TASK 27

Performance of Solar Facade Components

Performance, durability and sustainability

of advanced windows and solar components for building envelopes

Final Report

Subtask C: Sustainability

Project C1: Environmental Performance

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Project C1: Environmental Performance

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1 Introduction

This report is the synthesis of all works performed in the IEA Task 27 subtask C, project C1. Project C1 dealt with the environmental performances of solar façade components.

Major contributions to IEA T27 C1 came from CSTB (Jean Luc Chevalier team) and Palermo university (Mauricio Cellura team) with substantial support from Hanne Krogh (from Danish Building and Urban Research), Helen Rose Wilson (from Interpane) and Mario Tarantini (from ENEA) providing data about windows frame and glazings and comparisons of LCA studies.

Four major activities were completed:

1. comparison of LCA studies previously performed on a wooden window,
2. life cycle assessment of windows (frame + glazings)
3. energy balance of windows and glazings (energy content compared to energy saved due to the use of insulating glazings),
4. life cycle assessment of solar heating systems (two studies, one from France and one from Italy).

2 Glazings and windows

2.1 LCA comparison of wooden windows: results and methodology

By Hanne Krogh Danish Building and Urban Research, Denmark (hmk@byogbyg.dk) and Mario Tarantini, Energy Department Sustainable Systems Division, Italy (tarantin@bologna.enea.it)

2.1.1 Purpose

The purpose was to identify and discuss important differences in data, methodology and results from LCA of the same wooden window when using different tools and the databases connected to these tools.
In Europe life cycle assessments (LCA) of building components have use different tools e.g. LCA of a wooden window in Denmark and Italy. It was therefore decided to compare results achieved by using SIMAPRO 4 (a Dutch tool) and Building Environmental Assessment Tool BEAT (a Danish tool). It was known and must be clearly stated that several differences in the two studies are a consequence of the different goals and scopes.

2.1.2 Results

Inventory and impact assessments were carried out for a wooden window. In table 1 the composition of a wooden window, used in the Italian project SCILLA, is compared to a wooden window used in the Danish project.

Table 2-1 Composition of the used wooden window (information from the Italian project) compared to a wooden window used in the Danish project.

		Italian window (Dimension 1,3 m*1,5 m) kg	Danish window (Dimension 1,23 m*1,48 m) kg
Frame	Wood	19,7	30
	Al		0,2
Metals	Brass	0,4	
	Iron	2,7	0,5
Seals	EPT;EPDM	0,4	0,3
Chemical products	Glue	0,2	
	Preservatives	0,5	0,9
	Paint	1,5	1,3
Glazing	Glass	32	28
	Aluminium	0,7	0,2
	Drying agents		0,3
	Sealants		0,8
Total		57	62

The Italian window has two frames with double opening, and the Danish window has a one frame and is top-hinged. The service life of the window in the Italian project is fixed to 30 years. Danish window project uses a service life on 40 years for the window and 20 years for the glazing.

The results differ for all impacts and inventory data, especially for photochemical oxidant formation.
The emission of volatile organic compounds (VOC) from preservative and paints contribute to photochemical oxidant formation, but VOC from these materials wee not included in the Beat calculation because of incomplete information about the composition of VOC.

Table 2-2 Results from the LCA calculated for the same wooden window using two different tools.

		SimaPro	BEAT
Environmental impacts			
Global warming	kg CO_2	147	79
Depletion of ozone layer	kg CFC-11	5,29E-05	0
Acidification	kg SO_2	1,03	0,73
Eutrophication	kg PO_4	0,0742	0,77
Photochemical oxidant formation	kg C_2H_4	0,242	0,029
Resources			
Primary energy	MJ	1600	1270
Waste			
Bulk waste	kg	70	48

2.1.3 Discussion

The results may differ because of differences in effect factors in the impact assessment and/or in the inventory.

2.1.3.1 Impacts

Environmental impacts are calculated by multiplying the different emission with an effect factor. In Europe these factors for global and regional impacts do no differ very much in the different models for life cycle assessment. Therefore environmental declaration of building products include these impacts, in the Danish project we uses an aggregation of them (see table 3).

Table 2-3 Indictors in the Danish environmental declaration for building components and used in the Danish project.

	Impacts	**Aggregated impacts**
Resources	Energy raw materials Materials (metals)	Energy sources Materials
Global impacts	Global warming Depletion of ozone layer	Impact on climate
Regional impacts	Acidification Photochemical oxidant formation	Air pollution
Local impacts	Bulk waste Hazardous waste	Waste

The purpose of the Italian project was to compare different production options. Table 4 shows the impact categories and inventory data that were judged to be relevant for the production of a wooden window.

Table 2-4Inventory data and impacts used in the Italian project.

	Inventory data/Impacts
Resources	Primary energy
Global impacts	Greenhouse effect
Regional impacts	Acidification Photochemical oxidant formation
Local impacts	Solid Waste

The two software tools are based on different models for life cycle assessment. In SimaPro 4 software is possible to use different methods: the one selected for analysing the SCILLA project was developed by Centre for Environmental Studies (CML), University of Leiden, 1992. BEAT uses the Danish LCA model (Environmental Design of Industrial Products EDIP),developed by the Institute for Product Development ,Technical University of Denmark,1996.

Table 2-5 Environmental impacts in the used models.

	SimaPro	**EDIP**
Resources		
Primary energy	√	√
Fossil fuels		√
Metals		√
Minerals		√
Effect		
Global warming	√	√
Depletion of ozone layer	√	√
Acidification	√	√
Eutrophication	√	√
Photochemical oxidant formation	√	√
Persistent toxicity		√[1]
Human toxicity		√[1]
Ecotoxicity		√[1]
Heavy metals	√	
Winter smog	√	[2]
Pesticides	√	[3]
Waste	√	√
Bulk		√
Slag and ashes		√
Hazardous waste		√

[1]The toxicity is aggregated :
Persistent toxicity or ecotoxicity on a regional scale e.g human toxicity in water and soil compartments together with groundwater and chronic toxicity in aquatic environment.
Human toxicity on a local scale includes toxicity in the air compartment,
Ecotoxicity on a local scale includes acute toxicity in water and toxicity in wastewater treatment plant.
[2] Winter smog is not defined in EDIP.
[3] The effect of pesticides is calculated in EDIP.

The new version of Simapro software (Simapro 5) includes also other impact assessment methods including the EDIP method, the EPS (Environmental Priorities strategy) 2000 default methodology and the Swiss Ecopoints 1997 (environmental scarcity) methodology.

2.1.3.2 Inventory

The results may vary because of:

- Limits of the system
- Differences in handling of the data (credits for “end of life processes” and allocation).
- Data for important materials

Limits of the system

An inventory should include all phases of the life cycle, from extraction of raw materials to disposal of the materials after use. In this case the analysis was simplified and does not include replacement. A maintenance phase has been taken in account, a complete repainting of the window with hand brush and water based paint every 5 years.

Table 2-6 Life cycle phases included in the inventory.

	SimaPro	BEAT
Extraction of raw materials	√	√
Production of materials	√	√
Manufacture of window	√	√
Maintenance	√	√
Use		
Disposal of materials after use	√	

The inventory does not include the use phase (energy loss). In fact the methods to calculate the energy loss should have been compared and discussed as energy loss included in the inventory has a big influence on the results from the inventory. Anyway this is included in the Danish proposal for environmental declaration of a window using the Danish energy labelling of glazings and windows and in the complete analysis of SCILLA project. In the inventory small amount of materials were not included in the BEAT calculation because of missing information about the materials (preservatives, paint).

Credits for “end of life processes”

In the Danish model no “end of life processes” were included and no credit was given for the reuse of materials. The models calculate the amount of secondary raw materials (waste products) and the amount of different type of waste (bulk waste, slag and ashes and hazardous waste).

Table 2-7 Reuse and disposal of different materials in %, used in the Italian project and in this case.

Materials	Recycled %	Disposal %
Wood	30	70
Glass	30	70
Iron	30	70
Aluminium	30	70
Brass	30	70

The calculations have used the information in table 7 but BEAT does not give credit for reuse of materials. The calculation with SimaPro takes into account the actual situation of the Italian region Emilia Romagna. The recycled wood is supposed to be reused for chipboard manufacturing and so only credits for the extraction of virgin wood from the environment has been considered. For recycling of glass, iron, aluminium and brass the energy credits are given for the saved energy consumption when mancufaturing these products from recycled materials instead of from ores. The calculation with SimaPro includes the methane emission due to wood landfilling (0.3 kg per wood kg); it was assumed that 25% of methane emission is captured and burnt in the landfill and the remaining part goes to the environment, contributing to the global warming.

Inclusion of “end of life processes “ demands documentation for existing systems to collect, separate and recycle the materials. However the materials stayed in the buildings for a long time period and during this period different systems can be developed.

Allocation

The allocation procedure may differ in the different countries e. g allocation for production of metals from scrap. In this case all metals were produced from ores and no allocation was used.

Data for important materials

Production of floatglas contributes very much to the environmental impacts for the glazings. The data for production of float glass does not include extraction of the raw materials and the emissions are calculated from information of fuels and from decarbonization of carbonate in the raw materials. Pilkington (1998-2000) gave these data. SimaPro uses IVAM database (Netherlands) for floatglass production The floatglass data were developed by TNO using a mixed oil and natural gas (each 50%) and with external cullet (14%) in the raw material mixture .

For the frame the most important data are wood and the energy to produce the frame. Data for wood are representatives for the Nordic countries and collected in the period 1996-1998.

Table 2-8 Environmental data of materials.

	Glass pr t		Wood per m^3 [1]	
	Used in Beat	Used in SimaPro	Used in Beat	Used in SimaPro
Energy MJ	11400	13900	2,7	
CO_2 kg	930	1100	83	
SO_2 g	5400	7150	530	
NO_x g	2410	7580	480	
Bulk waste kg	37	54	17	
Hazardous waste g	0,6		0,35	

[1]Density of the wood 480 kg/m^3.The wood data for wood includes processes from logging of the wood in the forest to sawn timber.

In the Beat calculation we use data for production of electricity in Europe (1990). In SimaPro calculation data for production of electricity in Italy production have been used for window manufacturing.

2.1.4 Conclusion

In environmental declaration very often global and regional impacts are included:

- Global warming
- Acidification

- Photochemical oxidant formation
- Eutrophication

These impacts are very close related to consumption of energy raw materials and the consumption of electricity.

The results from LCA of a wooden window differ and many factors can have an influence on the results. A detailed study should focus on

- rules for handling of the data and
- try to get the data of good quality for the most important materials.

Furthermore emission from preservatives with organic solvents would have a great influence on photochemical oxidant formation and some kind of toxicity.

2.2 LCA of windows (frame and glazings): sensitivity analysis and energy balance

By Isabél GONZALEZ CUENCA (CSTB), Jacques CHEVALIER (CSTB), Jean Luc CHEVALIER (CSTB)

2.2.1 Introduction

In this study, the life cycle assessment (LCA) methodology was applied to glazings and complete windows (with frame). The main goal of the study was a sensitivity analysis of LCA results. This study enabled to determine the most influent parameter of the LCA study. Another interest is the identification of major contributors (life cycle steps and materials) to the environmental burdens of windows during their life cycle. This study also made a clear distinction between the energy content of a system and the energy saved thanks to this system when used in a building. In most studies, these two data are taken into account in the LCA. We considered that the thermal balance (energy saved) doesn't have to be considered in the LCA of the window. The energy saved has to be considered as a complementary issue. Lastly, the energy content of windows is compared with the energy saved when using insulating glazings in a reference building (reference office of IEA Task 27 project).

We first present the LCA methodology. After, we present the results of the LCA sensitivity analysis for glazings. Then, we present the results of the thermal balance of a window (energy saved when decreasing the thermal loss in winter and by decreasing the energy inputs in summer) . Lastly, the thermal balance will be extended to the reference office. In each case, comparison of energy content and energy savings is performed.

2.2.2 Life cycle assessment methodology

Life Cycle Assessment is a tool for the analysis of the environmental impacts of products or process. It takes into account all the stages of their life cycle; extraction of raw materials, manufacturing, use, maintenance, end of life, reuse, recycling and for final disposal.

LCA is a multicriteria decision making tool, and it is normalised in the ISO 14040 standards.

The parts of LCA methodology are described in 4 steps:
1. Goal and scope definition. ISO 14041
2. Life cycle inventory. ISO 14041
3. Life cycle impact assessment. ISO 14042
4. Interpretation. ISO 14043

2.2.2.1 Goal and scope definition. (ISO 14041)

The goal of a LCA is the specification of the aim of the study. Therefore, the product or process to analyse and the applications of results must be identified. Moreover, the destination persons involved and the initiator must be explained.
The scope of the LCA describes the model of the system of the study. It must be coherent with the goal of the study. The elements to define are the functions of life system, also functional unit; the system boundaries; the methodology applied; the level of depth of the study and the database specifications.
In the scope definition, the functions' specification has to be clear, defining all the performances of the product or process. The functional unit is a way for comparing different systems studied. It specifies a quantity, a function and duration of the product or process.
Defining the system boundaries means modelling all the outputs and inputs like elementary flows.

2.2.2.2 Life cycle inventory. ISO 14041

The objective of this stage is counting and quantifying all the elementary flows (materiel and energy balance). Subsequently, the realisation of a table is realised for taking into account all the stages of the life product or process; raw material extraction, product manufacturing, setting up, service life and end of life.

2.2.2.3 Life cycle impact assessment. ISO 14042

The life cycle impact assessment consists in evaluating the contribution of the system of product to the environmental impacts, in order to get the environmental conclusions.
Therefore, the inventory analysis results are processed into the impact categories. The impacts categories utilised are the followings; Climate Change, Primary Energy, Acidification, Raw material, Eutrophication, Air ecotoxicity, Water ecotoxicity, Waste production, Water consumption.

2.2.2.4 Interpretation. ISO 14043

The life cycle analysis interpretation consists in judging all the results and hypothesis, and establishing the conclusions.
Finally, the results presentation must be easy, complete and coherent to the goal and scope definition.

2.2.3 LCA of windows

Firsty, the LCA of windows is enough complicated because it is a multiproduct and multifunction system. The principal materiels involved are glass, aluminium, steel, PVC

and wood. Each one has its own different stages. The window must be assembled, taking all the different components.
Nevertheless, the LCA doesn't take into account the energy saved during the life window's life. It's the reason why realising link between the thermal balance and the energy content of the product. A window with serious environmental impacts in during its manufacturing can economise enough energy with regard to a simple window.

2.2.4 LCA results and sensitivity analysis

2.2.4.1 Goal and scope of the study, studied systems

The goal of this study is the life cycle assessment of different types of windows with regard to environmental and thermal aspects.
The main result is the comparison between the embodied environmental burdens and the saved energy during the life cycle of different glazings.
The first part of this study is the environmental impact assessment of different types of glazing in order to realise a sensitivity analysis of glazing components. In this way, the most critical parameters of glazing constitution are shown. Subsequently as a function of these parameters, some typical cases of glazing are chosen and studied.
Finally, the window frames are studied. The materiel chosen are wood, PVC et Al. The goal is the same as in the glazing case.
The tool for realising the life cycle analysis is the software SIMAPRO 5.

Table 2-9 Studied Glazings:

System	Float glass panes	Coatings	Spacers	Filling	Others
simple Glazing classic 4mm	1	X	X	X	X
Laminated glazing simple 44.2	2	X	X	X	Glass joined by PVB
Double Glazing 4/12/4	2	X	1 (aluminium)	X	X
Double glazing 6/12/6	2 (6mm)	X	1 (aluminium)	X	X
Double glazing 4/16/4 low-e, air filling	2	1	1 (aluminium)	Air	X
Double glazing 4/16/4 low-e, argon filling	2	1	1 (aluminium)	Argon	x
Double laminated glazing 4/12/442	3	X	1 (aluminium)	X	Glass joined by PVB
Double glazing 4/22/4 with film	2	X	1 (aluminium)	X	Film very thin
Triple glazing 4/12/4/12/4	3	X	2 (aluminium)	X	X

2.2.4.2 Results of the LCA (glazings)

For each environmental impact, we normalized the results by giving the score 0 to the system the minimum impact value and 10 to the worst system (Lower value are better for environment). Intermediate scores are calculated by linear extrapolation.

Table 2-10 Normalized LCA results for glazings.

System	Simple glazing	Laminated simple glazing	Double glazing 4/12/4	Double glazing 6/12/6	Double glazing 4/16/4, low-e, air filled	Double glazing 4/16/4, low-e, argon filled	Double glazing with laminated 4/12/442	Double glazing 4/22/4 with film	Triple glazing 4/12/4/12/4
Climate Change	0,00	3,66	4,70	8,20	5,21	5,21	8,20	5,58	10,00
Primary Energy	0,00	3,40	4,84	7,88	5,63	5,63	7,88	6,03	10,00
Acidification	0,00	4,89	4,98	9,87	4,98	4,98	9,87	5,02	10,00
Raw material	0,00	3,97	4,73	8,60	4,96	4,96	8,57	5,32	10,00
Eutrophication	0,00	4,28	4,53	8,77	4,67	4,67	8,77	4,75	10,00
Air ecotoxicity	0,00	2,17	5,98	8,13	7,23	7,23	8,13	9,17	10,00
Water ecotoxicity	0,00	0,58	7,20	7,78	9,41	9,41	7,78	12,72	10,00
Waste production	0,00	0,11	5,35	5,46	7,09	7,09	5,46	9,75	10,00
Water consumption	0,00	4,18	4,28	8,41	4,30	4,30	8,41	4,35	10,00

The primary energy varies from 156MJ (simple glazing) to 524MJ (triple glazing).
The triple glazing has the worst embodied burdens.

2.2.4.3 Results of the LCA (complete windows)

Table 2-11 Normalized LCA results for complete windows (glazing + frame).

	Wood frame + DG 4/12/4	PVC frame + DG 4/12/4	Al frame + DG 4/12/4	Wood frame +DG 4/16/4	PVC frame +DG 4/16/4	Al frame +DG 4/16/4
Climate Change	0,00	1,39	9,74	0,26	1,65	10,00
Primary Energy	0,00	1,97	9,72	0,25	2,22	10,00
Acidification	0,00	10,00	4,30	0,04	10,00	4,34
Raw material	4,97	0,00	9,85	5,13	0,15	10,00
Eutrophication	0,00	1,84	9,83	0,19	2,01	10,00
Air ecotoxicity	0,00	0,23	9,82	0,15	0,40	10,00
Water ecotoxicity	0,00	0,06	9,82	0,15	0,22	10,00
Waste production	0,00	0,07	9,84	0,15	0,23	10,00
Water consumption	0,00	7,18	9,87	0,13	7,31	10,00

The primary energy varies from 1290MJ (wood frame +DG 4/12/4) to 4890MJ (Aluminium frame + DG 4/16/4).
The frame is the major contributor to the environmental burdens of the window (about 80%). The aluminium frame is responsible for the higher environmental burdens (three

or four times more than PVC or wood frame). Our study considered a frame with no recycled aluminium. The results would be probably different with recycled aluminium.

Conclusions of the sensitivity analysis

The study demonstrates that the frame is the major contributor to the embodied environmental burdens of a window.

For glazing, the conclusions of the sensitivity analysis are:
- the essential parameter is the mass of glass.
- the gas space thickness has a small but non-negligible influence.
- the windows with different filling gas have the same impacts.

The last conclusion is due to the cut off rules (the production step of argon and air are not taken into account).

2.2.5 Energy Balance considering only energy flows through the window

2.2.5.1 Thermal calculations principles

The goal of the thermal calculations is to determine the energy saved when using insulating windows.
They are different in winter and in summer. In winter, the insulating glazings have to decrease the thermal losses. In summer, the insulating glazings have to decrease the thermal inputs.
The reference system for calculation of energy saved is the simple glazing and the wood frame (for complete system). The thermal calculations were performed for glazing only and complete windows.

2.2.5.2 Study on glazings

The reference system is the simple glazing because it has the worse thermal performances.

	simple Glazing 4mm	**Laminated glazing simple 44.2**	**Double Glazing 4/12/4**	**Double glazing 6/12/6**	**Double glazing 4/16/4 low-e, air filling**	**Double glazing 4/16/4 low-e, argon filling**	**Double laminated glazing 4/12/442**	**Double glazing 4/22/4 with film**	**Triple glazing 4/12/4/12/4**
Power saved (W)	nothing	nothing	3,63	3,87	5,16	8,54	3,79	nothing	5,85
Energy saved during 1 year (MJ)	nothing	nothing	1,14E+03	1,22E+03	1,63E+03	2,69E+03	1,19E+03	nothing	1,85E+03

It is impossible to define the energy saved of the laminated simple glazing and double glazing with a film, because they don't lead to energy savings (if reference is the simple glazing). In summer, the energy saved by using insulating glazings is very important, especially in case of the DG 4/22/4 with a film.
However, the study in summer must be discussed because the model of calculation in summer considered energy consumption for cooling. But, air conditioning is not current

everywhere. It's the reason why we consider the energy's savings in summer are less important than thermal loss savings in winter.

SUMMER:

	simple Glazing classic 4mm	Laminated glazing simple 44.2	Double Glazing 4/12/4	Double glazing 6/12/6	Double glazing 4/16/4 low-e, air filling	Double glazing 4/16/4 low-e, argon filling	Double laminated glazing 4/12/442	Double glazing 4/22/4 with film	Triple glazing 4/12/4/12/4
Power saved (W)	-	12,33	20,03	26,77	58,55	58,74	33,32	136,55	36,02
Energy saved during 1 summer (MJ)	-	3,89E+03	6,32E+03	8,44E+03	1,85E+04	1,85E+04	1,05E+04	4,31E+04	1,14E+04

Then, we calculate the average of energy savings (winter and summer values). We compare this value with the primary energy needed to manufacture the glazing.

Conclusions for glazings

The glazing with the best performances is the DG 4/16/4 low-e argon filling. This glazing enables to save more energy without consuming too energy during its manufacturing process.

Nevertheless, all glazings studied lead to important energy savings. The change from a simple glazing to whichever case studied is interesting.

2.2.5.3 Study on complete windows

The same study was performed for the complete windows. The reference system was a wood frame window with DG 4/12/4.

Some cases have been chosen:

FramE	Glazing
wood	DG 4/12/4
Al	DG 4/12/4
PVC	DG 4/12/4
Wood	DG 4/16/4 low-e, argon filled
Al	DG 4/16/4 low-e, argon filled

This enabled us to study the influence of the frame material change and the influence of glazing change.

In order to compare the energy saved with the overconsumption of primary energy during manufacturing, the life of the systems has been specified for each material of window's frame.

The lifetime of a window was set to 20 years.

Conclusions for windows

The change from a wooden frame to a frame in Al or PVC doesn't have any advantages for energy savings. They have worse energy performance sand worse energy content.

On the other hand the change of glazing from 4/12/4 to 4/16/4 (on a wood frame) is interesting from an energy savings point of view.

A complete change from wood +DG4/12/4 to Al+DG4/16/4 is not interesting from an energy point of view. In fact, the energy content increase and the energy losses in summer can’t be balanced by the energy savings in winter.

General conclusion

For glazings, the mass of the glass is the most influent parameter on the LCA results (glass thickness and panes quantity). Glass production and aluminium production are responsible for the major impacts of glazings. For complete windows system (with frames), the material of frame is very influent. The aluminium frame has very heavy environmental burdens. The frame represents about 80% of the embodied impacts of a window.

Despite these conclusions, the environmental balance of insulating glazings and windows is very positive. The energy saved by using these products balances the environmental burdens of product manufacturing in a few days only.

But this study also demonstrates that a minimum gap of performances is necessary when proposing innovative windows systems to counterbalance the potential increase of the environmental burdens content of the product.

3 Solar heating systems
3.1 French Study

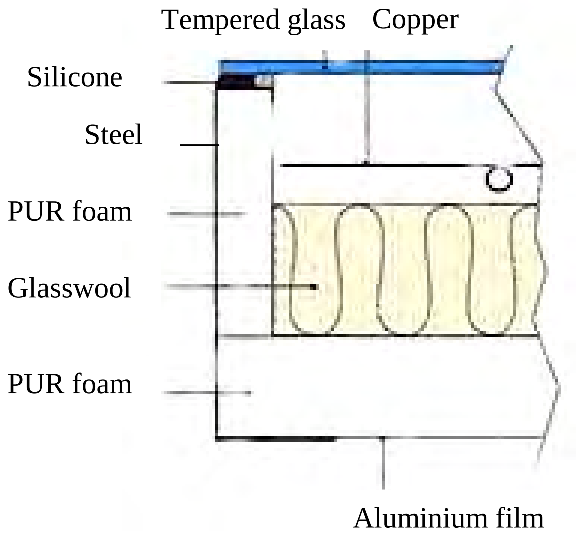
By Guillaume COLLAS (CSTB) and Jacques CHEVALIER(CSTB).

The following section presents the main results of a detailed absorbing collector Life Cycle Assessment.
The study was carried out in accordance with the standards in force (ISO standard 14040 to 14043). This part also present some methodological aspects of the study.

3.1.1 Goal and scope definition

Objectives :
To identify strong points and weak points of the life cycle of the solar collector
To quantify the influence of technical choices (materials) on global environmental impact

Studied solar collector : This one was made in France by a French manufacturer (who wants to stay anonymous).



Functional Unit : It is a solar collector with an optical factor B=0,72 and a transmission coefficient K=4,36 W/m².K which produce energy during 10 years.

Environmental criteria :
- Primary energy (MJ) :
- Non energy resources consumption (kg)
- Water consumption (l)
- Solid waste production (kg)
- Climate change (kg CO_2)

- Acidification (kg SO2)
- Water ecotoxicity (m3) :
- Air ecotoxicity (m3)
- Stratospheric ozone depletion (kg CFC-11)
- Photo-oxidant formation (kg ethylene)

Boundaries :
The study included the extraction of ore, the production of raw materials, the fabrication, the transport, the maintenance and the end of life. The impact of the implementation has been neglected. We define the boundaries thanks to the 5 % cut rule with respect to the French standard XP-P01 010. We have to consider neither the odours, nor the noise. The process generally excluded were excluded : construction and maintenance of the infrastructures and environmental flows due to the users of the site.

3.1.2 Data's collect and inventory

For the fabrication of the collector, all the data were collected on the industrial site : they date from the year 2002 and first half of 2003. The data for the others step of the lifecycle were found in databases and in the French standard XP-P01 010.
The complete inventory is not presented here.

3.1.3 Environmental impact: comparison of the different steps of the lifecycle

The most impacting step of the life cycle of the solar collector lifecycle in the phase of extraction of ore and production of raw materials.
So, for the study of the contribution of each material, we only considered this step.

3.1.4 Contribution of each material to the environmental impacts.

In this part of the study, we worked on the contribution of each material of the solar collector on each criteria studied.

3.1.4.1 Primary energy

The primary energy consumption is related to the extraction work and to all the transformations made to obtain materials (operation of the various machines used and generation of the transformations). The importance of transport is not negligible.
Copper reclaims more work from its ore to its used form and it is also the most impacting (45 %). Then, we have tempered glass (17 %) and PUR foam (14 %).

3.1.4.2 Water consumption

Some manufacturing processes require great quantities of water, in particular obtaining paper pulp and work on it but also obtaining the components of PUR. That is why this impact is principally due to PUR foam (56 %) and cardboard (20 %). We can notice that the fabrication step is not a big water consumer (less than 1 %) : the washing of the glass is done with a closed water circuit so there is only a few loses.

3.1.4.3 Wastes production

Copper is the most responsible for this impact (98 %). For this study, we considered a non-recycled copper and, as we know, it is considered that a copper ore is rich starting from 1,7 % of content of copper. While adding to that all waste coming from the work of this ore until the development of the raw material usable, one arrives at large quantities.

3.1.4.4 Climate change

Emission of greenhouse effect gases (mostly CO_2) contributes to climate change. They are produced while consuming primary energy (combustion are responsible of this gases). This impact is directly connected to the primary energy one. Thus we also found that the materials the more impacting are copper (41 %), tempered glass (25 %), steel (14%) and PUR foam (12 %).
Transformation work on ore, extraction and transport are responsible of this energy consumption thus of the gases emission.

3.1.4.5 Acidification

This impact is also caused by gases (mostly SO_2) from combustion of primary energy. Thus there is also a link with the primary energy impact but the proportion are not the same. Indeed while transforming copper until its usable form we produce a large quantity of SO_2. So we obtain copper as the most impacting (69 %) and PUR foam with less measurement (22 %).

3.1.4.6 Air ecotoxicity

As the two precedent impact, this one is directly related to combustion of primary energy. So copper (42 %), tempered glass (24 %), steel (15 %) and PUR foam (12 %) are the responsible.

3.1.4.7 Water ecotoxicity

The chlorides ions rejected have the most important contribution to this impact. The two materials which generate water ecotoxicity are the ones which reject these ions during their elaboration : PUR foam (64 %) and tempered glass (33 %). These two ones are water consuming during their manufacture but there is an other water consuming material, which is not rejected dangerous substances.

3.1.4.8 Stratospheric ozone depletion

There is only elaboration of PUR foam which rejected pollutant for such an impact so it is the unique contribution.

3.1.4.9 Photo-oxidant formation

Copper is the most responsible (91 %) because of the fact it generates a lot of combustion gases (CO, SO_2, NO_2, CH_4).

3.1.4.10 Summary – Interpretation

Environmental criteria	Principal responsible (contributed to more than 75 % of the impact)
Primary energy	Copper, Tempered glass, PUR foam
Climate change	Copper, Tempered glass, Steel
Acidification	Copper, PUR foam
Air ecotoxicity	Copper, Tempered glass, Steel
Water ecotoxicity	PUR foam, Tempered glass
Wastes production	Copper
Water consumption	PUR foam, Cardboard, Steel
Stratospheric ozone depletion	PUR foam
Photo-oxidant formation	Copper
Non energy natural resources	Steel, Tempered glass, Copper

Thanks to this table, we can see at a glance that the same materials are responsible of every environmental impact. We can also notice these materials also are the most important functional components of solar collector : copper for its thermal properties, PUR foam for its isolating properties, tempered glass for its optical properties. These ones are ones that define the capacity of the collector to produce energy. If we want to change them we will decrease the technical performances of the device and so we will not be profitable any more environmentally.

3.1.5 Energy study

It can be interesting in this study to put in parallel the energy produce by one solar collector in its entire life and the energy necessary to its production.

1200 to 1300 MJ of energy are needed to produce the studied absorbing collector. The amount of produced energy depends on several factors of which the implementation (place, orientation). In France, it is considered that the production of a captor lies between 350 and 600 kWh per m² of captor and per year. If we consider the smaller production for the captor we studied (surface : 2 m², lifetime : 10 years), the total energy produced is more than 25000 MJ. Thus, we can see that after a few months only, it has been produced more energy than it has been used for the manufacturing of the captor.

The energy part of the elaboration is so smaller in comparison with the one produced, that such a study is not very relevant for ecoconception of captors. It is only relevant to optimise systems when thermal properties are well defined.

3.1.6 Commentaries

It has been shown previously that the most impacting materials are whose that define the technical performances of the solar collector. It is not environmentally profitable to try to change this one for others, if it leads to worse performances.

If we consider the energy aspect, the production of energy is 20 times more important than the consumption for the manufacture of the collector. Doing a life cycle assessment of such a solar collector is not relevant as a first ecoconception step because the global environmental impact of the production of all the economised energy would be more consequent.

3.2 Italian study

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3.2.1 LCA

The present report shows the results of an LCA performed upon a solar thermal collector. Production process, installation, maintenance, transports and disposal were checked. We have calculated an overall primary energy consumption of 11.5 GJ. However, the energy directly used during the production process and installation is only the 5% of the overall consumption; another 6% is consumed for transports during the various life cycle phases. The remaining percentage is consumed for the production of raw materials, used as process input.
These results show that the direct energy requirement is less important than the indirect one (in fact, the production processes consist mainly in cutting, welding, bending and assembling steps with a low energy demand). Consequently, including or neglecting some materials, the results will be sensibly modified. For example excluding the collector's support, the primary demand decreases of 1 GJ (10% of the overall consumption). Furthermore, maintenance can involve a large primary energy consumption related to the substitution of spare parts. We supposed two maintenance cycles with an overall primary energy demand of 1.1 GJ.
The production of the solar collector causes mainly direct emissions of metals (Fe, Mn, Mo, Cr, etc.) related to cutting and welding phases. Regarding the other pollutants, it is possible to comment in a similar way as done in the energy analysis. In fact, the indirect emissions (related to production of raw materials) are about the 80-90% of the overall releases, and the results sensibly depend on the materials included in the calculations. Direct emissions related to transports have an incidence of 10-15 %. Water soil releases and wastes are very low.
As previously showed, it is very important to clearly define the study's boundaries and the involved materials. To grant transparency of results, we have presented the study as much disaggregated as possible and we have described all the study's assumptions. The readers can separate all the contributions and follow all the calculation steps. The eco–profiles of materials, energy sources and transports are summarised in Annex 2. Finally it is possible to modify the initial hypothesis (e.g. excluding or adding some components) and to re-calculate the LCA results.

3.2.2 Sensitivity analysis

LCA studies have generally an intrinsic uncertainty related to various factors (i.e. difficulty in the survey of data, lack of detailed information sources, data quality, etc.).

Consequently, it is more important for the experts to evaluate the order of magnitude of input-output flows ascribable to the product than to trace an “exact” ecoprofile of products.
In particular, the LCA studies heavily depend upon exact, complete and sharp data that unfortunately are not always available. Because LCI results are generally used for comparative purposes, the quality of data is essential to state if the results are potentially valid or not. This problem, commonly detected into every LCA, has been strongly detected in our case study. Regarding the solar thermal collector, we have detected a strong dependence of the FU ecoprofile from input materials. They are globally responsible of about 70 ÷ 80 % of the environmental impacts. Large impacts are also caused by the other life cycle steps (transports, installation and maintenance). Impacts caused by the production process are only 5 % (excepting some air pollutants released during cutting and welding steps). Consequently, to investigate more precisely the FU’s environmental impacts, the analysis shall focus on the study’s assumptions.
Uncertainty on input data has been the first problem to be faced. All physical measurements have a degree of uncertainty. Often uncertainty is, itself, uncertain (i.e. the distribution of errors is not well characterised). If one tries to describe the uncertainty through the statistic approach, he faces difficulties not easily surmountable. It is well known that the deviation of a parameter from its “real” value can be described by an uncertainty distribution. When the extreme values of this distribution are known, but not the shapes of the distribution itself, it is possible to use uniform confidence intervals where all the values are equally probable.
Being the statistical approach not easy to follow, “rules of thumb” may be a useful strategy .
These are generic estimations of the uncertainty range for different categories of data based on the expert’s experience. Environmental impacts of material have been therefore supposed enclosed within a variation range. These intervals have been realised on the base on environmental information coming from environmental databases, LCA tools and, in general, to European environmental studies.
It is necessary to distinguish uncertainty, which arises due to the lack of the knowledge about the true value of a quantity, from variability that is attributable to the natural heterogeneity of values.
However, low transparency of references and LCA tools do not allow to distinguish uncertainty from variability. Consequently in this study they have been jointly considered.
The analysis of data quality has been based on many parameters as: geographical coverage, technological level, representativeness, etc. Results have showed a great uncertainty regarding aluminium, copper, thermal fluid and galvanized steel, the dominant material. Considering average values of materials, we have obtained the following results:
The global energy consumption can vary from 8.9 to 13.0 GJPrim, with a variation range of about ± 20% from the referring value of 11.0 GJPrim;
CO_2 emission can vary from 581 to 815 kg CO_2, with a variation range of about ± 17% from the referring value of 700 kgCO_2;
Successively we have calculated the contribution of each life cycle step to the global energy consumption and the CO_2 emission. We have investigated transports,

production, installation, maintenance and disposal processes. A scenario analysis has been employed. We have obtained the following results:
The incidence of transports on the global energy and CO2 balances varies from 2.5% to 5%. A considerable incidence is related to extra regional transports;
The incidence of the production process into global energy consumption has small variation (from 5 to 6%) while incidence into CO2 emission varies from 3 to 7%
The introduction of a copper coating, although not relevant, is not negligible. In general this process increases the environmental impacts from 1 to 2 %. More than energy consumption, the process influences the air emissions and, in particular, the methane emission.
The production process and, in particular, the plasma cutting is responsible for the air emission of metallic substances (mainly iron, chromium and manganese). Being not possible a direct measurement, we have estimated them indirectly. Assumptions can sensibly modify the emitted quantities (iron emission can vary from 0.120 kg to 0.35 kg; manganese from 0,01 kg to 0.06 kg; chromium from 5· 10-3 kg to 0.03 kg);
The incidence of installation process on the global energy balance varies from 1% to 2%. Regarding the CO2 balance, the incidence varies from 1% to 3%;
The contribution of maintenance into LCA results is not negligible. The incidence of maintenance on global energy balance varies from 5% to 10%. On carbon dioxide balance, the incidence varies from 4% to 8%. We have observed that even the partially substitution of thermal fluid involves significant impacts;
The analysis of disposal scenarios has showed that the incidence of disposal on the global impacts could vary from 2 to 5 %. Considerable reductions of impacts could be obtained with the reuse of some parts (till 5 % of energy consumption and 6 % of CO2 emissions).

3.3 Other European LCA studies study on same systems

A study was made by Dutch people (A. Veenstra and H.P. Oversloot) about the environmental performance of solar energy systems : they made a case study and a comparison between two different collectors (a reference collector with the usual materials (many metals) and a roof-integrated collector mostly composed of plastics (ethylene-propylene for the collector) which combines the normal function of weather protection of the roofing material with the collection of solar energy).
In order to compare the results, a surface, which has the same fractional energy savings, has been chosen for each collector. It was also decided that all the materials of mass less than 50 g were not included unless a serious impact was probable.
They showed, for all considered impacts, that the roof-integrated collector scores better. They also conclude that the production phase is the dominant phase regarding environmental impacts (if we do not consider the electricity consumption for the pumps during use). It was shown that metals induce more impacts than plastics, especially because of the extraction of ore. They are mostly responsible for a large increase in waste production, primary energy consumption and climate change.
We can notice that, in order to have the same fractional energy savings, the surface of the roof-integrated collector is four times bigger that the one of the reference solar collector. Thus, we see that the technical performances decrease when we use

plastics instead of metals. So, it is necessary to have a bigger surface and it becomes less profitable.
They thought that Life Cycle Assessment does not really suited for process design because it is too detailed. They also made the following conclusion : this method is too dependant on the start decisions for the study and they are thinking about creating a tool to help in this kind of work.

3.4 General conclusions on solar heating system

Results of the three studies (French, Italian and Dutch) are quite different. But results seem to be the same order. And some conclusions are common to all studies:

- The energy content of solar heating system seems to be quite small in comparison with the energy produced by the solar heating system during its life cycle. This conclusion is quite stable except if the lifetime of the system is short.
- The important requirements on ecoconception of solar heating system must apply to energy efficiency, lifetime improvement, maintenance of energy performance. Choice of manufacturing materials in terms of environmental performances is less important.

General conclusions are more difficult to establish for other impacts not directly linked with energy (energy consumption, climate change, acidification). Further studies with data more precise would have been required.

3.5 Life Cycle Analysis of solar thermal collector: Sensitivity Analysis of Results

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3.5.1 Introduction

The reliability of life cycle assessment (LCA) strictly depends on the quality of available data. The International Standards of series ISO 14040 [1] recommend to investigate all those parameters that could heavily modify the final ecoprofile. In particular, regarding data quality, LCA studies should include:

- time-related coverage
- geographical coverage
- technology coverage
- precision, completeness and representativeness of data;
- consistency and reproducibility of methods used throughout the LCA;
- sources of the data and their representativeness;

- uncertainty of the information.
-

However the standard gives few practical guidance on how to manage such information. In addition to previous listed parameters, other sources of uncertainty are [2]:

- Data inaccuracy (due to errors and imperfection in the measurements);
- Data gaps or not representative data;
- Structure of the model (as simplified model to represent the functional relationships);
- Different choices and assumptions;
- System boundaries definition;
- Characterisation factors and weights (as those used in the calculation of potential environmental impacts);
- Mistakes (unavoidable in every step of LCA)

Moreover the study of uncertainty sources is itself affected by uncertainty. It is necessary to distinguish uncertainty, which arises due to the lack of the knowledge about the true value of a quantity, from variability that is attributable to the natural heterogeneity of values [2]. Uncertainty could be reduced by more precise and accurate measurements while variability is intrinsic to processes. Details contained in the normal LCI study do not often allow distinguishing uncertainty from variability. Consequently in this study they will be jointly considered.
Starting from the results of previous life cycle analyses [3.a, 3.b, 3.c] we have performed a sensitivity analysis upon solar thermal collector. Sensitivity analysis is a systematic procedure for estimating the effects on the outcome of a study of the chosen methods and data [4]. It can be applied with either arbitrarily selected ranges of variation, or variations that represent known ranges of uncertainty.

The study follows three main steps:

1. Individuation of main sources of uncertainty: The ecoprofiles of input materials are one of the main uncertainty sources. They have been analysed in detail in paragraph 2. Finally a table summarises attributes regarding data quality above mentioned. Analogously other uncertainty sources have been investigated. In particular we have revised the main initial assumptions (as system boundaries or impacts allocation) to determine their influence on final results.
2. Variation of initial data: Following the previous considerations, we have tried to translate the uncertainties of a parameter in a variation range. Analogously we have performed a scenario analysis to analyse incidence of different assumptions
3. Estimation of Environmental Impact Indexes: We depict uncertainty of input data and assumptions by using some environmental impact indexes. Being the study concerned upon a renewable energy system, we have focused our attention on the energy indexes and in particular on the “global energy consumption”. Following the Kyoto protocol’s principles, we have studied also the variation of “CO_2” emissions.

The calculation has been performed adopting a linear model and supposing all the input variables independent one from each others. This hypothesis allows to modify one input parameter, taking all other parameters constant, and to observe the variation of the output value.

3.5.2 Synthesis of LCA results

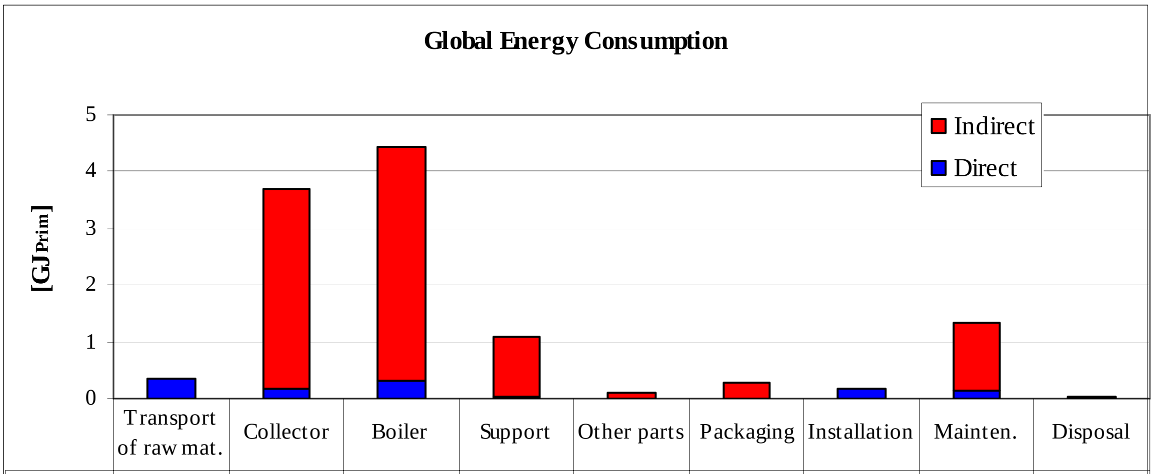
The Life Cycle Inventory regarding the production of the passive solar thermal collector has showed an overall mass input of about 190 kg of various materials. The mass balance also includes:

- Produced scraps;
- Cardboard and plastics for packaging;
- Welding rods for metal welding;
- Antifreeze liquid

Table 1 lists the detail of input masses accounted in the life cycle inventory.
Direct emissions and energy consumptions have been measured in a field analysis performed at the producing factory. Successively indirect impacts have been calculated by employing literature data.
Finally we have carried out the complete ecoprofile of the Functional Unit (FU).
In the following (Fig.1; Table 2) we summarise the global energy and resource consumptions and the main pollutants released during the entire collector's Life Cycle.

Table 3-1: Summary of input masses

Total Mass Inputs		
Galvanised steel	112.6	[kg]
Stainless Steel	29.1	[kg]
Thermal Fluid	37.5	[kg]
Copper	13.6	[kg]
Glass	10.5	[kg]
Rigid Polyurethane (PUR)	9.00	[kg]
Aluminium	4.00	[kg]
Cardboard	3.0	[kg]
Epoxy dust	1.1	[kg]
Steel	1.0	[kg]
High Density Polyethylene (HDPE)	0.9	[kg]
Low Density Polyethylene (LDPE)	0.8	[kg]
Magnesium	0.72	[kg]
Welding rod	0.29	[kg]
Brass	0.14	[kg]
Flexible Polyurethane (PUR)	0.03	[kg]
Polyvinylchloride (PVC)	0.03	[kg]
Tot	224.3	[kg]



	Transport of raw mat.	Collector	Boiler	Support	Other parts	Packaging	Installation	Mainten.	Disposal
Indirect		3.51	4.13	1.07	0.11	0.29		1.17	
Direct	0.35	0.19	0.32	0.03			0.17	0.16	0.02

Fig. 1: Global primary energy consumption

The main assumptions of the study are described in the following (for further detail see [3]):

- We have had no information regarding stainless steel (it has been computed as normal steel);
- The producing company has employed glass with low iron oxides. Missing information about this glass, we have referred to the normal flat glass;
- The company has used epoxy dusts as coating. Missing information about these dusts, we have referred to epoxy resin;
- No information has been found about welding rod production. However, the rod mass is very low and it has been neglected in the calculations, following the 1% cut-off criteria;
- Regarding the ecoprofile of electricity we have referred to the average Italian energy mix;
- The thermal fluid flowing in the tubes is assumed as a 50% mix of water and propylene glycol;
- Ecoprofiles of materials have been referred to average environmental national data. When not available, data have been taken from other environmental database [6,7];
- Input materials has been always computed as not recycled materials;
- The study has included the transport of raw materials to the factory. However these materials are often purchased from intermediate sellers and not directly from the producing companies. Having no possibility to trace back every transport, calculations are arrested to the available information regarding the supplying firms;
- Disposal has included only the transport of the collector and of production's scraps to the landfill. Recycling has been not computed.

Table 3-2: Main air, water and soil pollutants released during collector's Life Cycle

Air Pollutants		Water Pollutants		Soil Pollutants	
CO_2 [kg]	657.0	COD [kg]	18.1	Normal Waste [kg]	64.0
CO [kg]	4.5	Fe [g]	49.8	Special Waste [kg]	0.8
SO_2 [kg]	3.6	Mg [g]	16.4	Ash [kg]	6.8
CH_4 [kg]	2.2	K [g]	7.8		
NO_x [kg]	1.8	NH_3 [g]	4.8		
Dust [kg]	0.6	P [g]	1.4		
NMCOV [kg]	0.3	Cr [g]	1.1		
Mn [kg]	0.3	Pb [g]	0.5		
Fe [kg]	0.1	Na [g]	0.4		
Cr (total) [g]	10.6	Ni [g]	0.4		
Ni [g]	5.0	Mn [g]	0.3		
Cu [g]	3.4	Cd [mg]	5.4		
Mo [g]	0.6	Hg [mg]	4.0		

3.5.3 Sensitivity analysis of INPUT materials

By performing the Life Cycle Assessment we have observed the dominance of indirect energy consumptions upon direct ones. The embodied energy of materials represents, in fact, about 80% of the overall consumption. Consequently sensitivity analysis shall focus upon input materials. Table 3 lists the percentage incidence[1] of each material on the overall energy balance. We choice to investigate those materials whose incidence on the total energy requirement is greater than 1 %.

Table 3-3: Incidence of materials on the global energy balance

Material	Incidence	Material	Incidence
Zinc steel	37.2%	Epoxy dust	1.4%
Propylene Glycol	12.6%	Glass	1.3%
copper	9.8%	HDPE	0.6%
Steel	9.3%	LDPE	0.6%
Rigid PUR	7.6%	Brass	0.1%
Aluminium	5.0%	Flexible PUR	0.03%
Cardboard	2.0%	PVC	0.02%
Magnesium	1.6%		

The main data sources are represented by:
- "*ANPA database*" [5]: it is the Italian official environmental database. The database clearly shows limits and assumption of different methods. Anyway the database misses many important materials.
- "*GEMIS database*" [6]: it is the German official environmental database. Data refers to European environmental researches adapted to the German context. Study's hypotheses, input materials and system's boundaries are often not clearly showed

[1] We have calculated the incidence "i" as ratio between the energy consumption related to a material divided by the global energy consumption.

- “*Boustead Model database*” [7]: this database allows to adapt the ecoprofile of the generic product to the various national contexts by changing the reference energy mix. Data quality is generally good but the transparency of processes is very low.

When possible, data contained in database have been compared to study performed by specialised company (as those regarding aluminium, steel and plastic products).

The following paragraphs show different values of the overall energy consumption and CO_2 emissions obtained by changing a single parameter per time. Successively we recalculated the FU’s ecoprofile based on average data retained most reliable.

A further consideration is necessary regarding the use of calorific values.

The ISO 14041 standard [4] advises that the flow of fossil fuel masses can be transformed into energy flows by multiplying them by the relative calorific values. However the standard does not define what type of calorific value – net or gross- has to be used.

Gross calorific value is the heat energy evolved when all the products of combustion are cooled to atmospheric temperature and pressure. The gross calorific value will therefore include the latent heat of vaporisation and the sensible heat of water in the combustion products [7.b].

Net calorific value is defined as the heat evolved when the products of combustion are cooled so that the water remains as a gas. It is the equal to the gross calorific value less the sensible heat and the latent heat of vaporisation of water [7.b].

Consequently, the gross calorific value represents the total energy resource associated with any fuel [7.c]. Thus gross calorific value is a measure of the total energy resource extracted from the earth whereas net calorific value is essentially a design parameter that underestimates the effective resource demand.

In the present report we have used the gross calorific values. However, the LCAs regarding the ecoprofile of some materials have been calculated using the low calorific values. Being these references often not transparent, it has been not possible to recalculate them turning low calorific values with gross ones. We have clearly declared when low calorific values have been used.

3.5.3.1 Galvanised steel

Galvanised steel (or zinc steel[2]) is the main constituent of the Functional Unit (representing more than half of the overall employed mass) and, having also a great specific value of embodied energy, it is responsible of about 37% of the overall energy consumption.

The previous zinc steel ecoprofile has been taken from GEMIS and it involves about 38 MJ_{Prim} of embodied energy and the emission of 2.4 kg_{CO2} [6].

A research on scientific literature has showed a great variability of these variables depending on the production process. In particular, we have observed an overestimation of embodied energy. Table 4 lists reference values about galvanised steel coil (the average is calculated on values of 11 different sites and on the base of *net calorific value* of fossil fuels) [8].

[2] Galvanisation consists in a zinc coating on the surfaces. For this reason we also refer to this material as “zinc steel”.

The new collector's ecoprofile will involve smaller environmental impacts and, in particular, a reduction of 7.4 % in the energy consumption and a reduction of 3.4 % of CO_2 release. In particular we have calculated the following impacts ascribable to galvanised steel use:
energy consumption = 3.43 GJ_{Prim} (with a variation range from 2.67 to 4.27 GJ_{Prim}).
CO_2 emission = 250 kg_{CO2} (with a variation range from 204 to 313 kg_{CO2}).

Table 3-4: Ecoprofiles of galvanised steel coils

	Minimum	Average	Maximum
Energy [MJ/kg]	27.3	30.5	37.9
Emission [kg_{CO2}/kg]	1.81	2.22	2.78

3.5.3.2 Thermal fluid (water & propylene glycol)

The collector employs about 12.5 kg of thermal fluid composed by a mix of water and propylene glycol. This mix avoids freezing problems during the cold season. As suggested by the selling company the fluid mix can involve from 20% (in high temperature site) to 50% of glycol (in site with low temperature in the winter season). In our study we considered a 50% mix that it is the solution that implies greater energy and environmental impacts. This choice can induce to over-estimate the global energy consumption, in particular, during maintenance (two operations with an overall consumption of 25 kg of fluid).
We have re-calculated the new specific ecoprofile of the thermal fluid considering a mix of demineralised water ad glycol in variable percentage[3]. Data come from various sources [6, 7]. Results are shown in the following figures.

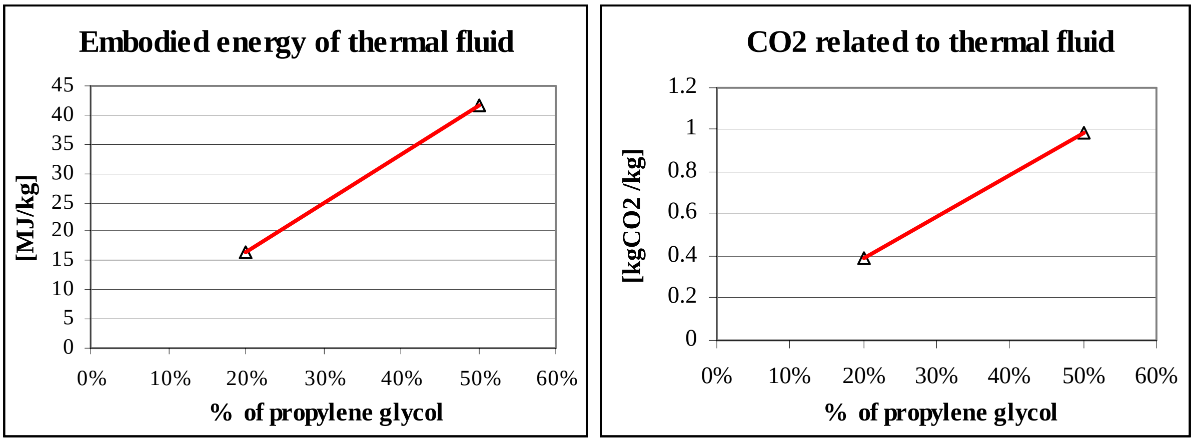


Fig. 2: Embodied energy and CO_2 emissions for variable percentages of glycol in the thermal fluid

The global energy consumption can so vary from 10.7 GJ_{Prim} to 11.6 GJ_{Prim}. Analogously the CO_2 release varies from 630 kg_{CO2} to 667 kg_{CO2}. Considering as reliable the average condition (correspondent to a 35% glycol mix) we have:

[3] Calculation has been made employing data from [7].

Energy consumption = 1.1 GJ_{Prim} (with a variation range of ± 0.467 GJ_{Prim})
CO_2 emission = 26 kg_{CO2} (with a variation range of ± 11 kg_{CO2})

3.5.3.3 Copper

Copper is used for the production of the absorbing plate and pipes for the fluid circulation.
The study of copper's ecoprofiles has showed a great uncertainty in the energy and environmental data due to differences in the production process (ascribable to the use of heat for melting and electricity in the electrolysis) and to the ratio of reused copper scraps.
Following the Italian environmental database [5], the production of 40% recycled copper involves 91 MJ of primary energy per kg and the emission of 6 kg_{CO2} [9]. Compared to other copper's ecoprofiles, Italian data suppose greater environmental impacts: the GEMIS database supposes the consumption of 80 MJ_{Prim} and 5.6 kg_{CO2} per kg of 50% recycled copper; the Boustead database supposes instead a consumption of 56,9 MJ_{Prim} and 5.6 kg_{CO2} per kg of copper (without detail regarding the ratio of recycled scraps).
Consequently to this great variability, we have referred to an average ecoprofile calculated on the basis of Italian and Boustead data, supposing a 23% variation range of the energy use and 29% of the CO_2 emission. Under this hypothesis, copper parts involve:
energy consumption = 1 GJ_{Prim} (with an uncertainty of ± 0.230 GJ_{Prim})
CO_2 emission = 649 kg_{CO2} (with an uncertainty of ± 18 kg_{CO2})

3.5.3.4 Stainless steel

Stainless steel is a largely employed material thanks to its corrosion resistance and longevity. The production of the solar collector implies the use of 29 kg of this material. However, at the time of the first report we had no information regarding stainless steel and we computed it as normal steel.
We have analysed variations in the collector's ecoprofile by introducing the environmental data regarding stainless steel. These data comes from EUROFER [10] and they refer to cold rolled austenitic (grade 304) stainless steel (see table 5).
Respect to the normal steel, the production of stainless steel requires a larger amount of energy (62 MJ_{Prm}/kg with an increase of about 75%) and larger environmental impacts (emission of CO_2 is more than doubled with a specific factor of 6.2 kg_{CO2}/kg). These variations are mainly caused by the additional raw materials and, in particular, by the use of nickel [11].
In the FU's Life Cycle stainless steel will involve a consumption of 1.8 GJ_{Prim} (increase of 770 MJ_{Prim}) and the emission of 180 kg_{CO2} (increase of 94 kg_{CO2}).
Having only one reference, it has been no possible to calculate a variation range for stainless steel. We also would like to point out that the use of data regarding normal steel instead of stainless steel drastically changes the final ecoprofile. This is an example that stresses a key question in the LCA: we need a clear description of limits

and assumptions in a generic study, particularly when we have to compare replaceable products.

Table 3-5: Stainless steel's ecoprofile

Functional Unit: **1 kg of Stainless Steel**

Data Source: **EUROFER**

INPUTS			**OUTPUTS: Air**			**OUTPUTS: Water**		
Cr	159.2	g	CO_2	6.2	kg	NH_3	126.8	mg
Coal	1084.2	g	CO	14.1	g	Cd	0.074	mg
Dolomite	48.6	g	Cr (total)	144.4	mg	Cr (total)	2.8	mg
Iron	155.0	g	Dioxins	7.7E-06	mg	COD	2.8	g
Lignite	116.9	g	Ni	76.1	g	Hydrocarbons	74.8	mg
Limestone	243.0	g	NOx	21.2	g	Cu	0.45	mg
Mn	18.8	g	Particulate	7.9	g	Fluorides	153.4	mg
Mo	1.0	g	SOx	41.2	g	Fe	227.5	mg
Natural Gas	293.1	g				Pb	1.8	mg
Ni	55.9	g				Mn	6.4	mg
Oil	361.0	g				Ni	11.7	mg
Steel Scraps	738.4	g				NO^{3-}	3.6	g
Water	84.2	kg				Nitrogen (as N)	4.25	g

3.5.3.5 Polyurethane (PUR)

Polyurethane rigid foam (or rigid PUR) is employed as insulation for the absorbing surface and the water tank. PUR is injected directly in interstices and it is blown with pentane. Ecoprofile of PUR has been performed by Boustead [12] and data quality is very good (embodied energy 105 MJ_{Prim}/kg; emission of 3.7 kg_{CO2}). However these data use the English electricity mix. The ecoprofile has been therefore recalculated using the Italian electricity mix. Employing these modified data, the PUR use will involve:

- energy consumption = 1 GJ_{Prim} (with a variation range of $\pm$ 0.06 GJ_{Prim})
- CO_2 emission = 30 kg_{CO2} (with a variation range of $\pm$ 3 kg_{CO2})

Aluminium has a sensible incidence in the global energy balance mainly due to the high specific energy consumption related to its production. To perform the sensitivity analysis regarding this material we have referred to a study of the EAA (European Aluminium Association) [13].

Table 3-6: Ecoprofile of the primary aluminium, recycled aluminium and rolled aluminium sheet

	1 kg of Primary Aluminium			1 kg of 100% Recycled Aluminium			1 kg of Rolled Aluminium Sheet		
Main Inputs	Bauxite	4.11	[kg]	Aluminium scraps	1.27	[kg]	Aluminium ingot	1.012	[kg]
	Water	16.1	[kg]	Alloying elements	0.08	[kg]	Alloying (total)	0.01	[kg]
	Salt	0.09	[kg]	Salt	0.01	[kg]	Water	0.04	[kg]
	Limestone	0.16	[kg]	H_2SO_4	8	[g]	Nitrogen	0.40	[g]
	H_2SO_4	0.03	[kg]	Lime	8	[g]	Ar	0.91	[g]
	Calcium fluoride	0.03	[kg]	Water	8	[g]	Salts	0.38	[g]
	Alloying elements	0.01	[kg]	Cl	2	[g]	Cl	0.008	[g]
	Coal	1.46	[kg]	Coal	50	[g]	Coal	0.07	[kg]
	Lignite	1.33	[kg]	Lignite	50	[g]	Lignite	0.08	[kg]
	Natural gas	0.41	[kg]	Natural gas	0.23	[kg]	Natural gas	0.10	[kg]
	Oil	1.37	[kg]	Oil	30	[g]	Oil	0.02	[kg]
	Nuclear electricity	9.24	[MJ]	Nuclear electricity	0.51	[MJ]	Nuclear electricity	0.90	[MJ]
	Hydroelectricity	29.9	[MJ]	Hydroelectricity	0.21	[MJ]	Hydroelectricity	0.37	[MJ]
Main Outputs	CO_2 (air)	10.6	[kg]	CO_2 (air)	0.8	[kg]	CO_2 (air)	0.5	[kg]
	CO (air)	96	[g]	CO (air)	0.3	[g]	CO (air)	0.15	[g]
	CH_4 (air)	20	[g]	Dust (air)	0.29	[g]	Dust (air)	0.33	[g]
	Dust (air)	27	[g]	NOx (air)	1.1	[g]	NOx (air)	0.81	[g]
	NOx (air)	27	[g]	SO_2 (air)	2	[g]	SO_2 (air)	1.56	[g]
	SO_2 (air)	72	[g]	NH_3 (air)	0.02	[g]	CH_4 (air)	1.3	[g]
	HCl	1.4	[g]	N (air)	2.5	[g]	other HC (air)	0.4	[g]
	HF	0.75	[g]	HC (air)	2.6	[g]	VOC (air)	0.44	[g]
	NH_3 (water)	0.06	[g]	ball mill dust(land)	64.3	[g]	COD (water)	0.08	[g]
	COD (water)	0.23	[g]	rubber (land)	24.3	[g]	Cl (water)	1.3	[g]
	Bauxite (land)	1.29	[kg]	filter dust (land)	13	[g]	Solid waste (land)	7.1	[g]
	carbon waste(land	3.9	[g]	Solid waste (land)	3.4	[g]	Haz. waste (land)	4.8	[g]

Primary aluminium metal is produced from aluminium oxides by an electrolytic process that requires large amount of electricity. Furthermore, the production employs a large amount of bauxite (4 kg of bauxite per kg of aluminium) coming from abroad and with a consequent great incidence of transport. These data (Table 6) are representative of the present production in Europe. Recycled aluminium is instead obtained by melting process after refining processes to remove coating, ink, impurities, etc. Successively

scraps are melted with the addition of alloying elements. Scraps can be melted and reused without loss of quality. The recycling process saves raw materials, it requires much less energy than the primary aluminium production and it also reduces demands on landfill sites [14]. However, referring to the great variability in scrap processing, a model for the recycled aluminium (Table 6) should be considered as indicative [13].
It is possible to observe the great difference between the energy consumption of primary aluminium (184 MJ/kg) and recycled aluminium (17 MJ/kg)[4].
The output of recycling is a recycled aluminium ingot. This material can be used interchangeably with primary aluminium ingot in every semi-finished aluminium product fabrication process. The solar collector employs rolled aluminium sheets in the inner framework. The primary energy consumption of an aluminium sheet is 11 MJ/kg; a detail of its ecoprofile is shown in table 6 [13]. Successively we calculate the global ecoprofile of aluminium sheet related to the recycled fraction. Obtained results are showed in fig. 3.

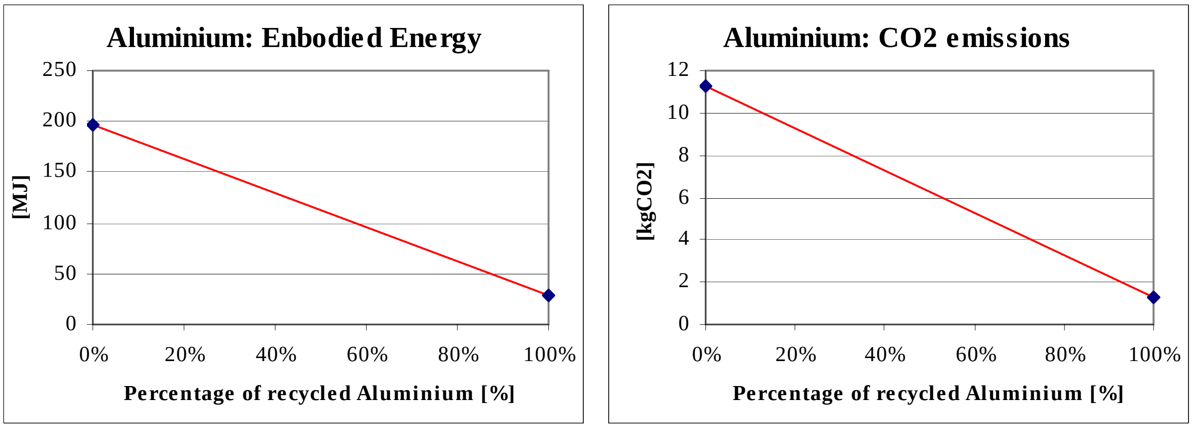


Fig. 3: Embodied energy and CO_2 emissions for variable percentages of recycled aluminium in the aluminium sheet

Unfortunately no information is available regarding the percentage of recycled aluminium in the semi-products used in the collector. Supposing to employ 30% of recycled aluminium we have:

- Energy consumption = 584 MJ_{Prim} (with a variation range from 111 MJ_{Prim} to 787 MJ_{Prim})
- CO_2 emission = 33 kgCO2 (with a variation range from 5 kg_{CO2} to 45 kg_{CO2})
-

3.5.3.6 Cardboard

Three kilograms of cardboard are used to package collector's parts for sale. Ecoprofiles of cardboard have a great variability mainly due to the different quality of paper and raw materials. In the study we have referred to an average value (Table 7) calculated from databases [5, 7]. The global energy consumption is enclosed in the range from 26.7 to 54.1 MJ_{Prim}/kg while carbon dioxide varies from –0.7 to 2.6 kg_{CO2} (*negative value is related to use of biomass in the production*).

[4] Energy consumptions values have been calculated with the following gross calorific values: Coal 28 MJ/kg; Oil 45 MJ/kg; Gas 54.1 MJ/kg.

Table 3-7: Average ecoprofile of cardboard

Cardboard							
Main Inputs	Coal	0.1	[kg]	Main Outputs	CO (air)	2.2	[g]
	Natural gas	0.03	[kg]		CO_2 (air)	1.0	[kg]
	Oil	0.1	[kg]		Dust (air)	2.4	[g]
	Nuclear electricity	3.02	[MJ]		NOx (air)	4.2	[g]
	Hydroelectricity	0.3	[MJ]		SO_2 (air)	10.4	[g]
	Lignite	0.01	[kg]		HC (air)	4.2	[g]
	Wood	1.41	[kg]		CH_4 (air)	6.1	[g]
	Other energy sources	0.03	[MJ]		COD (water)	21.4	[g]
	Clay	0.3	[kg]		Phenol (water)	0.004	[g]
	Limestone	0.02	[kg]		NH_3 (water)	0.004	[g]
	Salt	0.02	[kg]		Ashes (land)	2	[g]
	Water	25.5	[kg]		Inert waste (land)	0.2	[kg]

Using these data, contributions of cardboard to the collector's ecoprofile are:
- Energy consumption = 121 MJ_{Prim} (with a variation range of ± 41 MJ_{Prim})
- CO_2 emission = 2.8 kg_{CO2} (with a variation range of ± 5 kg_{CO2})

3.5.3.7 Magnesium

Although the use magnesium in the LCA of solar collector is very low (0.3% of the overall mass) it incidence in the energy balance is not negligible. This is due to a very high specific value of embodied energy. However few LCA upon magnesium are available. Table 8 shows the ecoprofile of magnesium as reported in the GEMIS (257 MJ/kg) [6] and Boustead Model (361 MJ/kg) [7] databases. Boustead data are more reliable but have a low transparency. The average of the two magnesium ecoprofiles has been used in the solar collector's life cycle inventory. Details are shown in table 8.Contributions of magnesium to collector's ecoprofile are:
- energy consumption = 221 MJ_{Prim} (with a variation range of ± 37 MJ_{Prim})
- CO_2 emission = 12.7 kg_{CO2} (with a variation range of ± 1.7 kg_{CO2})

Table 3-8: Magnesium ecoprofile- average values

Magnesium							
Main Inputs	Coal	1.3	[kg]	Main Outputs	CO (air)	22	[g]
	Natural gas	3.0	[kg]		CO_2 (air)	18	[kg]
	Oil	1.4	[kg]		Dust (air)	38	[g]
	Nuclear electricity	23.8	[MJ]		NOx (air)	0.12	[kg]
	Hydroelectricity	22.6	[MJ]		SO_2 (air)	94	[g]
	Lignite	0.03	[kg]		HC (air)	31	[g]
	Biomass	0.01	[kg]		CH_4 (air)	87.2	[g]
	Other energy sources	4.8	[MJ]		COD (water)	0.5	[g]
	Mg	1.0	[kg]		Acid (water)	0.01	[g]
	Limestone	3.8	[kg]		NH_3 (water)	0.01	[g]
	Water	15.6	[kg]		Ashes (land)	0.23	[kg]
					Inert waste (land)	0.57	[kg]

3.5.3.8 Epoxy dusts

Epoxy dusts are used for the collector's coating. Missing information about these dusts, we have referred to epoxy resin (epoxy dusts are generally derived by epoxy resins). However, the computational error is not significant because epoxy dusts are about 0.6 % of the overall empty mass and they could be neglected, following the 1% cut-off criteria.

Table 3-9: Ecoprofile of epoxy resin

Epoxy Resin							
Main Inputs	Coal	0.4	[kg]	Main Outputs	CO (air)	2	[g]
	Natural gas	1.3	[kg]		CO_2 (air)	6	[kg]
	Oil	0.7	[kg]		Dust (air)	15	[g]
	Nuclear electricity	8.1	[MJ]		NOx (air)	35	[g]
	Hydroelectricity	1.3	[MJ]		SO_2 (air)	19	[g]
	Lignite	0.21	[kg]		HC (air)	6	[g]
	Salt	1.8	[kg]		CH_4 (air)	31.1	[g]
	Limestone	0.7	[kg]		COD (water)	51.4	[g]
	Water	404	[kg]		Acid (water)	0.06	[g]
					NH_3 (water)	0.01	[g]
					Ashes (land)	0.03	[kg]
					Inert waste (land)	0.3	[kg]

The ecoprofile is shown in Table 9 [7, 15] involving 140.7 MJ/kg of embodied energy and the emission of 5.9 kg_{CO2}. These values have been compared to those coming from analogous works showing that the energy variability is lower than 10% and

emission variability lower than 2 % (from GEMIS database we calculate that epoxy resin involves 154 MJ/kg of embodied energy and the emission of 6 kg_{CO2}).
To take into account the uncertainty due to missing information about dust production we have decided to increase the energy variation range till up 20% and the emission variability till up 10%. Consequently epoxy use will involve:
energy consumption = 152 MJ_{Prim} (with a variation range of ± 30 MJ_{Prim})
CO_2 emission = 6.4 kg_{CO2} (with a variation range of ± 0.6 kg_{CO2})

3.5.3.9 Flat Glass

The collector's absorbing-surface is covered by a high transparent tempered single glass. Thanks to its low percentage of iron oxides content, this glass has a greater transparency to solar radiation increasing the collector's efficiency.
However having no specific data regarding this typology of glass we refer to coated flat glass for windows. Data as reported in GEMIS database has been modified with the Italian energy mix, obtaining a specific primary energy consumption of 14.5 MJ and the emission of 1.2 kg_{CO2} per kg of glass.
A reference research regarding glass ecoprofiles has showed a variation range from 8.6 MJ_{Prim}/kg for normal glass [16] to 22.8 MJ_{Prim}/kg for flat glass processed with electric melting [7]. Consequently, glass use will involve:

- Energy consumption = 152 MJ_{Prim} (with a variation range from 90 to 240 MJ_{Prim})
- CO_2 emission = 12 kg_{CO2} (with a variation range form 7 to 13 kg_{CO2})

3.5.3.10 Data quality

Table 10 lists the quality of data used to estimate indirect impacts related to input materials. In particular the table lists:

- Age of data or period which data refer to;
- Geographical coverage: location which data refer to (when possible ecoprofiles have been adapted to Italian case study by using the Italian energy mix);
- Technological level: it describes the functional unit and the process to produce it;
- Completeness of data (underlying possible gaps);
- Representativeness: it represents the extent to which a set of measurements taken in a space-time domain reflects the actual conditions in the same or different space-time domain;
- Transparency of the study (taking into account if are clearly described the study's boundaries, inputs and outputs);
- Relevance: it summarise if materials have a or not a great incidence on the study
- References

When possible, uncertainties of the previous indexes are summarised in the energy and emission variation ranges. Facing with ecoprofiles affected by great uncertainties we have to compare data with others coming from similar studies to state the range within values can probably vary. Actually the width of these ranges can be related to uncertainties as much as to the natural variability in the process. However, as previously described, having no way to distinguish uncertainties from inner variability, they are managed together. Following our experience, we formulate a qualitative global data-quality indicator that, on the basis of the previous indexes, summarises our judgement about the studies.

Table 3-10: Data quality of input materials

Material	Age	Geographical coverage	Technology coverage	Completeness of data	Representativeness	Energy variation range [MJ/kg]	CO_2 emission variation range [kg_{CO2}/kg]	Transparency of data	Relevance in the study	Data quality indicator	Reference
Galvanised Steel	1994-1995	Average of 11 sites	Hot-dip galvanised steel coil	Low air emission details, not clear energy consumption (missing uranium & hydroelectricity)	Data could be assumed as an European Average	27.3 - 37.9	1.8 - 2.8	Medium	Very high	Good	[8]
Stainless Steel	not specified	Average of the most important European producers	Cold rolled austenitic stainless steel coil (grade 304)	Low detail on the energy consumption (missing uranium & hydroelectricity)	Data could be assumed as European Average. No available other similar study which compare to.	62.1	6.2	Low	Very High	Medium	[10]
Thermal Fluid	1998	Data adapted to Italian case study	Mix demineralised water and propylene glycol	All the main energy and environmental impacts are shown	Average value from two European studies, recalculated with Italian energy mix	17 - 41	0.4 - 1.0	Medium	High	Good	[6,7]
Copper	1980-1990	Estimation from other European studies adapted to Italian case study	Copper with 40%-50% of reused scraps	All the main energy and environmental impacts are shown	Average value from two European studies, but one is very old and not complete and the other is not transparent	57 - 91	3.3 - 5.9	Low	High	Low	[6,7,9]
Rigid PUR	1997	Average of European producers. Data adapted to Italian case study	Polyurethane foam used as thermal insulation	All the main energy and environmental impacts are shown	Representative of the European average. Adapted with Italian energy mix	105 - 118	3.4 - 3.8	High	High	Very Good	[12]
Aluminium	2000 (refers to data from 1992-1994)	Average of 70% - 90% of the European producers	Aluminium cold rolled sheet.	All the main energy and environmental impacts are shown	Average European data about primary aluminium. Estimation of recycling process. From 30 to 100% recycled aluminium	28 - 198	1.3 - 11.3	High	High	Very Good	[13,14]
Magnesium	1990-2000	Estimation from two European studies adapted to Italian case study	Magnesium metal	Data from estimations. Some production steps are missing.	Data refer to two European study modified with Italian energy mix. Study's boundaries not well defined	258 - 361	15 - 20	Low	High	Medium	[6,7]

Material	Age	Geographical coverage	Technology coverage	Completeness of data	Representativeness	Energy variation range [MJ/kg]	CO_2 emission variation range [kg_{CO2}/kg]	Transparency of data	Relevance in the study	Data quality indicator	Reference
Glass	1990-2000	Estimation from European studies adapted on the Italian case study	Average of data regarding normal glass, flat coated and electrically melted glass	Data estimated. System boundaries not precisely defined	No data regarding glass with low iron oxides. Estimation from other process	8.6 - 22.8	0.75 - 2.7	Low	Medium	Low	[6,7,16]
Epoxy dust	1999	Estimation from two European studies adapted to Italian case study	Epoxy liquid resin is the main constituent of Epoxy dust	Data estimated. System boundaries not precisely defined	No data regarding epoxy dusts. Estimation form other process	113 - 167	4.7 - 7.1	Medium	Medium	Medium	[5,7,15]
Cardboard	1996-1998	Estimation from two European studies adapted to Italian case study	Paperboard form primary papers.	Data of two studies calculated with different methods (as the CO_2 emission and biomass contribution)	We have examined many studies and we have observed a large variation range.	26.7 - 54.1	-0.7 - 2.6	Low	Medium	Low	[5.8]
HDPE	1990-2000	Average of main European producers	High density polyethylene	All the main energy and environmental impacts are shown	Representative of the European average	88	2.1	High	Medium	Very good	[17]
LDPE	1990-2000	Average of main European producers	Low Density polyethylene	All the main energy and environmental impacts are shown	Representative of the European average	81	1.4	High	Medium	Very good	[18]
Normal Steel	1994-1995	Average of 4 sites	Normal steel plate	Low air emission detail, not clear energy consumption (missing uranium & hydroelectricity)	Data could be assumed as an European Average	26.4 - 33.1	1.7 - 2.9	Medium	Low	Good	[19]
Brass	1996	Secondary data from European studies, adapted to Italian case study	Brass calculated as 58% copper and 42% zinc	Data from estimation. Specific impact related to production not investigated	Rough estimation from data about copper and zinc	107	5.0	Low	Low	Low	[5]
Flexible PUR	1997	Average of main European producers	Flexible Polyurethane used as sealing	All the main energy and environmental impacts are shown	Representative of the European average	105	4.1	High	Low	Very good	[12]
PVC	1990-2000	Average of main European producers	PVC small	All the main energy and environmental impacts are shown	Representative of the European average	64	1.8	High	Low	Very good	[20]

3.5.3.11 Summary

Following hypotheses of previous paragraphs, we have recalculated the FU's ecoprofile. A summary of the main energy and environmental impacts is below shown (Table 13.a). If we compare the previous ecoprofile with the last one, it is possible to observe small variations of the global energy consumption (- 4%) and of the CO_2 emission (+6 %). Other parameters sensibly change and, in detail, we have observed very large variations for "CH_4" and "*Dusts*" in air emissions and for "COD" in water emissions. This is mainly due to sensible differences in ecoprofiles of steel products. Calculating the incidence of materials in the global energy balance (Table 11) and comparing results with data of Table 3, it is possible to observe that galvanised steel is always the dominant material but stainless steel is the parameter with had the greatest variation. This is due to higher environmental impacts regarding the stainless steel in substitution to data referring to the normal steel.

Table 3-11: Incidence of materials in the global energy balance

Material	Incidence	Material	Incidence
Galvanised Steel	31.2%	Epoxy dust	1.4%
Stainless Steel	16.4%	Cardboard	1.1%
Thermal Fluid	9.9%	HDPE	0.7%
Copper	9.1%	LDPE	0.6%
Rigid PUR	9.1%	Steel	0.3%
Aluminium	5.3%	Brass	0.1%
Magnesium	2.0%	Flexible PUR	0.03%
Glass	1.4%	PVC	0.02%

Table 3-12: Incidence of materials in the CO_2 emission balance

Material	Incidence	Material	Incidence
Galvanised Steel	35.7%	Epoxy dust	0.9%
Stainless Steel	25.8%	Cardboard	0.4%
Copper	8.9%	Steel	0.3%
Aluminium	4.7%	HDPE	0.3%
Rigid PUR	4.4%	LDPE	0.2%
Thermal Fluid	3.7%	Brass	0.1%
Magnesium	1.8%	Flexible PUR	0.02%
Glass	1.8%	PVC	0.01%

Table 3-13: Summary of Collector's ecoprofile

Furthermore, the reference research has shown that other material's embodied energy has been overestimated and consequently their incidence has been reduced/increased of variable percentages. In particular galvanised steel's incidence moves from 37% to 31%, thermal fluid from 13% to 10% and copper from 10% to 8%. Embodied energy of

other materials (aluminium, magnesium, PUR) has a growing value but their incidence remained lower then 10%.
Analogous considerations can be made about material's incidence in the CO_2 emission balance (Table 12). However incidence of steel components (galvanised and stainless steel) become greater (responsible of more than 60% of the carbon dioxide emission balance).

Primary Energy Consumption	
Not Renewable Sources	
Coal [kg]	125.9
Natural Gas [kg]	50.0
Wood [kg]	6.3
Lignite [kg]	10.0
Oil [kg]	75.9
Uranium [kg]	0.001
Renewable Sources [MJ]	272.2
Fuel Energy [GJ]	9.8
Feedstock Energy [GJ]	1.2
Total Primary Energy [GJ]	**11.0**

Resource Consumption	
Ferrous Minerals [kg]	171
Water [m^3]	9.3
Iron Scraps [kg]	29.1
C_aCO_3 [kg]	24.1
NaCl [kg]	14.9
Bauxite [kg]	11.7
Copper Minerals [kg]	7.6
Zinc [kg]	4.1
Sand [kg]	4.5
Copper Scraps [kg]	2.7
KCl [kg]	2.3
Ni [kg]	1.6
Clay [kg]	0.9
Nitrogen [kg]	1.6

Water Pollutants	
COD [kg]	0.3
NH_3 [g]	12.5
Fe [g]	12.3
Pb [g]	11.2
K [g]	8.3
Mg [g]	6.3
Ni [g]	0.5
Mn [g]	0.3
Cr [g]	0.2
Na [g]	0.2
P [g]	0.1
Cd [mg]	2.9
Hg [mg]	1.8

Air Pollutants			
CO_2 [kg]	699	Ni [g]	7.1
CO [kg]	4.6	Cu [g]	4.7
SO_2 [kg]	4.2	N_2O [g]	3.9
CH_4 [kg]	0.6	Zn [g]	3.7
NO_x [kg]	2.5	Mo [g]	0.6
Dust [kg]	1.1	C_6H_6 [mg]	99
Cr (total) [g]	14.8	Cd [mg]	113
Pb [g]	11.2		

Soil Pollutants	
Normal Waste [kg]	53.5
Ash [kg]	3.6
Special Waste [kg]	0.4

We have developed a sensitivity analysis to estimate the variation induced on the FU's ecoprofile by changing ecoprofiles of input materials. Considering average values of materials, the FU have involved the energy consumption of *11* GJ_{Prim} and the emission of *700* kg_{CO2} (Table 13.a).

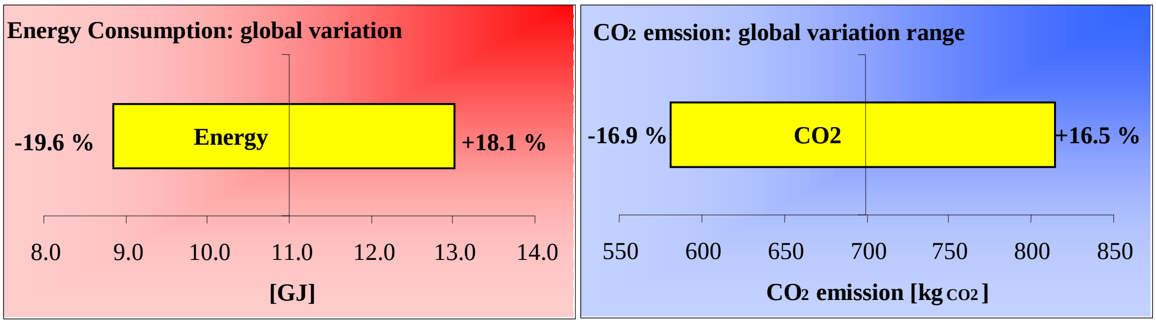


Fig. 4: Summary of Energy and emission global variation ranges

Changing each material within its variation range, environmental indexes referred to the FU change sensibly. In particular we have calculated the variation intervals referred to the "energy consumption" and "CO_2 emission" indexes. The left and right extremes of these interval have been obtained supposing respectively all the input materials with their lowest ecoprofiles and then with their highest ones (Fig. 4). Considering the lowest values, global energy consumption is decreased of 19.6% and the CO_2 emission is decreased of 16.9%. Analogously considering the highest values, the global energy consumption is increased of 18.1% and the CO_2 emission of 16.5%.

Successively we have studied the variations of these indexes caused by each material, taking all the others fixed to their average values. Figures 5 and 6 show the incidence of the ecoprofile of each input material to the global FU ecoprofile. Regarding the galvanised steel it is possible to observe that, modifying its ecoprofile, the global energy consumption changes from 10.25 GJ_{Prim} to 11.85 GJ_{Prim} and the CO_2 emission changes from 655 kg_{CO2} to 762 kg_{CO2}.

Percentage variations of FU's environmental indexes are showed in Table 13.b. For example, galvanised steel can modify the global energy consumption from -6.9% to +7.6% (with a variation range of 1.6 GJ_{Prim}) and the CO_2 emission from –6.6% to +9.0% (with a variation range of 109 kg_{CO2}).

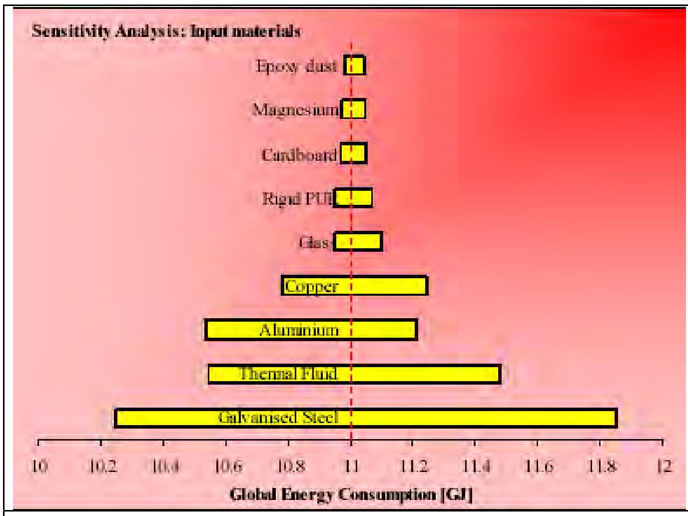


Fig. 5: Sensitivity analysis of the global energy consumption due to input materials

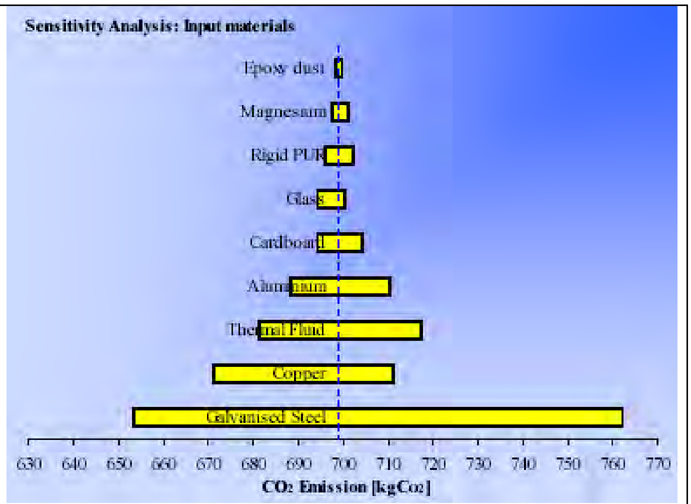


Fig. 6: Sensitivity analysis of the CO2 emissions due to input materials

Table 3-14: Sensitivity Analysis of the global energy consumption and CO_2 emission due to input materials

Variations of global energy consumption related to the energy embodied into materials			
Materials	Lower variation extreme [%]	Upper variation extreme [%]	Variation Range [MJ_{Prim}]
Galvanised Steel	-6.9	7.6	1600
Thermal Fluid	-4.2	4.2	934
Aluminium	-4.3	1.8	676
Copper	-2.1	2.1	460
Glass	-0.6	0.8	150
Rigid PUR	-0.5	0.5	116
Cardboard	-0.4	0.4	82
Magnesium	-0.3	0.3	74
Epoxy dust	-0.3	0.3	60

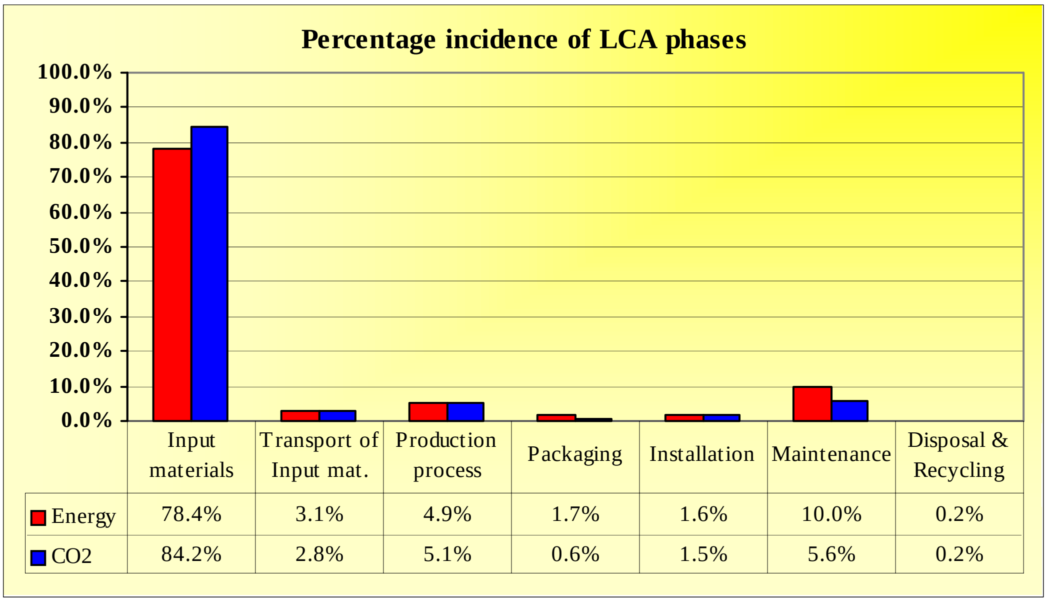
Variation of CO_2 emission related to input materials			
Materials	Lower variation extreme [%]	Upper variation extreme [%]	Variation Range [kg_{CO2}]
Galvanised Steel	-6.6	9.0	109
Copper	-4.0	1.7	40
Thermal Fluid	-2.6	2.6	36
Aluminium	-1.6	1.6	22
Cardboard	-0.7	0.7	10
Glass	-0.7	0.1	6
Rigid PUR	-0.4	0.4	6
Magnesium	-0.2	0.2	3
Epoxy dust	-0.1	0.1	1

These results show that the impacts related to input materials can sensibly change the FU ecoprofile. We can make the following considerations:

- The global energy consumption can vary from 8.9 to 13.0 GJ_{Prim}. It means a variation range of about ± 20% from the referring value of 11.0 GJ_{Prim};
- CO_2 emission can vary from 581 to 815 kg_{CO2}. It means a variation range of about ± 17% from the referring value of 700 kg_{CO2};
- The variation ranges are not symmetric and it depends from asymmetric ranges of input materials (Fig 4 - 6);
- Galvanised steel, the dominant material (see table 11), is also the component which ascribe the greatest uncertainty to. It is responsible of 40% of the global uncertainty on the energy consumption and of 50% on that related to the CO_2 emission;
- PUR, magnesium and cardboard are responsible of a low incidence in the variation range (less than 5%). On the contrary, the great variability on the ecoprofiles of aluminium, copper and thermal fluid causes large variation ranges (from 10% to 20%).

3.5.4 Sensitivity analysis of LCA phases

In this section we describe results of sensitivity and uncertainty analysis upon LCA phases. Starting from the above described ecoprofile (§ 4.) we have calculated the contribution of each process to the global energy consumption and CO_2 emission (Fig. 5.).



	Input materials	Transport of Input mat.	Production process	Packaging	Installation	Maintenance	Disposal & Recycling
Energy	78.4%	3.1%	4.9%	1.7%	1.6%	10.0%	0.2%
CO2	84.2%	2.8%	5.1%	0.6%	1.5%	5.6%	0.2%

Fig. 5: Percentage incidence of LCA phases on global energy consumption and CO_2 emission

We can observe that:

- Input materials, as already investigated, are the dominant factor in the LCA results. They weight for 80% in the overall energy and emission balance.
- The incidence of maintenance is considerable, especially regarding the energy consumption (10 % of the global consumption), mainly related to the substitution of spare parts.
- Incidence of maintenance in the CO_2 balance is lower (5 %). This is caused by the use of propylene glycol, a material with a high specific embodied energy (especially as feedstock) and a relatively low CO_2 emission factor.
- % of impacts are ascribable to the production process, 3 % to transports of raw materials and 2 % to installation and packaging.
- Disposal and recycling process is negligible.

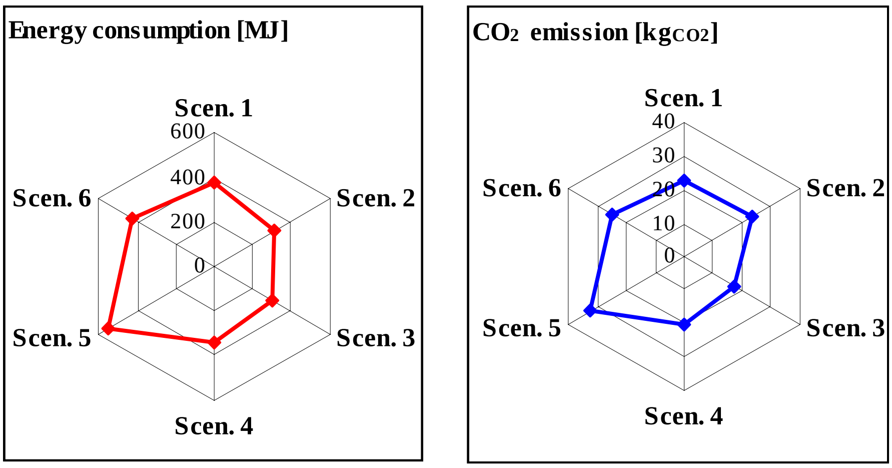
The incidence of input materials has been investigated in detail in previous paragraphs. Here the analysis focuses on those parameters that characterise each LCA's step. We proceed with new sets of assumptions managed separately, aiming to individuate the most significant issues (scenarios analysis).

3.5.4.1 Transport of Input materials

The transport of raw materials to the productive site has been estimated as about 3 % of global environmental impacts.

The analysis focused on the transported masses and distances. Investigated transports occur exclusively by diesel trucks. The functional unit for truck's transport is the "tkm": *the energy and environmental impacts are related to the transport of a ton of products for 1 km route* (that is equal to transport 1 kg for 1000 km). Uncertainty grows regarding transport conditions. In fact we have collected information only regarding direct supplying firms. Details are missing about the transport of some materials and in particular regarding plastic components (coming from northern Italy) and glass (produced abroad). These materials are commercialised by intermediate purchasers and their transports plans are not available.

Furthermore the company acquires great stocks of metals in different periods. Successively, the metals are stored and then used on demand for many different products. Being not possible to relate the exact number of travels to the production of solar collector, it is only possible to define different scenarios of transports.
Initially we suppose to employs exclusively 28 tons trucks. The values of consumption are referred to ANPA-database [5] (Scenario 1) or to Boustead database [7] (Scenario 2). Both scenarios refer to average conditions of roads and traffic and a 50% load factor.
Scenario 3 supposes that transports of glass and plastics occur by means of 40 tons truck. Scenario 4 supposes instead that only glass is transported with high load trucks for about half of the distance (till an intermediate transfer station located in central Italy). Data concerning the fuel consumption come from ANPA database [5].
Regarding the other three scenarios, we have decided to use 16 tons trucks for the regional transports and supposing extra regional transport with 28 tons trucks (scenario 5) or neglecting them (scenario 6). In particular the last scenario supposes all the supplies within the regional context. Following this hypothesis transports would involve 100 tkm. Data refer to ANPA ecoprofiles for transports.



Environmental Impact		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Energy consumption	[MJ]	380	313	296	344	544	418
CO_2	[kg]	22	23	17	20	32	25
CO	[g]	64	173	48	57	101	82
NOx	[g]	290	257	228	264	409	311
SOx	[g]	19	95	15	17	27	21
Dust	[g]	16	17	12	14	25	20
VOC	[g]	31	-	23	28	53	44
Benzene	[mg]	7	-	5	6	10	8

Fig. 6: Comparison of different transport's scenarios

Scenarios have been compared regarding energy consumption and the main air pollutants. From their comparison we can observe that:

- The lower is the capacity of the trucks the larger are the related impacts. In particular Scenario 5 has the highest impacts while Scenario 3 has the lowest;
- The incidence of transports on the global energy and CO_2 balances varies from 2.5% to 5%;

- Comparison between data form ANPA and Boustead databases shows that the last one involve a smaller energy consumption while overestimates emissions of CO and SO_x;
- Extra regional transports have a considerable weigh that varies from the 50 % (Scenario 1) to 25% (Scenario 3).
- The hypothesis of purchaser enclosed in the regional boundaries would decrease the environmental impacts till up 1%.

3.5.4.2 Production process

Electricity ecoprofile

The production process concerns mainly on cutting, bending, welding and assembling phases. Electricity is the only energy source directly employed during the production. The global consumption is estimated in 190 MJ of power energy. The conversion to primary energy (540 MJ_{Prim}) followed the hypothesis of medium voltage electricity produced with the average Italian mix [5]. The analysis has been repeated supposing five different scenarios, here described:

Scenario 1: Electricity referred to the average medium voltage electricity [5]. This is the assumption that characterises the previous calculations;

Scenario 2: Electricity referred to the average low voltage electricity [5]. The ecoprofile of low voltage electricity takes into account the energy losses for distribution and transformation;

Scenario 3: Electricity referred to the averaged Italian energy mix (without specifying the voltage) [7];

Scenario 4: Electricity referred to the regional case study. Regarding electricity production, Sicily is autonomous (a large amount is also exported to other Italian regions). Data have been estimated on the basis of the regional electricity production mix (97.04 % from thermoelectric, 2.94% from hydroelectric and 0.02 % from wind farms) [7, 21];

Scenario 5: Electricity referred to the averaged European energy mix (without specifying the voltage) [6].

The comparison of different scenarios has interested the primary energy consumption and the main air emission (CO_2, CO, SO_x, NO_x, Dusts). Results are shown in figure 9. We observe that:

The energy consumption can vary from 540 to 610 MJ_{Prim} while carbon dioxide emission from 22 to 40 kg_{CO2};

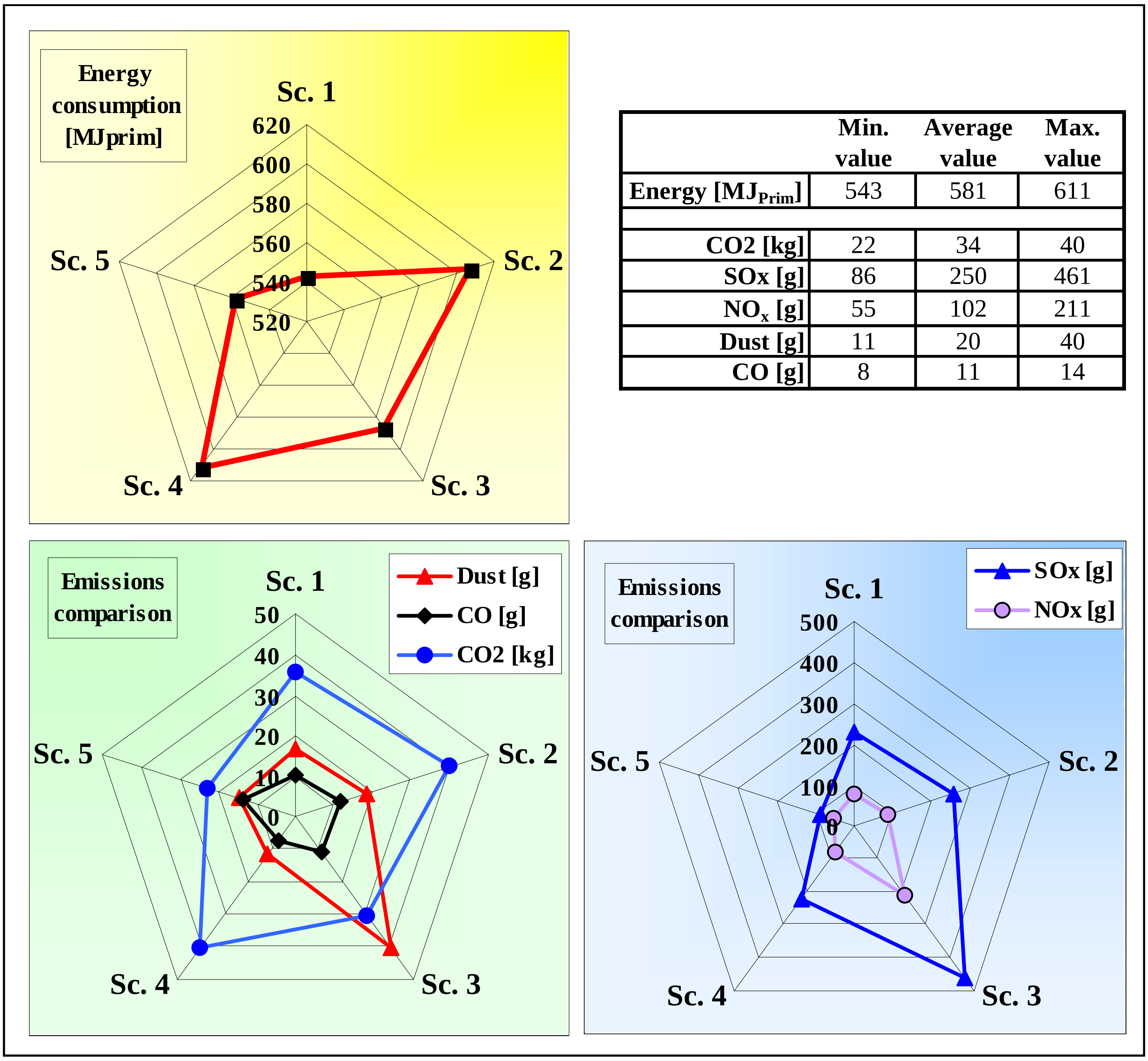
The incidence of the production process into global energy consumption has small variation (from 5 to 6%) while incidence into CO_2 emission varies from 3 to 7 %;

The greatest energy and CO_2 impacts are those related to Scenario 4. However this is the most representative scenario being that related to the regional electricity mix;

Furthermore, data used in scenario 4 have a good quality regarding the emission values and, in particular, regarding carbon dioxide. In fact these values come from direct measurements that the regional electrical company did on the main power plants. Regarding the energy consumption data quality is instead lower being the values estimated.

The greatest variations compete to scenario 3 that, in particular, overestimates SO_x and NO_x.

In general, the small variations affecting energy and CO_2 values suppose a good reliability of electrical ecoprofiles.
On the contrary, data regarding other pollutants have very large variations. However, this not necessarily means low data reliability but it can be related to the different energy mix. For example lower impacts compete to scenario 5 that supposes a greater percentage of renewable energy sources.



	Min. value	Average value	Max. value
Energy [MJ_{Prim}]	543	581	611
CO2 [kg]	22	34	40
SOx [g]	86	250	461
NO_x [g]	55	102	211
Dust [g]	11	20	40
CO [g]	8	11	14

Fig. 7: Comparison of electricity scenarios

Absorbing copper coating

The solar thermal collector uses a copper as absorbing surface. The collector's surface and the pipes for fluid circulation are covered by a black coating to increase heat absorption and the overall efficiency. In the previous calculation we have neglected this contribution having no detail about this producing process.
In this paragraph we have introduced the effect of coating process in the global environmental balances using data of a German factory that produces solar components

[22]. Starting form these data we have calculated the impacts related to the coating of 1 m^2 copper sheet.
We have then compared the final FU's ecoprofile supposing to neglect (Scenario 1) or to realize the coating of the 2 m^2 absorbing surface (Scenario 2).
The analysis has shown that coating's contribution, although not relevant, is not negligible. In general the introduction of this process increases the environmental impacts from 1 to 2 %. More than energy consumption, the process influences the air emissions and, in particular, the methane emission. Negligible is instead the release of water pollutants and waste. Table 15 lists results of two scenarios.

Table 3-15: Scenarios about absorbing copper coating

Environmental Impacts		Scenario n° 1	Scenario n° 2	Variation
Energy consumption	[MJ]	11.0	11.1	0,8%
CO_2 (air)	[kg]	699.2	708.5	1,3%
NOx (air)	[kg]	2.46	2.50	1,7%
SO_X (air)	[kg]	4.24	4.33	2,1%
Dust (air)	[kg]	1.06	1.08	1,2%
NMVOC (air)	[kg]	0.133	0.135	0,9%
CH_4 (air)	[kg]	0.64	0.67	3,6%
COD (water)	[g]	300	300.3	0,2%
Metals ions (water)	[g]	4.8	4.8	0,2%
Total waste (land)	[kg]	57.5	57.7	0,3%

Emission during the production process

As above mentioned, electricity is the only energy source directly used during the production phase. This means that the company does not release directly air pollutants related to the combustion.
However, we made some assumptions regarding particular production steps. In fact the very high temperatures occurring during plasma cutting and welding can cause the gasification of some elements composing the metal alloys. Released quantities are small but, having them hazardous effects (as chromium or nickel), their contribution should not be neglected a priori.
Having no possibility to directly measure these quantities, we have calculated them indirectly from reference values. In this section we have analysed in detail the different assumptions to determine the influence into output values and to determine variation ranges of emissions.

The amount of fumes and gases in *plasma cutting* operation depends on a multitude of parameters. Reference values for the cutting of mild and stainless steel have shown a generally dependence of fumes to the cutting speed and, consequently, to the cutting time [23]. A dependence to plate thickness has been observed but no functional relationship is traceable. Being available data referred to different thickness from that employed in our case study, we suppose to reduce fumes amount in a linear way. The risk is to underestimate in this way the air pollutants. The percentage composition of fumes remains almost independent of plate thickness and cutting speed [23]. Following these considerations we decide to study three different scenarios here described:

- Scenario 1: fumes amount depends on plate thickness in a linear way.
- Scenario 2: fumes amount independent from thickness.
- Scenario 3: average values of previous scenarios

The calculation has showed a great variability of emission fumes (Figure 8) and, in particular, emissions more than doubled in scenario 2. These results became more significant if we consider that, regarding metals pollutants, contribution due to plasma cutting is dominant. Only regarding NOx balance, plasma cutting weights from 3 to 7%.
Although a linear dependence of emissions from plate thickness underestimates the amounts of fumes, the independence hypothesis causes the opposite problem. Scenario 3 is therefore considered as the most reliable. More precise results can be obtained only by means of measurements in situ.

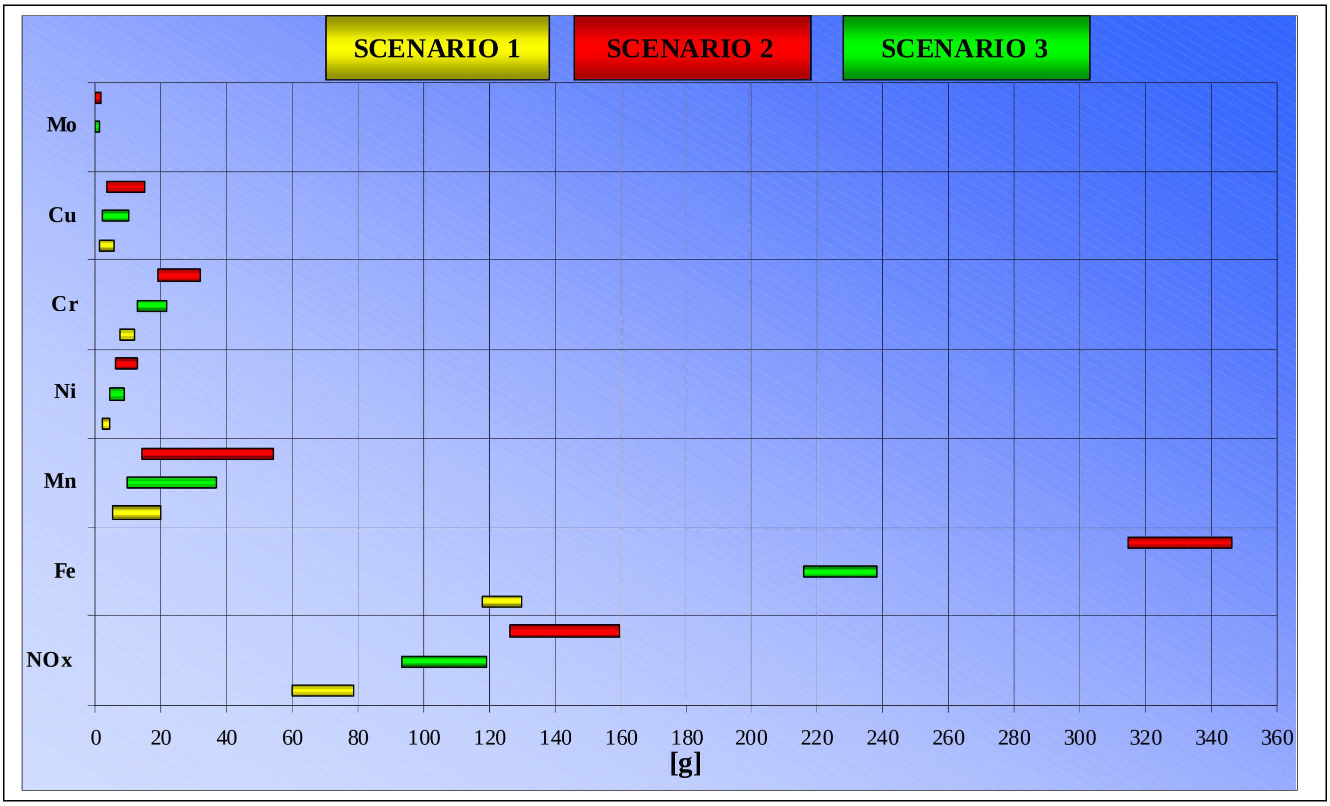


Fig. 8: : Plasma cutting – Scenarios results

Another source of air pollutants during production is represented by welding and, in particular during *Shielded Metal Arc Welding* (SMAW). It uses a consumable electrode that both conducts electricity to produce the electric arc and provides filler metal for the joint. Hazardous metal fumes are emitted while electrodes are welded. However composition and amount of fumes largely depend on electrode's composition.
In this section we analyse the variation in the output emissions by investigating the electrodes mainly used for normal and stainless steel weddings. Calculations are based on reference emission factors [24]. It is possible to observe a great variability of the fumes amount (Table 16), especially when electrodes rich in chromium are employed (electrodes E308, E310 and E316). Having no detail about effective composition of electrodes used during the production, further details are not possible. More precise results could be obtained with direct measurements. However welding emission are not

critical elements of LCA being welding pollutants one order of magnitude lower compared to plasma cutting ones.

Table 3-16: Emission related to use of welding electrode [25]

Electrode type	Hazardous Air Pollutant Emitted [mg]					
	Cr	Cr (VI)	Co	Mn	Ni	Pb
E308	116	106	0.3	74	13	
E310	744	553		647	58	7
E316	153	98		160	16	
E410				201	4	
E6010	0.9	0.3		291	1.2	
E6011	1.5		0.3	293	1.5	
E6013	1.2		0.3	278	0.6	

The production process is also responsible of the release of Volatile Organic Compounds (VOC) during the painting processes. These emissions have been indirectly estimated in about 5 ÷ 6 % of the global VOC balance [3]. The incidence of the process is not significant.

3.5.5 Installation

Following the installation procedures carried out by the selling company we have estimated that the global incidence of this LCA step is less than 2% of the global environmental impacts. In particular the effective electricity necessary to fasten the support to the roof is negligible.
The only significant contributions are those related to the transport of collectors from factory to selling point and finally to the purchaser’s home. However distance and transport’s conditions are very changeable parameters.
We suppose that transports from factory to selling points occur always by 28 tons trucks. About the final destination we suppose:

- Scenario 1: transport by means of 3.5 tons van for a global distance of 15 km;
- Scenario 2: transport by means of 3.5 tons van for a global distance of 30 km;
- Scenario 3: transport by means of 3 tons rigid truck for a global distance of 15 km;
- Scenario 2: transport by means of 3 tons rigid truck for a global distance of 30 km.

Data regarding 3.5 tons truck refer to ANPA database [5] while data regarding 3 tons truck refer to Boustead database [7]. Results are listed in Table 17. We can observe that:

- Data of regarding the two different trucks have the same order of magnitude.
- Scenarios calculated referring to 3.5 tons truck have larger impacts;
- The incidence of installation process on the global energy balance varies from 1% to 2%;
- The incidence of installation process on the CO_2 balance varies from 1% to 3%;

Table 3-17: Sensitivity analysis of transport's conditions

Environmental Impact		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Energy consumption	[MJ]	109	175	145	247
CO_2	[kg]	6.3	10.2	10.9	19.4
CO	[g]	26.6	46.2	13.8	20.7
NOx	[g]	46.2	61.2	116.3	201.5
SOx	[g]	3.2	4.4	36.4	70.7
Dust	[g]	7.1	12.4	8.6	15.6
VOC	[g]	8.1	12.8	3.3	3.3

3.5.6 Maintenance

The LCA has shown a not negligible influence of maintenance in the energy and emissions balances. In particular, we have estimated that maintenance processes are responsible of about 10% of the cumulative energy requirements (Fig. 5). This amount is mainly due to the substitution of some collector's parts as the magnesium anode and the electrical resistance (subjected to corrosion and foul problems), sealing, gasket and thermal fluid.
Propylene glycol is just the main responsible of the great environmental impacts of maintenance phase. The high temperatures reached during the hot season can cause the fluid to evaporate. A security valve in the boiler is designed to decrease the pressure into pipes and avoid damage to the collector. Furthermore, during the long working period, the thermal fluid could have modified its thermal capacity. For these reasons the company prefers to re-establish the normal composition of the fluid and substitute the glycol mix, even if it would not be strictly necessary.
However, a more detailed study about the efficiency of the fluid along years would be necessary. The company has not direct measurements (also because the collector's production line is relatively young), and consequently we decide to investigate the problem with different scenarios:

- Scenario 1: two[5] maintenance cycles with only 20% fluid refilling
- Scenario 2: three maintenance cycles with only 20% fluid refilling;
- Scenario 3: two maintenance cycles with total fluid substitution
- Scenario 4: three maintenance cycles with total fluid substitution

[5] The number of maintenance cycles has been established considering that the technicians operate every 4 ÷ 5 years and supposing 15 years of useful collector's life.

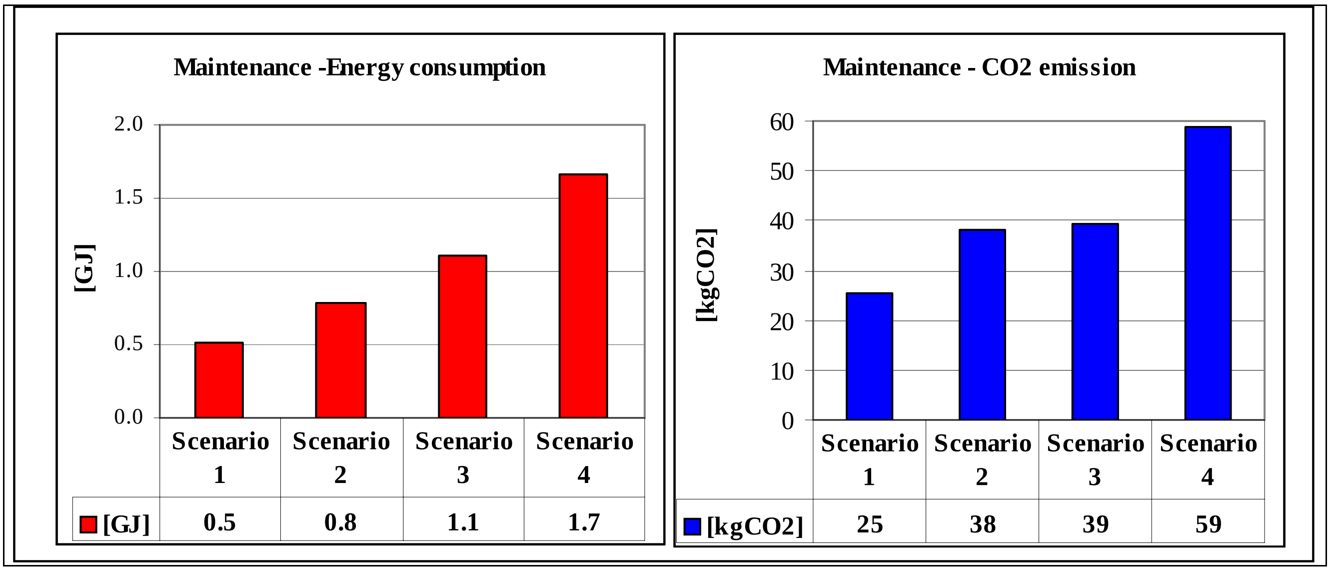


Fig. 9: Maintenance – Sensitivity Analysis

Figure 9 shows the results. From scenario 1 to scenario 4 CO_2 emissions are doubled while energy consumption is trebled. This involves that the incidence of maintenance on global energy balance varies from 5% to 10% and incidence on carbon dioxide balance varies from 4% to 8%. It is possible to observe that, even substituting only a part of the fluid, scenarios 1 and 2 involve significant impacts. In every scenario, contribution of maintenance into LCA results has been never negligible.

3.5.7 Disposal and Recycling

Regarding the FU's disposal, no data are available. In fact the firm started the production of solar collectors few years ago and, consequently, the sold collectors have not yet reached their "end-life". Data regarding disposal come from estimations.
The easiest end-life scenario would suppose the disposal of the collector to the nearest landfill (*scenario 1*). This scenario would involve only the energy consumption and the emissions related to transport by truck along a 50 km distance. Results show that the contribution of this hypothesized process to the global energy consumption or to the released CO_2 is negligible (less than 0.2%).
These very low values are related to the assumption that transports occur by truck (28.000 kg of capacity) as those used for the normal waste collection. Consequently we suppose the collector responsible only for a fraction of the overall truck's consumption (proportionally to its weight). This could underestimate the consumption related to disposal. Anyway, the calculation has been repeated supposing a selective transport for the dismissed collector by low capacity truck (scenario 2)[6]. This assumption will involve the energy consumption of 250 MJ_{Prim} (2.2% of the global energy demand) and the release of 18 kg_{CO2} (2.4 % of the overall CO_2 emission).
The environmental impacts would further raise increasing the covered distance. In scenario 3 we suppose that the collector, after its useful life, is brought to the factory and assigned to the disassembling before disposal. The global distance would vary from 50 to 100 km and, consequently, the energy consumption could vary from 250 MJ_{Prim} to 500

[6] The ecoprofile of this truck typology comes from Boustead database [7].

MJ_{Prim} (till up 5 % of the global energy demand) and CO_2 emission could vary from 18 kg_{CO2} to 35 kg_{CO2} (5 % of the overall CO_2 emission).
Regarding possible recycling scenarios no data are available. At the time of the present report we are planning to start a re-design of the collector taking into account also the possibility to recycle or reuse the collector's parts. The only recycling that effectively occurs is concerned with the use of steel scraps to produce smaller parts (as bolds or connection) employed inside the collector or other products worked in the same factory. However it is no possible to precisely measure this recycled flow. In scenario 4 we suppose that collector's bolds (0.6 kg of iron) are produced from steel scraps. This assumption would involve a reduction of about 0.2 % of the environmental impacts and, in particular, a reduction of 18 MJ_{Prim} and 1.5 kg_{CO2}.
Considerable reductions of impacts could be obtained with the reuse of some parts. From a preliminary analysis performed together with the technicians of the productive process, we have individuated the possibility to reuse the selective glass (scenario 5) and the support (scenario 6).
If no shocks have place glass could be re-inserted in new collectors. However further studies should be performed about the decay of selective properties. Also the support could be recovered but, being it subjected to corrosion problems, the reuse is conditioned to its status after its end life and, in any case, it should be cleaned and painted with protective paints.
The reduction of impacts is also related to the number of times of possible reuses. Considering 15 years of collector's useful life, no more than three reuse cycles are probable. From this assumption follows that the impacts related to the production of the glass or the support can be shared by three collectors and reduced till 1/3.

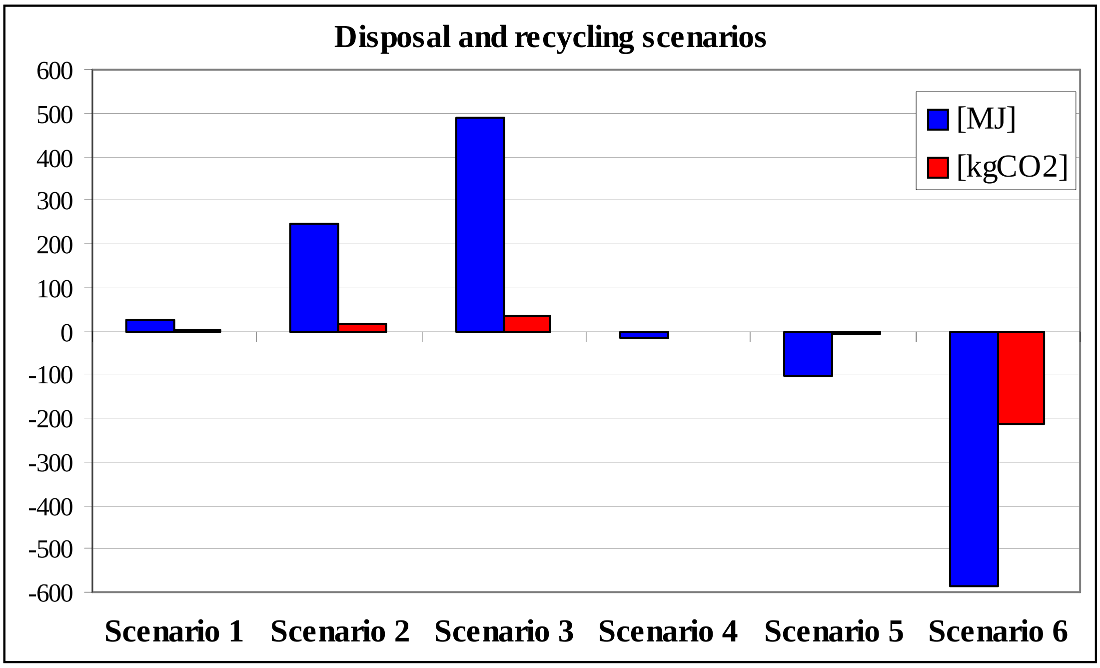


Fig. 10: Effects on the collector ecoprofile of different disposal and recycling scenarios

Results of scenario analysis are showed in Figure 10. We can observe that:

- The previous assumptions regarding disposal can underestimate the effective environmental impacts. A superficial observation on previous scenarios could led to believe that the environmental impacts of disposal are only related to transports. Actually there are many other environmental problems that have been not included into the energy and environmental balances (as waste management, use of soil, landfill management, contamination of soil-water and air, resource depletion, etc.) ;

- Following scenarios 2 and 3, the incidence of disposal on the global impacts could vary from 2 to 5 %;
- On the other side, the adoption of re-use and recycle processes could sensibly reduce the overall impacts (till 5 % of energy consumption and 6 % of CO_2 emissions). However we have only hypothesized some possible recycling processes that should be verified and adapted to productive and economic requirements.

3.5.8 Conclusions

LCA studies have generally an intrinsic uncertainty related to various factors (i.e. difficulty in the survey of data, lack of detailed information sources, data quality, etc.). Consequently, it is more important for the experts to evaluate the order of magnitude of input-output flows ascribable to the product than to trace an “exact” ecoprofile of products.

In particular, the LCA studies heavily depend upon exact, complete and sharp data that unfortunately are not always available [25]. Because LCI results are generally used for comparative purposes, the quality of data is essential to state if the results are potentially valid or not [26, 27,28].

This problem, commonly detected into every LCA, has been strongly detected in our case study. Regarding the solar thermal collector, we have detected a strong dependence of the FU ecoprofile from input materials. They are globally responsible of about 70 ÷ 80 % of the environmental impacts. Large impacts are also caused by the other life cycle steps (transports, installation and maintenance). Impacts caused by the production process are only 5 % (excepting some air pollutants released during cutting and welding steps). Consequently, to investigate more precisely the FU’s environmental impacts, the analysis shall focus on the study’s assumptions.

Uncertainty on input data has been the first problem to be faced. All physical measurements have a degree of uncertainty [29]. Often uncertainty is, itself, uncertain (i.e. the distribution of errors is not well characterised). If one tries to describe the uncertainty through the statistic approach, he faces difficulties not easily surmountable [30]. It is well known that the deviation of a parameter from its “real” value can be described by an uncertainty distribution. When the extreme values of this distribution are known, but not the shapes of the distribution itself, it is possible to use uniform confidence intervals where all the values are equally probable [31].

Being the statistical approach not easy to follow, “rules of thumb” may be a useful strategy [32]. These are generic estimations of the uncertainty range for different categories of data based on the expert’s experience. Environmental impacts of material have been therefore supposed enclosed within a variation range. These intervals have been realised on the base on environmental information coming from environmental databases, LCA tools and, in general, to European environmental studies.

It is necessary to distinguish uncertainty, which arises due to the lack of the knowledge about the true value of a quantity, from variability that is attributable to the natural heterogeneity of values. However, low transparency of references and LCA tools do not allow to distinguish uncertainty from variability. Consequently in this study they have been jointly considered.

The analysis of data quality has been based on many parameters as: geographical coverage, technological level, representativeness, etc. Results have showed a great uncertainty regarding aluminium, copper, thermal fluid and galvanized steel, the dominant material. Considering average values of materials, we have obtained the following results:

- The global energy consumption can vary from 8.9 to 13.0 GJ_{Prim}, with a variation range of about ± 20% from the referring value of 11.0 GJ_{Prim};
- CO2 emission can vary from 581 to 815 kg_{CO2}, with a variation range of about ± 17% from the referring value of 700 kg_{CO2};

Successively we have calculated the contribution of each life cycle step to the global energy consumption and the CO_2 emission. We have investigated transports, production, installation, maintenance and disposal processes. A scenario analysis has been employed. We have obtained the following results:

- The incidence of transports on the global energy and CO_2 balances varies from 2.5% to 5%. A considerable incidence is related to extra regional transports;
- The incidence of the production process into global energy consumption has small variation (from 5 to 6%) while incidence into CO_2 emission varies from 3 to 7%
- The introduction of a copper coating, although not relevant, is not negligible. In general this process increases the environmental impacts from 1 to 2 %. More than energy consumption, the process influences the air emissions and, in particular, the methane emission.
- The production process and, in particular, the plasma cutting is responsible for the air emission of metallic substances (mainly iron, chromium and manganese). Being not possible a direct measurement, we have estimated them indirectly. Assumptions can sensibly modify the emitted quantities (iron emission can vary from 0.120 kg to 0.35 kg; manganese from 0,01 kg to 0.06 kg; chromium from $5 \cdot 10^{-3}$ kg to 0.03 kg);
- The incidence of installation process on the global energy balance varies from 1% to 2%. Regarding the CO_2 balance, the incidence varies from 1% to 3%;
- The contribution of maintenance into LCA results is not negligible. The incidence of maintenance on global energy balance varies from 5% to 10%. On carbon dioxide balance, the incidence varies from 4% to 8%. We have observed that even the partially substitution of thermal fluid involves significant impacts;
- The analysis of disposal scenarios has showed that the incidence of disposal on the global impacts could vary from 2 to 5 %. Considerable reductions of impacts could be obtained with the reuse of some parts (till 5 % of energy consumption and 6 % of CO_2 emissions).

3.5.9 REFERENCES

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4 General conclusions

All the studies performed in project C1 of IEA task 27 show interesting results.

As stated in part 3, project C1 enabled to confirm some ideas about solar heating systems ecoconception. Project C1 confirm that for energy producing system lifetime and efficiency are more important parameters than the choice of manufacturing materials to reach better environmental performances.

For windows and glazings, an optimum between energy content increase due to new technologies and energy savings has to be determined. More precise data and refined assumptions are required to decide of the environmental relevance of a technological improvement of glazings and windows.

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