mix. Eco-profiles of raw materials refers to average European data and are referred to Ecoinvent database.

Concerning the insulation, Armaflex® is employed. It is a closed cell, CFC free elastomeric rubber material made in tube and sheets form for insulating piping, ducts and vessels. Missing data about such insulation, eco-profile of common rubber have been considered.

6. Life Cycle Inventory

<table>
<tr><td rowspan="3">Main employed materials and components:
Carbon steel (housing): 136 kg
Stainless steel (tube & shell): 110 kg
Stainless steel (vessels): 25 kg
Ammonia (60%) & water (40%) (working solution): 25 kg
Stainless steel (plate): 21 kg
Stainless steel (piping): 20 kg
Carbon steel (pumping system): 15 kg
Stainless steel (pumping system): 5 kg
Aluminium (pumping system): 10 kg
Copper (pumping system): 5 kg
Others (pumping system): 6 kg
Electronics (various): 10 kg</td><td>Main Air Emissions</td></tr>
<tr><td>Main Water Emissions</td></tr>
<tr><td>Main Wastes</td></tr>
</table>

Armaflex (insulation): 4 kg Cast iron (valves): 2 kg	

7. Product Eco-profile

Global Impact Indexes	Total	Per unit of power
Global Energy Requirement (GER)	26.01 [GJ]	2.16 [GJ/kW]
Global Warming Potential (GWP)	1394.9 [kg CO_{2eq}]	116.24 [kg CO_{2eq}/kW]

A.2 Absorption chiller Pink PC 19

1. **Product:** Absorption chiller Pink PC 19 (F.U. 1 unit)

2. **Authors and reference:** data elaborated by Beccali, M., Cellura, M., Longo, S.

3. **Description of the product** Absorption chiller Pink PC19

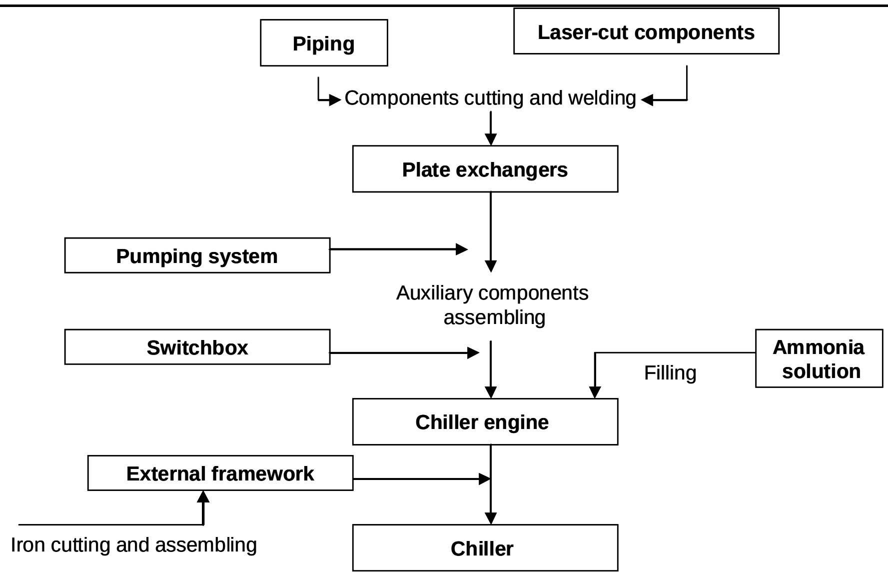
The Absorption Chiller Pink PC19

4. **Characteristics of the product**

Nominal power/surface/other: power 19 kW
Measured/estimated yearly energy production and/or consumption: -
Information about the operation phase: The chiller, filled with ammonia/water solution, generates cold through a closed, continuous cycle. The absorption chiller consists of four main components: the generator, the condenser, the evaporator and the absorber. Inside the generator, hot water is supplied to the chiller through a heat exchanger. A part of the ammonia is being expelled from the ammonia/water solution and condensed again inside the condenser. The ammonia condensate is fed to the evaporator where it is evaporated. During this process, heat energy is discharged from the cooling cycle, which cools it down. Inside the absorber, the ammonia is absorbed from the low concentrated refrigerant ammonia/water solution and the cycle starts over again.
Information about the end-of-life phase: -

5. **Metadata**

Age of the study: Materials and energy data have been investigated in 2013.
System boundaries: production and transport of raw materials, manufacturing process in the factory, end-of-life. The production of the chiller consists mainly in the cutting, TIG welding (Tungsten Inert Gas welding with argon gas) and assembling of semi-manufactured components.



Production diagram flow

The supplying of raw metal materials comes mainly from North Italy, France and North Europe. Few components are locally purchased. Almost all the transportations occur by road, except a short shipping from Sweden to Denmark. Total transportations amount to 294 tkm by large capacity trucks and 2.8 tkm by ship.

Useful life-time:20 years

Cut-off rules: a cut off rule of 3% has been adopted. Electronic components (electric cables, sensors, and motor parts), that represent the 2.5% of the overall system mass, have been neglected.

Allocation rules: concerning the assessment of the specific consumption of electricity and natural gas, and the production of wastes per FU, allocation has been undergone with a mass criterion. In particular, the yearly consumption of electricity (50,000 kWh/year), the yearly natural gas consumption (155,000 kWh/year from biomass district heating) and the yearly disposed wastes (metal scraps 10,000 kg/year) have been allocated considering that the produced absorption chiller represent about 6% of the yearly company's production.

Further details: -

Data Quality Assessment: the absorption chiller is produced in the plant of the "Pink" company, sited in Austria. Impacts related to the use of electricity refer to the Austrian energy mix. Eco-profiles of raw materials refers to average European data and are referred to Ecoinvent database.

Concerning the insulation, Armaflex is employed. It is a closed cell, CFC free elastomeric rubber material made in tube and sheets form for insulating piping, ducts and vessels. Missing data about such insulation, the eco-profile of a common rubber has been considered.

6. Life Cycle Inventory

	Main employed materials and components:	Main Air Emissions
	Carbon steel (housing): 125 kg Stainless steel (tube & shell): 150 kg Stainless steel (vessels): 20 kg Ammonia (50%) & water (50%) (working solution): 36 kg Stainless steel (plate): 29 kg Stainless steel (piping): 20 kg Carbon steel (pumping system): 30 kg Stainless steel (pumping system): 5 kg Aluminium (pumping system): 5 kg Aluminium (motor): 5 kg Copper (motor): 5 kg Others (motor): 6 kg Electronics (various): 5 kg Armaflex (insulation): 6 kg Cast iron (valves): 2 kg	- **Main Water Emissions** - **Main Wastes** -

7. Product Eco-profile

Global Impact Indexes	Total	Per unit of power
Global Energy Requirement (GER)	42.8 [GJ]	2.25 [GJ/kW]
Global Warming Potential (GWP)	2014.8 [kg CO_{2eq}]	106.04 [kg CO_{2eq}/kW]

A.3 Adsorption chiller (8 kW)

1. **Product:** Adsorption chiller (F.U. 1 unit)

2. **Authors and reference:** data published by Beccali, M., Cellura, M., Ardente, F., Longo, S., Nocke, B., Finocchiaro, P., Kleijer, A., Hildbrand, C., Bony, J., 2010. Life Cycle Assessment of Solar Cooling Systems – A technical report of subtask D Subtask Activity D3, Task 38 Solar Air-Conditioning and Refrigeration, IEA. Solar Heating & Cooling Programme.

3. **Description of the product** Adsorption chiller Sortech ACS 08

The Sortech ACS 08 Adsorption Chiller

4. **Characteristics of the product**

Nominal power/surface/other: power 8 kW
Measured/estimated yearly energy production and/or consumption:
Information about the use phase: The adsorption chiller, filled with silica gel/water pair, generates cold through a closed and continuous cycle. The chiller uses silica gel as sorption material and the internal structure follows a four compartments principle: evaporator, condenser and two compartments, interchanging periodically between adsorber and desorber function. The empty weight of the ACS 08 is 265 kg. The four process chambers are connected to each other by internal, automatically functioning steam valves. These valves influence the directional flow of the evaporated coolant into adsorber chambers or the condenser, depending on the phase of the process. In operating phase 1, hot water passes through adsorber 1. The coolant, which has accumulated on the inner surface of the silica gel, is expelled, thus causing it to condense on the cooled condenser. The condensation heat emitted is removed through the re-cooling circuit. The condenser has a constantly low temperature and pressure level and, therefore, acts as a temperature sink. Simultaneously, adsorber 2 adsorbs (i.e. water vapor from the evaporator is bound in the silica gel). During the conversion of the state of aggregation from a liquid to a gas, energy is extracted from the coolant (enthalpy of evaporation). This lower temperature level is led away through the evaporator as the cooling circuit. During adsorption of the water vapor in the silica gel, adsorption heat is released. This heat is removed through the re-cooling circuit of the ACS. This process is concluded once the average target temperature is reached.

All hydraulic components, necessary for the internal switchings, are installed inside of the chiller; this allows an easy connection of the chiller to the external three hydraulic circuits (high temperature source HT, heat rejection circuit MT and chilled water circuit LT).

Information about the end-of-life phase:

5. Metadata

Age of the study: -
System boundaries: production and delivery of raw materials, production process in the factory and disposal of production wastes at the end-of-life. The energy use for the fabrication of the chiller and the transport of the materials to the plant have not been taken in account.
Useful life-time:25 years
Cut-off rules: All materials have been taken in account excluded some vacuum components representing less than 1% of the mass.
Allocation rules: -
Further details:
Data Quality Assessment -

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions
	Main Water Emissions
	Main Wastes

7. Product Eco-profile

Global Impact Indexes	Total	Per unit of power
Global Energy Requirement (GER)	42.8 [GJ]	3.026 [GJ/kW]
Global Warming Potential (GWP)	1401.0 [kg CO_{2eq}]	175.12 [kg CO_{2eq}/kW]

A.4 Auxiliary gas boiler/gas boiler

1. Product: Gas boiler (F.U. 1 unit)

2. Authors and reference: data published by Thomas Heck in Ecoinvent ver.2.0

3. Description of the product Gas boiler (10 kW of power)

4. Characteristics of the product

Nominal power/surface/other: power 10 kW
Measured/estimated yearly energy production and/or consumption::
Information about the use phase:
Information about the end-of-life phase: wastes as plastics, packaging and hazardous wastes are incinerated. Rock wool wastes are discharged in an inert material landfill. The end-of-life of other wastes is not included.

5. Metadata

Age of the study: Materials data have been investigated in 1993. Data for energy use during the production phase have been estimated based on an environmental report for 1998.
System boundaries (production phase, use phase, end-of-life phase): data are referred to the production of a gas boiler in Switzerland and in Germany, including materials and energy use of production, and disposal of the product at the end of life. The transport of these materials and the energy and water needed for production are included.
Useful life-time:25 years
Cut-off rules: impacts related to transport of the gas boiler from the productive site to the utilization site and to the use phase are not included.
Allocation rules:
Further details:
Data Quality Assessment: input data have been extrapolated assuming that the material requirement for a gas boiler is approximately the same as for an oil boiler. Moreover, is has been assumed that these materials are about the same in modern (2000) boilers as well as in average installed boilers.

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions
Electricity, medium voltage: 81.7 kWh Natural gas: 472 MJ Light fuel oil: 249 MJ Water: 182 kg	SO_2: 1.4 kg CO_2: 371.5 kg CO: 3.19 kg Particulates: 1.53 kg

	Alkyd paint, white, 60% in solvent: 1.25 kg Aluminium: 7.5 kg Brass: 0.05 kg Brazing solder, cadmium free: 4 kg Chromium steel: 5 kg Copper: 3.03 kg Polyethylene, HDPE granulate: 0.9 kg Rock wool: 8 kg Corrugated board, mixed fibres: 5 kg Steel, low-alloyed: 115 kg	CH_4: 0.9 kg NO_x: 0.96 kg NMVOC: 201 g Al: 113 g NH_3: 57.9 g HCl: 20.7 g CS_2: 50 g N_2O: 9.36 g
		Main Water Emissions
		Si: 12.4 kg Cl^-: 2.92 kg SO_4^{2-}: 2.46 kg COD: 1.15 kg Ca^{2+}: 1.14 kg BOD_5: 598 g TOC: 434 g DOC: 430 g Na^+: 0.79 kg Solid substances: 664 g $Fe^{2}+$: 247 g Al: 266 g Mg: 93.4 g PO_4^{3-}: 81.5 g Oils: 93.2 g K^+: 41 g
		Main Wastes:
		Oils: 90.9 g

7. Product Eco-profile

Global Impact Indexes	Total	Per unit of power
Global Energy Requirement (GER)	6.8 [GJ]	0.7 [GJ/kW]
Global Warming Potential (GWP)	377.7 [kg CO_{2eq}]	37.7 [kg CO_{2eq}/kW]

A.5 Auxiliary conventional chiller (Heat pump brine-water)/Conventional chiller

1. **Product:** Heat pump brine-water (F.U. 1 unit)
2. **Authors and reference:** data published by Thomas Heck in Ecoinvent ver.2.0
3. **Description of the product:** heat pump brine-water 10 kW of output. Refrigerant R134a.
4. **Characteristics of the product**

Nominal power/surface/other: power 10 kW
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase: plastic wastes are incinerated. The end-of-life of other wastes is not included.

5. **Metadata**

Age of the study: 2004.
System boundaries (production phase, use phase, end-of-life phase): The module includes the most important materials used for production. It includes also the transport of these materials, energy and water needed for production. It includes emissions of refrigerant (R134a) during production and scrapping. It does not include emissions during operation. It does not include the borehole heat exchanger. A buffer heat storage is not included. Data are referred to the end of life of some parts of the product.
Useful lifetime: 25 years.
Cut-off rules: impacts related to transport of the storage from the productive site to the utilization site and to the use phase are not included.
Allocation rules:
Further details:
Data Quality Assessment: input data have been collected using literature and manufacturer information.

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Electricity, medium voltage: 140 kWh	CO_2: 376.9 kg
Natural gas: 1400 MJ	CO: 2.52 kg
Tube insulation, elastomere: 10 kg	Particulates: 1.35 kg
Refrigerant R134a: 3.09 kg	CH_4: 963.8 g
Copper: 22 kg	NO_x: 1.07 kg
Polyvinylchloride: 1 kg	SO_2: 3.17 kg

	Steel, low-alloyed: 20 kg Reinforcing steel: 75 kg Lubricating oil: 1.7 kg	NMVOC: 263 g Al: 188 g NH_3: 78.9 g HCl: 13.9 g Cr: 1,58 g Si: 2.19 g N_2O: 10.6 g
		Main Water Emissions: Si: 5.61 kg Cl^-: 3.93 kg SO_4^{2-}: 2.77 kg COD: 1.01 kg Ca^{2+}: 1.28 kg BOD_5: 479 g TOC: 430 g DOC: 428 g Na^+: 1.51 kg Solid substances: 269 g Fe^2+: 190 g Al: 184 g Mg: 85.9 g PO_4^{3-}: 60.2 g Oils: 75 g K^+: 42.7 g
		Main Wastes: Oils: 74.5

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	8.14 [GJ]
Global Warming Potential (GWP)	1576.3 [kg CO_{2eq}]

A.6 Cooling tower

1. **Product:** Cooling tower (F.U. 1unit)

2. **Authors and reference:** Sonia Longo, Maurizio Cellura, Marco Beccali

3. **Description of the product:** the cooling tower components are:

- axial fan, made of fibreglass-reinforced polyester. It has a low noise level and it is statically and dynamically balanced;
- PVC/Polypropylene exchangeable packs (fill material), very resistant to all types of acid and oil-polluted water as well as to high temperatures The PVC/Polypropylene droplet separator, specially designed to prevent the water loss due to the action of the fan;
- The water distribution system, made up of one or several polypropylene or galvanized steel pipes, with ABS water spray nozzles and waterways big enough to avoid the obstruction by accumulated sediments;
- Compact casing made of galvanized steel and fibreglass-reinforced polyester, with supports inlaid in the polyester. This material is highly resistant to all aggressive conditions, as well as to extreme temperatures.

4. **Product characteristics**

Nominal power/surface/other: - Nominal power: 34-48 kW; - Weight empty: 53 kg; - Weight in service: 144 kg; - Motor power: 0.33 kW.
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase: all wastes are recycled.

5. **Metadata**

Age of the study: 2010.
System boundaries (production phase, use phase, end-of-life phase): system boundaries include the life cycle of materials used to produce the tower and the disposal of the product at the end of life.
Useful lifetime: 25 years.
Cut-off rules: impacts related to transport of the tower from the productive site to the utilization site and to the use phase are not included. Environmental impacts and benefices related to the recycling of wastes at the end-of-life of the tower are not included.
Allocation rules:-
Further details:-

	Data Quality Assessment: estimation based to direct measurements.

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Galvanized steel: 19.7 kg	CO_2: 120.2 kg
Fibreglass-reinforced polyester: 19.4 kg	CO: 593.3 g
PVC: 11.5 kg	CH_4: 398.2 g
Polypropylene: 2.4 kg	SO_2: 331 g
	NO_x: 298 g
	Particulates: 258 g
	NMVOC: 125 g
	N_2O: 77 g
	SO_4^{2-}: 15.6 g
	Al: 11.8 g
	HCl: 6.62 g
	CS_2: 4.56 g
	Main Water Emissions:
	Cl^{-}: 6.08 kg
	Na^{+}: 1.68 kg
	Si: 1.58 kg
	COD: 1.08 kg
	BOD_5: 514 g
	SO_4^{2-}: 479 g
	Ca^{2+}: 260 g
	TOC: 191 g
	DOC: 186 g
	Solid substances: 77.4 g
	Al: 66.5 g
	Fe^{2}+: 54.8 g
	Mg: 25 g
	Acetic acid: 24.2 g
	K^{+}: 21.1 g
	Oils: 16.4 g
	PO_4^{3-}: 14.1 g
	Main Wastes:
	-

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	2.96 [GJ]
Global Warming Potential (GWP)	153.1 [kg CO_{2eq}]

A.7 Evacuated solar thermal collectors

1. Product: Evacuated tube collectors (F.U.: 1 m^2 of evacuated tube collectors)

2. Authors and reference: data published by Niels Jungbluth in Ecoinvent ver.2.0

3. Description of the product: Evacuated tube collectors for hot water production.

4. Product characteristics

Nominal power/surface/other: surface 1 m^2
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase: -
Information about the end-of-life phase: wastes as plastics, packaging, hazardous wastes and others are incinerated. Glass and rock wool wastes are recovered.

5. Metadata

Age of the study: Materials data have been investigated for a collector produced in 2002. Data for energy uses during production have been investigated for 2001.
System boundaries (production phase, use phase, end-of-life phase): data are referred to the production of an evacuated tube collector in Northern-Ireland, including materials and energy use of production, and disposal of the product at the end of life.
Useful lifetime: 25 years.
Cut-off rules: impacts related to transport of the solar thermal collectors from the productive site to the utilization site and to the use phase are not included.
Allocation rules: -
Further details: -
Data Quality Assessment: input data of materials used to produce the solar thermal collector have been collected using questionnaires. Energy uses during production investigated in another factory for another type of tube collector. Data have been validated.

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Electricity (medium voltage): 17 kWh	CO_2: 101.3 kg
Natural gas: 16.5 MJ	SO_2: 505 g
Water: 53.6 kg	NO_x: 329 g
Glass tube: 14.2 kg	Particulates: 249 g
Chromium steel: 4 kg	CH_4: 196 g
Packaging: 3.33 kg	CO: 182 g
Sheet rolling, copper: 2.8 kg	NMVOC: 41.7 g

	Copper: 2.8 kg Rock wool: 2.03 kg Synthetic rubber: 667 g Propylene glycol, liquid: 645 g Hydrochloric acid: 113 g Brazing solder, cadmium free: 100 g Silicon: 53.3 g Chemicals organic: 11.3 g Anti-reflex-coating, etching, solar glass: 1 m^2 Selective coating, copper sheet: 1 m^2	CS2: 12.2 g SO42-: 11.6 g HCl: 9.06 g Cr: 3.49 g N_2O: 2.75 g Main Water Emissions: Si: 3.44 kg Cl^-: 2.11 kg Ca^{2+}: 1.47 kg SO_4^{2-}: 724 g Na^+: 612 g COD: 586 g BOD_5: 309 g TOC: 184 g DOC: 178 g Al: 143 g Solid substances: 143.5 g Fe^2+: 88.8 g Mg: 24 g Oils: 21.7 g NO^{3-}: 14 g Main Wastes: Oils: 21.4 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	1.59 [GJ]
Global Warming Potential (GWP)	90.91 [kg CO_{2eq}]

A.8 Flat plate collectors

1. **Product:** Flat plate collectors (F.U.: 1 m^2 of flat plate collectors)

2. **Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.2.0

3. **Description of the product:** Flat plate collectors for hot water production.

4. **Product characteristics**

Nominal power/surface/other: surface 1 m^2
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase: -
Information about the end-of-life phase: wastes as plastics and packaging are incinerated. Glass and mineral wool wastes are recovered.

5. **Metadata**

Age of the study: Materials data have been investigated for a collector produced in 2002. Data for energy uses during production have been investigated for 2001.
System boundaries (production phase, use phase, end-of-life phase): data are referred to the production of a flat plate collector in Switzerland, including materials, water and energy use of production, and disposal of the product at the end of life. The flat plate collector has selective black chrome coating on copper made in United States. Main components of the collector are imported from United States. The glass is coated in Denmark.
Useful lifetime: 25 years.
Cut-off rules: impacts related to transport of the solar thermal collectors from the productive site to the utilization site and to the use phase are not included.
Allocation rules: -
Further details: -
Data Quality Assessment: input data of materials used to produce the solar thermal collector have been collected using questionnaires. Energy uses during production investigated in another factory. Data have been validated.

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Electricity (medium voltage): 1.16 kWh	CO_2: 102.8 kg
Water: 10.78 kg	SO_2: 682 g
Chromium steel: 4.14 kg	NO_x: 316 g
Corrugated board: 3.68 kg	Particulates: 327 g
Sheet rolling, copper: 2.82 kg	CH_4: 191.6 g

	Copper: 2.82 kg Rock wool: 2.43 kg Synthetic rubber: 732 g Propylene glycol, liquid: 1.01 kg Solar glass, low-iron: 9.12 kg Aluminium: 3.93 kg Brazing solder, cadmium free: 3.68 g Silicone product: 58.8 g Soft solder: 58.8 g Anti-reflex-coating, etching, solar glass: 1 m^2 Selective coating, copper sheet: 1 m^2	CO: 511 g NMVOC: 46.9 g HCl: 7.26 g Cr: 3.61 g N_2O: 3.05 g
		Main Water Emissions: Si: 4.02 kg Cl^-: 2.94 kg Ca^{2+}: 1.07 kg SO_4^{2-}: 693 g Na^+: 1.18 kg COD: 846 g BOD_5: 457 g TOC: 264 g DOC: 255 g Al: 232 g Solid substances: 136.2 g Fe^2+: 92.9 g Mg: 24.8 g Oils: 34.4 g NO^{3-}: 15.3 g
		Main Wastes: Oils: 35.6 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	1.75 [GJ]
Global Warming Potential (GWP)	2.3 [kg CO_{2eq}]

A.9 Heat storage

1. **Product:** Heat storage (F.U. 1 unit)

2. **Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.2.0

3. **Description of the product:** heat storage with a capacity of 2000 l for use in a solar collector heating system

4. **Characteristics of the product**

Nominal power/surface/other: capacity 2000 l
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase: packaging wastes are incinerated. Rock wool wastes are recovered. The end-of-life of other wastes is not included.

5. **Metadata**

Age of the study: 2003.
System boundaries (production phase, use phase, end-of-life phase): data are referred to the production of a heat storage in Switzerland, including materials and energy use of production, and disposal of the product at the end of life.
Useful lifetime: 25 years.
Cut-off rules: impacts related to transport of the storage from the productive site to the utilization site and to the use phase are not included.
Allocation rules:
Further details:
Data Quality Assessment: input data of materials used to produce the storage have been collected using questionnaires. Data have been validated.

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Electricity, medium voltage: 45 kWh	CO_2: 796 kg
Electricity, photovoltaic: 45 kWh	CO: 8.11 kg
Natural gas: 198 MJ	Particulates: 3.89 kg
Energy from biomass (wood): 146 MJ	CH_4: 2.14 kg
Rock wool: 25 kg	NO_x: 2.03 kg
Chromium steel: 35 kg	SO_2: 2 kg
Steel: 305 kg	NMVOC: 417 g
Water: 800 kg	Al: 181 g

		NH_3: 140 g HCl: 73.8 g CS_2: 69 g Cr: 39,6 g Si: 17.8 g N_2O: 16.3 g
		Main Water Emissions: Si: 44.3 kg Cl^-: 5.46 kg SO_4^{2-}: 4.1 kg COD: 2.89 kg Ca^{2+}: 2.78 kg BOD_5: 1.27 kg TOC: 1.1 kg DOC: 1.1 kg Na^+: 1.03 kg Solid substances: 1.2 kg Fe^2+: 794 g Al: 678 g Mg: 240 g PO_4^{3-}: 207 g Oils: 137 g K^+: 118 g
		Main Wastes: Oils: 126

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	14.8 [GJ]
Global Warming Potential (GWP)	793.0 [kg CO_{2eq}]

A.10 Heat rejection system

1.	**Product:** Heat rejection system (F.U. 1unit)
2.	**Authors and reference:** Lesbat (HEIG-VD, Switzerland)
3.	**Description of the product:** The heat rejection system (recooler) is the heat rejection part of the installation. The major components are steel, aluminum, cooper and plastic as PEHD.
4.	**Product characteristics**
	Nominal power/surface/other: - Nominal power: 24 kW;
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase: all metals are recycle and plastics are burned
5.	**Metadata**
	Age of the study: 2010
	System boundaries): production phase; All the components of the chiller are included in the production phase. As we do not have the energy use for fabrication phase, it is not included. No transport to the production site is taken in account due to the lack of information. Use phase; during the use phase, the energy is included in the LCIA of the whole installation. The maintenance is negligible. The transport is not included. End-of-life phase; All components which can be recycled have no impact (ecoinvent® rules) the rest is or for incineration, or for disposal in CH. The recycling has a cut-off approach.
	Useful lifetime: 25 years.
	Cut-off rules: impacts related to transport of the tower from the productive site to the utilization site and to the use phase are not included. The recycling has a cut-off approach.
	Allocation rules:-
	Further details:-
	Data Quality Assessment: The amount of material results of the company data.
6.	**Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Steel : 86 kg Aluminium : 58 kg Cooper : 35 kg Plastic (PEHD) : 35 kg	Heat waste: 15136 MJ CO_2: 967.1 kg SO_2: 17.6 kg CO: 8.8 kg NO_x: 6.5 kg

		CH_4: 2.1 kg Particulates: 4.3 kg Water: 1.2 kg Al: 800 g NMVOC: 702 g CS_2: 408 g NH_3: 327 g Cu: 89 g Pb: 80 g Ni: 63 g HF: 42 g
		Main Water Emissions: Heat waste: 803.3 MJ Si: 23.7 kg SO_4^{2-}: 12.1 kg Na^+: 7.1 kg Cl^-: 6.1 kg Ca^{2+}: 4.7 kg COD: 3.7 kg Al: 2.6 kg BOD_5: 1.9 kg TOC: 1.3 kg DOC: 1.3 kg Ti^+: 997 g Fe^{2}+: 640 g Solid substances: 406 g Solved solids: 344 g Oils: 333 g F^-: 250 g PO_4^{3-}: 14.1 g
		Main Wastes: Heat waste: 22.65 MJ Oils: 345 g

7. Product Eco-profile

Global Impact Indexes	Total

	Global Energy Requirement (GER)	14.36[GJ]
	Global Warming Potential (GWP)	875 [kg CO_{2eq}]

A.11 Pipes

1. **Product: PVC pipe**(F.U. 1 m)
2. **Authors and reference:** APME Brussels – http://lca.apme.org
3. **Description of the product:** PVC pipe
4. **Product characteristics**

Nominal power/surface/other:
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. **Metadata**

Age of the study: 2000
System boundaries): production of PVC pipes, including production of PVC resin, transport of the resin to the converter, the conversion process itself and packaging of the finished product for onward dispatch. In pipe exstrusion the molten polymer is extruded through an annular die and cooled by passing through a water tough.
Useful lifetime:
Cut-off rules: the effects of stabilisers have been ignored so that in the calculations all of the weight of the pipe is assumed to be PVC homopolymer,
Allocation rules:-
Further details:-
Data Quality Assessment: Data come from 3 plants in Netherlands, producing 60.000 tons of product.

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
	CO_2: 2.35 kg CO: 2.58 g NO_x: 12.8 g CH_4: 10 g Particulates: 4.03 g
	Main Water Emissions:
	SO_4^{2-}: 4.11 g Na^+: 7.85 g Cl^-: 39.4 g

		Suspended solids: 4.54 g Solved organics: 1.57 g
		Main Wastes:
		Chemical waste: 16.53 g Mineral waste: 57.3 g Slags and ashes: 13.9 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	65.82 [MJ]
Global Warming Potential (GWP)	2.73 [kg CO_{2eq}]

A.12 Pump

1.	**Product:** Pump (F.U. 1 unit)
2.	**Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.3.0
3.	**Description of the product:** Pump 40 W
4.	**Product characteristics**
	Nominal power/surface/other: power: 40W
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase:
5.	**Metadata**
	Age of the study: 2003
	System boundaries): production and disposal of a water pump. Including materials. Not including energy use of production and infrastructure for factory.
	Useful lifetime:
	Cut-off rules: the effects of stabilisers have been ignored so that in the calculations all of the weight of the pipe is assumed to be PVC homopolymer,
	Allocation rules:-
	Further details:-
	Data Quality Assessment: Pump produced in Switzerland.
6.	**Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Copper: 0.25 kg	Heat waste: 108 MJ
PVC: 0.03 kg	CO_2: 6.53 kg
Synthetic rubber: 0.007 kg	CO: 50.7 g
Aluminium: 0.02 kg	NO_x: 20.9 g
Cast iron: 1.2 kg	CH_4: 16.9 g
Chromium steel: 0.92 kg	Particulates: 37.6 g
	NMVOC: 3.26 g
	SO_2: 44.7 g
	Main Water Emissions:
	SO_4^{2-}: 1.4 kg
	Al: 31.2 g
	BOD5: 13.4 g

		Cl^-: 3850 g COD: 32.7 g Fe: 83.4 g Mg: 223 g Mn: 24.2 g PO_4^{3-}: 49.5 g Si: 720 g K: 127 g Na^+: 75 g
		Main Wastes:
		Oils, unspecified: 1.2 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	118.55 [MJ]
Global Warming Potential (GWP)	6.99 [kg CO_{2eq}]

A.13 Electric installation

1.	**Product:** Electric installation (F.U. 1 unit)
2.	**Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.3.0
3.	**Description of the product:** Electric installation for photovoltaic plant
4.	**Product characteristics**
	Nominal power/surface/other:
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase:
5.	**Metadata**
	Age of the study: 2007
	System boundaries: materials and packaging for the production and estimation for metal processing. Disposal of the product after use.
	Useful lifetime:
	Cut-off rules: the effects of stabilisers have been ignored so that in the calculations all of the weight of the pipe is assumed to be PVC homopolymer,
	Allocation rules:-
	Further details: The product includes all electric installations for a photovoltaic system with a capacity of 3kWp. Including cables, counter, etc.
	Data Quality Assessment: Produced in Switzerland.
6.	**Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Copper: 14.7 kg	Heat waste: 1.69 GJ
Brass: 0.02 kg	Al: 115 g
Zinc: 0.04 kg	NH3: 46.8 g
Steel, low-alloyed: 0.86 kg	CO_2: 129.3 kg
Nylon: 0.23 kg	CO: 359 g
HPDE: 17.61 kg	NO_x: 431 g
PVC: 2.13 kg	CH_4: 343.5 g
Polycarbonate: 0.2 kg	Particulates: 359.1 g
Epoxy resin: 0.002 kg	NMVOC: 160 g
	SO_2: 1.69 kg
	Main Water Emissions:

		SO_4^{2-}: 72.5 kg Al: 1.54 g Ca: 19.8 kg Fe: 4.23 kg Mg: 11.9 kg Mn: 1.34 kg PO_4^{3-}: 2.46 kg Si: 3.39 kg K: 6.71 kg Na^+: 72.5 kg
		Main Wastes: Oils, unspecified: 16.7 g Fe: 1.63 g Cl: 2.22 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	2.23 [GJ]
Global Warming Potential (GWP)	139.9 [kg CO_{2eq}]

A.14 Inverter (500 W)

1.	**Product:** Inverter 500 W (F.U. 1 unit)
2.	**Authors and reference:** data published by Matthis Techschmid in Ecoinvent ver.3.0
3.	**Description of the product:** Inverter for a photovoltaic system with a capacity of 500 W
4.	**Product characteristics**
	Nominal power/surface/other: efficiency: 93.5%; weight: 1.6 kg
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase:
5.	**Metadata**
	Age of the study: 2009
	System boundaries: materials, packaging and electricity use for the production of an inverse rectifier. Disposal of the product after use.
	Useful lifetime:
	Cut-off rules:
	Allocation rules:-
	Further details:
	Data Quality Assessment: Produced in Europe
6.	**Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Copper: 0.002 kg	Heat waste: 588 MJ
Steel, low-alloyed: 0.078 kg	CO_2: 37.56 kg
ABS: 0.148 kg	CO: 56.42 g
Polycarbonate: 0.068 kg	NO_x: 86.4 g
HPDE: 0.014 kg kg	Ethyl acetate: 27.9 g
SAN: 0.002 kg	CH_4: 83.56 g
PVC: 0.002 kg	Particulates: 48.9 g
Transformer: 0.31 kg	NMVOC: 25.1 g
Connector: 0.05 kg	SO_2: 119 g
Inductor: 0.074 kg	**Main Water Emissions:**
Integrated circuit: 0.006 kg	SO_4^{2-}: 4.69 kg
Transistor: 0.008 kg	Al: 127 g
Diode: 0.01 kg	BOD5: 141 g

	Capacitors: 0.13 kg Resistor: 0.001 kg	Ca: 1.32 kg Cl: 765 g COD: 356 g DOC: 136 g F^-: 240 g Fe: 232 g Mg: 688 g Mn: 70.6 g PO_4^{3-}: 166 g Si: 3.48 kg K: 401 g Na^+: 654 g
		Main Wastes: Oils, unspecified: 6.97 g Na: 6.97 g Cl: 6.38 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	686.9 [MJ]
Global Warming Potential (GWP)	37.6 [kg CO_{2eq}]

A.15 Inverter (2500 W)

1. Product: Inverter 2500 W (F.U. 1 unit)

2. Authors and reference: data published by Matthis Techschmid in Ecoinvent ver.3.0

3. Description of the product: Inverter for a photovoltaic system with a capacity of 2500 W

4. Product characteristics

Nominal power/surface/other: efficiency: 93.5%; weight: 18.5 kg
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2009
System boundaries: materials, packaging and electricity use for the production of an inverse rectifier. Disposal of the product after use.
Useful lifetime:
Cut-off rules:
Allocation rules:-
Further details:
Data Quality Assessment: Produced in Europe

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Aluminium: 1.4 kg Copper: 5.5 kg Steel, low-alloyed: 9.8 kg SAN: 0.01 kg PVC: 0.01 kg Transformer: 0.31 kg Connector: 0.237 kg Inductor: 0.351 kg Integrated circuit: 0.028 kg Transistor: 0.038 kg Diode: 0.047 kg Capacitors: 0.62 kg Resistor: 0.005 kg	Heat waste: 2.76 GJ Al: 68.3 g CO_2: 26.2 kg CO: 478.96 g NO_x: 503 g Ethyl acetate: 132 g CH_4: 350 g Particulates: 408 g NMVOC: 135 g SO_2: 1.12 kg **Main Water Emissions:** SO_4^{2-}: 4.69 kg Al: 127 g

		BOD5: 141 g Ca: 1.32 kg Cl: 765 g COD: 356 g DOC: 136 g F^-: 240 g Fe: 232 g Mg: 688 g Mn: 70.6 g PO_4^{3-}: 166 g Si: 3.48 kg K: 401 g Na^+: 654 g
		Main Wastes:
		Oils, unspecified: 37.8 g Na: 24.3 g Cl: 41.2 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	3.2 [GJ]
Global Warming Potential (GWP)	157.1 [kg CO_{2eq}]

A.16 Photovoiltaic panel a-Si

1. Product: Photovoltaic panel a-Si (F.U. 1 m^2)

2. Authors and reference: data published by Niels Jungbluth in Ecoinvent ver.3.0

3. Description of the product: PV thin film modules. Deposition of nine thin-film layers on the triple-junction cell

4. Product characteristics

Nominal power/surface/other: size: 2.3 m^2; weight: 8.2 kg/m^2; efficiency 6.45% at the beginning of the life time; rated nominal power: 128 W per module
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2005
System boundaries: electricity and heat use, materials, transport of materials, disposal of wastes and the product.
Useful lifetime:
Cut-off rules: data for direct air and water emissions were not available
Allocation rules:-
Further details:
Data Quality Assessment: Produced in United States

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
PV laminate, a-Si: 1 m^2 Aluminium alloy: 3.34 kg Steel, low-alloyed: 2.18	Heat waste: 900 MJ CO_2: 62.5 kg CO: 195.9 g NO_x: 130 g CH_4: 141.6 g Particulates: 98.3 g NMVOC: 20.2 g SO_2: 286 kg
	Main Water Emissions:
	SO_4^{2-}: 2.7 kg Al: 95.6 g

		BOD5: 49.5 g Cl: 627 g COD: 86.1 g F^-: 53.4 g Fe: 111 g Mg: 358 g Mn: 30.9 g PO_4^{3-}: 108 g Si: 787 kg K: 229 g Na^+: 481 g Suspended solids: 410 g
		Main Wastes: Oils, unspecified: 9.94 g Fe: 2.11 g Cl: 1.07 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	1.18 [GJ]
Global Warming Potential (GWP)	77.19 [kg CO_{2eq}]

A.17 Photovoiltaic panel CdTe

1. **Product:** Photovoltaic panel CdTe (F.U. 1 m^2)
2. **Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.3.0
3. **Description of the product:** PV thin film modules.
4. **Product characteristics**

Nominal power/surface/other: size: 1.2 m by 0.6 m; weight: 12 kg; efficiency 9%; rated nominal power: 65W per module
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. **Metadata**

Age of the study: 2005
System boundaries: electricity and heat use, materials, transport of materials, disposal of wastes and the product.
Useful lifetime:
Cut-off rules: data for direct air and water emissions were not available
Allocation rules:-
Further details:
Data Quality Assessment: Produced in United States

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
	Main Water Emissions:
	Main Wastes:

7. **Product Eco-profile**

Global Impact Indexes	Total
Global Energy Requirement (GER)	1.51 [GJ]
Global Warming Potential (GWP)	100.5 [kg CO_{2eq}]

A.18 Photovoiltaic panel CIS

1. Product: Photovoltaic panel CIS (F.U. 1 m^2)

2. Authors and reference: data published by Niels Jungbluth in Ecoinvent ver.3.0

3. Description of the product: PV thin film modules

4. Product characteristics

Nominal power/surface/other: size: 1.2 m by 0.6 m; weight: 12.6 kg; efficiency 10; rated nominal power: 75-80 W per module
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2007
System boundaries: electricity use, materials, transport of materials, disposal of wastes and the product.
Useful lifetime:
Cut-off rules: data for direct air and water emissions were not available
Allocation rules:-
Further details:
Data Quality Assessment: Produced in Germany

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
PV laminate, CIS: 1 m^2 Aluminium alloy: 1.57 kg Glass fibre: 0.04 kg	Heat waste: 1.67 GJ CO_2: 115.27 kg CO: 86.53 g NO_x: 198 g CH_4: 234.8 g Particulates: 100.7 g NMVOC: 23.2 g SO_2: 220 kg
	Main Water Emissions:
	SO_4^{2-}: 8.98 kg Ca: 2.49 kg Cl: 1.05 kg

		Mg: 1.14 kg Si: 1.59 kg Na^{+}: 1.14 kg
		Main Wastes: Oils, unspecified: 19 g Ca: 1.42 g Fe: 2.38 g Cl: 3.58 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	2.03 [GJ]
Global Warming Potential (GWP)	125.9 [kg CO_{2eq}]

A.19 Photovoiltaic panel multi-Si

1. Product: Photovoltaic panel multi-Si (F.U. 1 m^2)

2. Authors and reference: data published by Niels Jungbluth in Ecoinvent ver.3.0

3. Description of the product: PV modules

4. Product characteristics

Nominal power/surface/other:
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2007
System boundaries: production of the cell matrix, cutting of foils and washing of glass, production of laminate, isolation. Aluminium frame of the panel. Disposal after the end-of-life.
Useful lifetime:
Cut-off rules: Data for direct air emissions were not available
Allocation rules:-
Further details:
Data Quality Assessment: Produced in Europe

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Water: 21.28 kg	Heat waste: 2.61 GJ
PV cell, multi-Si: 0.93241 m^2	CO_2: 142.76 kg
Aluminium alloy: 2.63 kg	CO: 57.52 g
Solar glass: 10.08 kg	NO_x: 318 g
Copper: 0.11 kg	CH_4: 446.7 g
Glass fibre: 0.19 kg	Particulates: 130.5 g
	NMVOC: 228 g
	SO_2: 359 kg
	Main Water Emissions:
	SO_4^{2-}: 5.82 kg
	Ca: 1.72 kg
	Cl: 1.57 kg

		Si: 1.48 kg Na^{+}: 1.08 kg
		Main Wastes:
		Oils, unspecified: 28.4 g Si: 31.5 Ca: 2.39 g Fe: 16.8 g Cl: 6.01 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	3.06 [GJ]
Global Warming Potential (GWP)	160.9 [kg CO_{2eq}]

A.20 Photovoiltaic panel ribbon-Si

1. Product: Photovoltaic panel ribbon-Si (F.U. 1 m^2)

2. Authors and reference: data published by Niels Jungbluth in Ecoinvent ver.3.0

3. Description of the product: PV modules

4. Product characteristics

Nominal power/surface/other:
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2007
System boundaries: production of the cell matrix, cutting of foils and washing of glass, production of laminate, isolation. Aluminium frame of the panel. Disposal after the end-of-life.
Useful lifetime:
Cut-off rules: Data for direct air emissions were not available
Allocation rules:-
Further details:
Data Quality Assessment: Produced in Europe

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Water: 21.28 kg PV cell, ribbon-Si: 0.93241 m^2 Aluminium alloy: 2.63 kg Solar glass: 10.08 kg Copper: 0.11 kg Glass fibre: 0.19 kg	Heat waste: 2.04 GJ CO_2: 115.34 kg CO: 195.5 g NO_x: 259 g CH_4: 318.5 g Particulates: 102.3 g NMVOC: 215 g SO_2: 330 kg
	Main Water Emissions:
	SO_4^{2-}: 5.82 kg Ca: 1.72 kg Cl: 1.57 kg

		Si: 1.48 kg Na^{+}: 1.08 kg
		Main Wastes: Oils, unspecified: 21.4 g Si: 31.5 Ca: 1.98 g Fe: 16.1 g Cl: 4.38 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	2.41 [GJ]
Global Warming Potential (GWP)	130.9 [kg CO_{2eq}]

A.21 Photovoiltaic panel single-Si

1.	**Product:** Photovoltaic panel single-Si (F.U. 1 m^2)
2.	**Authors and reference:** data published by Niels Jungbluth in Ecoinvent ver.3.0
3.	**Description of the product:** PV modules
4.	**Product characteristics**
	Nominal power/surface/other:
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase:
5.	**Metadata**
	Age of the study: 2007
	System boundaries: production of the cell matrix, cutting of foils and washing of glass, production of laminate, isolation. Aluminium frame of the panel. Disposal after the end-of-life.
	Useful lifetime:
	Cut-off rules: Data for direct air emissions were not available
	Allocation rules:-
	Further details:
	Data Quality Assessment: Produced in Europe
6.	**Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Water: 21.28 kg	Heat waste: 3.32 GJ
PV cell, ribbon-Si: 0.93241 m^2	CO_2: 180.5 kg
Aluminium alloy: 2.63 kg	CO: 299.3 g
Solar glass: 10.08 kg	NO_x: 378 g
Copper: 0.11 kg	CH_4: 496.4 g
Glass fibre: 0.19 kg	Particulates: 164.7 g
	NMVOC: 233 g
	SO_2: 486 kg
	Main Water Emissions:
	SO_4^{2-}: 8.74 kg
	Ca: 2.52 kg
	Cl: 1.77 kg

		Mg: 1.11 kg Si: 4.42 kg Na^+: 1.45 kg
		Main Wastes: Oils, unspecified: 33.1 g Si: 31.6 Ca: 2.9 g Fe: 17.3 g Cl: 6.34 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	3.85 [GJ]
Global Warming Potential (GWP)	200.3 [kg CO_{2eq}]

A.22 Battery lead-acid

1. **Product:** battery lead-acid (F.U. 1 kg)

2. **Authors and reference:** McManus M. C. (2012). Environmental consequences of the use of batteries in low carbon systems: The impact of battery production. Applied Energy 93, 288–295.

3. **Description of the product:** battery lead-acid

4. **Product characteristics**

Nominal power/surface/other: energy density: 0.13-0.18 MJ/kg, 5.56-7.69 kg/MJ
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. **Metadata**

Age of the study: 2011
System boundaries: Cradle to gate study
Useful lifetime:
Cut-off rules: data for the production of antimony and arsenic were omitted for the production of lead acid battery
Allocation rules:-
Further details:
Data Quality Assessment: data were collected from previously published materials. Data associated with the impact of the production of the materials was taken, where possible, from the Ecoinvent database. Where no data were available from this, data were obtained from the Idemat database, or estimated using chemical substitutions and estimations.

6. **Life Cycle Inventory**

Main employed materials and components:	Main Air Emissions:
Antimony: 0.71% Arsenic: 0.03% Copper: 0.01% Glass: 0.02% Lead:60.69% Oxygen: 2.26% Polyethylene: 1.83% Polypropylene: 6.72%	Main Water Emissions: Main Wastes:

	Sulphuric acid: 10.33% Water (unsalted): 16.93% Other: 0.47%	

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	17 [MJ]
Global Warming Potential (GWP)	0.9 [kg CO_{2eq}]

A.23 Battery lithium-iron-phosphate

1. **Product:** battery lithium-iron-phosphate (F.U. 1 kg)

2. **Authors and reference:** Majeau-Bettez G., Hawkins T.R., Hammer Stromman A. Life Cycle Environmental Assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. Environmental Science & Technology (2011). Dx.doi.org/10.102/es103607c

3. **Description of the product:** battery lithium-iron-phosphate

4. **Product characteristics**

Nominal power/surface/other: Cell voltage (V): 3.4 Capacity of pure active material, positive electrode (1C rate) (mAh/g): 120 Capacity of pure active material, negative electrode (1C rate) (mAh/g): 350 Cycle depth of discharge (DoD) (%): 80 Charge discharge energy efficiency (%): 90 Cycle life expectancy (ca. 80% DoD) (cycles): 6000 Nominal Cell capacity (1C rate) (Ah/kgcell): 32.3 Nominal Cell energy density (1C rate)(Wh/kgcell): 110 Total battery pack energy density (Wh/kg): 88 Total battery pack power density (W/kg): 400-800
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. **Metadata**

Age of the study:
System boundaries: From cradle to gate. Infrastructure and transport requirements were included.
Useful lifetime:
Cut-off rules:
Allocation rules:-
Further details:
Data Quality Assessment: secondary data were taken from the Ecoinvent database. Average European conditions were generally assumed.

6. **Life Cycle Inventory**

	Main employed materials and components: Positive electrode paste: 24.8% Negative electrode paste: 8% Separator: 3.3% Substrate, positive electrode: 3.6% Substrate, negative electrode: 8.3% Electrolyte: 12% Cell container, tab and terminals: 20% Module and battery packaging: 17% Battery management system (BMS): 3%	Main Air Emissions: Main Water Emissions: Main Wastes:

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	192.6 [MJ]
Global Warming Potential (GWP)	22 [kg CO_{2eq}]

A.24 Battery lithium-ion-manganate

1. Product: battery (F.U. 1 kg)

2. Authors and reference: data published by Roland Hischier in Ecoinvent

3. Description of the product: ì

4. Product characteristics

Nominal power/surface/other:
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study:
System boundaries: raw materials, infrastructure, transport efforts, energy consumption and waste disposal for the production of a NiMH battery
Useful lifetime:
Cut-off rules: No emissions to air or water are taken into account
Allocation rules:-
Further details:
Data Quality Assessment: data are referred to a global context

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Electrode negative, Ni: 0.36 kg Electrode positive, LaNi5: 0.33 kg Electrolyte, KOH, LiOH additive: 0.08 kg	Heat waste: 311 MJ CO_2: 14.4 kg Al: 9.36 g CO: 16.5 g CH_4: 32.3 g NO_x: 47.2 g Particulates: 42.1 g SO_2: 622 g
	Main Water Emissions:
	SO_4^{2-}: 2.13 kg Al: 42 g BOD5: 29.8 g Ca: 559 g

		Cl: 238 g COD: 48.7 g Fe: 107 g Mg: 291 K: 165 g Si: 887 g Na^{+}: 164 g
		Main Wastes:
		Oils, unspecified: 4.61 g

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	120.6 [MJ]
Global Warming Potential (GWP)	6.78 [kg CO_{2eq}]

A.25 Battery nickel cadmium

1. Product: battery nickel cadmium (F.U. 1 kg)

2. Authors and reference: McManus M. C. (2012). Environmental consequences of the use of batteries in low carbon systems: The impact of battery production. Applied Energy 93, 288–295.

3. Description of the product: battery nickel cadmium

4. Product characteristics

Nominal power/surface/other: energy density: 0.14-0.22 MJ/kg, 4.55-7.14 kg/MJ
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. Metadata

Age of the study: 2011
System boundaries: from cradle to gate
Useful lifetime:
Cut-off rules:
Allocation rules:-
Further details:
Data Quality Assessment: data were collected from previously published materials. Data associated with the impact of the production of the materials was taken, where possible, from the Ecoinvent database. Where no data were available from this, data were obtained from the Idemat database, or estimated using chemical substitutions and estimations.

6. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Copper: 2.05% Polypropylene: 3.1% Water (unsalted): 11.48%	Main Water Emissions:
Cadmium:24.6% Cobalt: 1.4% Lithium hydroxide: 0.7% Nickel: 20.2% Nickel hydroxide: 17.4% Potassium hydroxide: 5.22%	Main Wastes:

	Steel (low alloy) 11.7% Steel (unalloyed): 2.05% Other inorganic: 0.1%	

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	37 [MJ]
Global Warming Potential (GWP)	2.1 [kg CO_{2eq}]

A.26 Battery nickel cobalt manganese

1. **Product:** battery nickel cobalt manganese (F.U. 1 kg)

2. **Authors and reference:** Majeau-Bettez G., Hawkins T.R., Hammer Stromman A. Life Cycle Environmental Assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. Environmental Science & Technology (2011). Dx.doi.org/10.102/es103607c

3. **Description of the product:** battery nickel cobalt manganese

4. **Product characteristics**

Nominal power/surface/other: Cell voltage (V): 3.7 Capacity of pure active material, positive electrode (1C rate) (mAh/g): 150 Capacity of pure active material, negative electrode (1C rate) (mAh/g): 350 Cycle depth of discharge (DoD) (%): 80 Charge discharge energy efficiency (%): 90 Cycle life expectancy (ca. 80% DoD) (cycles): 3000 Nominal Cell capacity (1C rate) (Ah/kgcell): 37.9 Nominal Cell energy density (1C rate)(Wh/kgcell): 140 Total battery pack energy density (Wh/kg): 112 Total battery pack power density (W/kg): 400-800
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase:

5. **Metadata**

Age of the study:
System boundaries: From cradle to gate. Infrastructure and transport requirements were included.
Useful lifetime:
Cut-off rules:
Allocation rules:-
Further details:
Data Quality Assessment: secondary data were taken from the Ecoinvent database. Average European conditions were generally assumed.

6. **Life Cycle Inventory**

	Main employed materials and components: Positive electrode paste: 23.3% Negative electrode paste: 9.4% Separator: 3.3% Substrate, positive electrode: 3.6% Substrate, negative electrode: 8.3% Electrolyte: 12% Cell container, tab and terminals: 20.1% Module and battery packaging: 17% Battery management system (BMS): 3%	Main Air Emissions:
		Main Water Emissions:
		Main Wastes:

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	196.8 [MJ]
Global Warming Potential (GWP)	22 [kg CO_{2eq}]

A.27 Battery nickel metal hydride

1.	**Product:** battery nickel metal hydride (F.U. 1 kg)
2.	**Authors and reference:** Majeau-Bettez G., Hawkins T.R., Hammer Stromman A. Life Cycle Environmental Assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. Environmental Science & Technology (2011). Dx.doi.org/10.102/es103607c
3.	**Description of the product:** battery nickel metal hydride
4.	**Product characteristics**
	Nominal power/surface/other: Cell voltage (V): 1.2 Capacity of pure active material, positive electrode (1C rate) (mAh/g): 275 Capacity of pure active material, negative electrode (1C rate) (mAh/g): 290 Cycle depth of discharge (DoD) (%): 80 Charge discharge energy efficiency (%): 80 Cycle life expectancy (ca. 80% DoD) (cycles): 3000 Nominal Cell capacity (1C rate) (Ah/kgcell): 55.5 Nominal Cell energy density (1C rate)(Wh/kgcell): 66.6 Total battery pack energy density (Wh/kg): 55.3 Total battery pack power density (W/kg): 200-400
	Measured/estimated yearly energy production and/or consumption:-
	Information about the use phase:-
	Information about the end-of-life phase:
5.	**Metadata**
	Age of the study:
	System boundaries: From cradle to gate. Infrastructure and transport requirements were included.
	Useful lifetime:
	Cut-off rules:
	Allocation rules:-
	Further details:
	Data Quality Assessment: secondary data were taken from the Ecoinvent database. Average European conditions were generally assumed.
6.	**Life Cycle Inventory**

	Main employed materials and components: Positive electrode paste: 19.7% Negative electrode paste: 12.6% Separator: 3.8% Substrate, positive electrode: 17.3% Substrate, negative electrode: 11.1% Electrolyte: 9% Cell container, tab and terminals: 9.5% Module and battery packaging: 17%	Main Air Emissions:
		Main Water Emissions:
		Main Wastes:

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	226.09 [MJ]
Global Warming Potential (GWP)	20 [kg CO_{2eq}]

A.28 Battery sodium-nickel chloride

1. **Product:** battery NaNiCl (F.U. 1 kg)

Authors and reference: Longo S., Antonucci V., Cellura M., Ferraro M.. Life cycle assessment of storage systems: the case study of a sodium/nickel chloride battery. Journal of Cleaner Production (2013), http://dx.doi.org/10.1016/j.jclepro.2013.10.004

Description of the product: 48-TL-200 ZEBRA battery, including the Battery Management Interface (BMI).

1. **Product characteristics**

Nominal power/surface/other: Nominal voltage V 48; Open circuit voltage V 51.6; Nominal capacity Ah 200; Nominal energy Wh 9600; Gravimetric energy density Wh/kg 91; Thermal loss in operation W 105; Operating temperature range °C -20 to +60; Mass kg 105; Dimensions mm 558 * 496 * 320

Measured/estimated yearly energy production and/or consumption:-

Information about the use phase:-

Information about the end-of-life phase: At the end-of-life, all battery components can be recycled. The stainless steel case and the glass wool can be recycled in established processes. The nickel, the salt and the ceramic contained in the cells are used in steel melting in stainless steel manufacturing. Due to the lack of data on the eco-profiles of the recycling of sodium/nickel chloride batteries, the end-of-life step was accounted for considering average data for a European recycling process that represents a combination of the recycling processes for lithium-ion batteries (pyrometallurgical and hydrometallurgical processes) and nickelemetal hydride batteries (pyrometallurgical process).

2. **Metadata**

Age of the study: 2013

System boundaries: battery manufacturing step, including raw material supply; manufacturing/assembly of the main components and final waste treatment, with the waste representing the raw material packaging; end-of-life step.

Useful lifetime:

Cut-off rules: The transportation of the battery to the end user and the transportation of packaging waste to the disposal site were not taken into account as their energy and environmental impact can be assumed to be negligible. The battery does not require maintenance. Consequently, the maintenance step does not cause any energy or environmental impact and is excluded from the analysis.

Allocation rules:-

Further details:

Data Quality Assessment: The eco-profiles of materials and energy sources used to produce the battery and the impacts related to the transportation step and to the end-of-life processes of packaging materials were based on the Ecoinvent database. The ecoprofile of the BMI was taken from Majeau-Bettez et al. (2011). The eco-profiles of electricity and natural gas used in the manufacturing process as well as the eco-profiles of raw materials are referred to the European context, with the exception of glass wool, which referred to the Swiss context, and of nickel, battery cables and the integrated circuits of the BMI, which referred to the worldwide context.

3. Life Cycle Inventory

Main employed materials and components:	Main Air Emissions:
Battery case - Stainless steel: 11.00 kg Sodium/nickel chloride cells: 80.50 kg Thermal insulation - Glass wool: 10.00 kg Ohmic heater - Silicon: 0.35 kg Insulation among cells - Mica: 0.35 kg BMI: 0.70 kg Electric cables - Nickel alloy: 0.20 kg Cells inter-connection - Nickel: 0.36 kg	Main Water Emissions: Main Wastes:

4. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	245.34 [MJ]
Global Warming Potential (GWP)	15.1 [kg CO_{2eq}]

A.29 Battery v-redox

1. Product: battery v-redox (F.U. 1 kg)

2. Authors and reference: Cellura M., Life Cycle Analysis applied for the assessment of energy and environmental impacts of V-redox batteries - Final report (2014) – Project: Electrochemical systems for the generation and storage of energy.

3. Description of the product: battery v-redox

4. Product characteristics

Nominal power/surface/other: Dimensions: 1.2 m*1.0 m*1.1 m Nominal energy: 20 kWh Weight power module: 142.4 kg Total weight (excluded pumps and BMI): 454.8 kg Power: 5 kW Efficiency: 80%
Measured/estimated yearly energy production and/or consumption:-
Information about the use phase:-
Information about the end-of-life phase: some components (plastic, steel, aluminium), that represent the 16.5% of the total weight of battery, are recycled. $VOSO_4$ and H_2SO_4, that represent the 41% of the total weight of battery, are disposed in a landfill for hazardous waste. The end-of-life of pumps and carbon products is not included.

5. Metadata

Age of the study: 2013
System boundaries: production of the main components of battery, end-of-life.
Useful lifetime:
Cut-off rules: the following steps are not included: installation, maintenance, transports, use of packaging, infrastructure.
Allocation rules:
Further details:
Data Quality Assessment:

6. Life Cycle Inventory

Main employed materials and components: Polypropylene: 56.91 kg Carbon fibres: 26.81 kg Carbon powder: 35.75 kg	Main Air Emissions:
	Main Water Emissions:

	Aluminium: 35.66 kg Steel: 4.25 kg PTFE: 2.17 kg Carbon felt: 8 kg Nafion: 2.9 kg $VOSO_4$ 54.68 kg H_2SO_4: 131.66 kg	Main Wastes:

7. Product Eco-profile

Global Impact Indexes	Total
Global Energy Requirement (GER)	77.67 [MJ]
Global Warming Potential (GWP)	7.98 [kg CO_{2eq}]