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LCA analysis of renewable domestic hot water systems with unglazed and glazed solar thermal panels

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Abstract

The paper presents a from-cradle-to-grave LCA (Eco-Indicator 99, Egalitarian Approach) study for two domestic solar hot water systems (DSHWS): a traditional one with glazed panels and a system with unglazed solar collectors. Both systems are coupled with a 300-liters storage tank. The performed LCA returns an EI99 equal to 198.19 for the traditional glazed DSHWS and equal to 18.28 for the unglazed one. For each DSHWS the energy, CO_2 and economic pay-back times were calculated for three different locations (Rome, Madrid and Munich) in order to take into account the influence of local climate on the solar panels yields. The payback times took as basis of comparison two competitive technologies: the natural gas and the electrical boiler.

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K*eywords* Unglazed solar collector; Life cycle assessment; Domestic Solar Hot Water System; CO_2-energy-economic payback time

1. Introduction

Renewable energy is a major worldwide issue since it involves scientific and business communities together with energy policy. In this context, solar thermal technologies significantly contribute to hot water production in several countries. In fact, the global solar hot water installed capacity at the end of 2011 was estimated in 232 GWth with an increase in the last year (2010-11) of 44.3 GWth of which 42.4 GWth were due to glazed systems and the rest to unglazed systems [1]. Even though the solar energy is usually defined a clean energy form, it is necessary to not neglect the environmental consequences of the systems necessary for its production, utilization and disposal. In order to face this issue, life cycle assessment (LCA) is a recognized methodology to model environmental impact throughout the whole life cycle of the product [2]. Despite many LCA analysis have been performed on solar energy sources, LCA

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on domestic solar hot water systems (DSHWS) is a topic not much addressed, in particular with regard to systems using unglazed solar thermal panels. The main originality of the paper consists in presenting both an LCA and a payback time analysis for a DSHWS with polypropylene unglazed solar thermal panel; furthermore the same analysis is performed for a DSHWS equipped with a traditional glazed solar thermal panel. Even if the latter system was already studied, with respect to existing literature [3, 4, 5] the paper presents elements of novelty also for the DSHWS with glazed panel; in particular: i) it presents Energy, Economic and CO_2 payback times for three European locations which differ for both climate (and consequently energy yields) and energy markets (and consequently price of commodities); ii) it updates the LCA of glazed solar thermal panels with 2011/12 data.

2. System description – Domestic solar hot water system

The main components of DSHWS are the solar collector and the thermal storage tank. The glazed panel studied in this work consists of an external case in aluminum which contains two sheets of mineral-wool (insulation), a sheet of absorber in copper and a serpentine pipe in copper alloy; the case is hermetically sealed with a 4mm-solar-glass by means of an EPDM gasket. The unglazed solar collector consists of an absorber without neither the glass cover nor the thermal insulator. Uncovered solar panel is mainly applied to seasonal water heating and it is best suited for low temperature applications where the required temperature is below 30°C. The unglazed solar panel considered in this study is a strip of polypropylene 7 mm thick, 313 mm wide and variable in length so that the plant could have a modular structure. The unglazed solar panel absorbing surface is obtained by an extruded strip of polypropylene; along the strip there are 37 channels 5.5 mm in diameter. Two header manifolds, having inner diameter of 38 mm, are welded at the extremities of the strip; their function is to distribute and collect the water flowing through the channels. The main difference between DSHWS with unglazed and glazed panels is the number of fluid circuits which reflects in the type of thermal storage. The unglazed panel directly heats the domestic hot water, hence it is usually coupled with a simple storage tank. On the contrary, the glazed panel heats up the mixture in the primary circuit which transfers the collected thermal energy to the domestic hot water through an heat exchanger in the storage.

3. Methodology

LCA analyzes the life cycle of products and identifies the environmental impact of each phase from manufacturing (including material extraction and processing) through final disposal.

Goal and scope definition: the main objectives of the study are i) a from-cradle-to-grave LCA analysis of two DSHWS with glazed and unglazed panels, respectively; ii) energy, CO_2 and economic payback assessment.

Functional Unit: with regard to solar thermal collector, in agreement with [6], in this paper the evaluated functional unit is the whole solar system. The functional unit of traditional solar collector is composed of two glazed solar collectors (absorbing surface of 2.30 m^2 each) coupled with a storage tank of 300 litres (typical installation for a 4-occupants apartment). The functional unit of the unglazed solar collector is composed of uncovered solar panels (for a total absorbing surface of 11.16 m^2) and the accumulator tank (300 litres).

System boundaries: the cradle-to-grave LCA analysis did not address the life cycle of the machinery used in manufacturing or distribution. All the components of both functional units were manufactured and assembled in Italian facilities. All the DSHWS components suppliers were located within a 500 km radius, in Italy. The reference year is 2011. The materials used in product assembly, which contributed less than 1% to the solar collector weight, were excluded from the analysis. The life span of the DSHWS was conservatively assumed 10 years even if 20-years-old working systems exist.

4. Life Cycle Inventory analysis (LCI)

The life cycle inventory was based on solar collector production schedules and bills of materials and on the manufacturing processes for each component. The source of data for “transports” throughout the “from cradle to market” phase is the GaBi database ELCD/PE International. The information source for the materials recycling percentages is the 2011 ECODOM eco-sustainability report [7].

5. Life Cycle Impact Assessment (LCIA) results and comments

LCIA was conducted according to the Eco-Indicator 99 (EI99) methodology. It is a damage-oriented approach. We adopted the Egalitarian Approach (EI99-EE), which is based on the precautionary principle with a long period perspective. The calculated EI99-EE indicator from-cradle-to-grave is equal to 198.17 for the traditional system and to 18.3 for the uncovered system. Tables 1 shows the main EI99-EE indicator damage components.

Table 1. EI99-EE indicator damage components for unglazed (U) and glazed (G) DSHWSs

	System From cradle to grave		*Solar panel cradle to market*		*Accumulation tank cradle to market*		End of life	
	U	**G**	**U**	**G**	**U**	**G**	**U**	**G**
EI99-EE (Egalitarian approach)	**18.28**	**198.19**	**8.12**	**184.81**	**9.86**	**12.54**	**0.30**	**0.84**
Ecosystem quality, Acidific./nutrification [PDF*m^2*a]	0.28	13.56	0.11	13.25	0.16	0.28	0.01	0.03
Ecosystem quality, Ecotoxicity [PDF*m^2*a]	0.12	2.34	0.05	2.19	0.06	0.13	0.01	0.02
Ecosystem quality, Land conversion [PDF*m^2]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ecosystem quality, Land-use [PDF*m^2*a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Human health, Carcinogenic effects [DALY]	2.56	0.26	0.06	0.13	2.46	0.03	0.04	0.10
Human health, Climate Change [DALY]	1.04	4.32	0.40	3.05	0.51	0.91	0.13	0.36
Human health, Ozone layer depletion [DALY]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Human health, Radiation [DALY]	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Human health, Respiratory (inorganic) [DALY]	1.76	143.66	0.59	141.81	1.12	1.70	0.05	0.15
Human health, Respiratory (organic) [DALY]	0.00	0.48	0.00	0.48	0.00	0.00	0.00	0.00
Resources, Fossil fuels [MJ surplus energy]	12.44	25.71	6.91	16.22	5.47	9.31	0.06	0.18
Resources, Minerals [MJ surplus energy]	0.08	7.84	0.00	7.66	0.08	0.18	0.00	0.00

The different weight of the solar panel impact on the whole life cycle is highlighted: the glazed panel and the accumulation tank EI99 are the 93% and the 6% of the DSHWS, respectively; the unglazed panel EI99 is the 44% of the DSHWS, being even lower than the EI99 of accumulation tank (54%). The end of life phase of both DSHWSs has a marginal impact over the entire life cycle being always lower than 2%.

6. Payback times

In this section we calculated the payback times of the DSHWSs under energy, CO_2 and economic points of view. Those paybacks were calculated as the amounts avoided or saved (in terms of MJ of primary energy, tons of CO_2 and Euros) divided by the amounts spent calculated in the LCIA analysis. In order to evaluate the influence of local climate on the solar panels yields, we simulated the performance of the systems in three different locations: Rome, Madrid and Munich. Simulations were carried out through a simulation software called Tolomeo® [8]. The base of comparison of the two systems was the domestic hot water thermal energy demand of an apartment with four occupants; we supposed a 300 litres storage. In the calculation of the energy and CO_2 payback times, the primary energy and the $CO_{2\text{-eq}}$

avoided were calculated with respect to two competitive technologies: the natural gas and the electrical boiler. Results are shown in Table 2.

Table 2. Energy (EPT), CO_2 (CO_2PBT) and economic (€PBT) pay-back times (months) for unglazed and glazed DSHWSs

	Unglazed solar panel						Glazed solar panel					
	with respect to traditional boiler (η_{th}= 70%)			*with respect to electrical boiler (η_{el}= 37%)*			*with respect to traditional boiler (η_{th}= 70%)*			*with respect to electrical boiler (η_{el}= 37%)*		
	EPT	CO_2PBT	€PBT	EPT	CO_2PBT	€PBT	EPT	CO_2PBT	€PBT	EPT	CO_2PBT	€PBT
Rome	5	2	9	3	1	4	9	22	8	5	12	4
Madrid	4	2	11	2	1	4	10	24	12	5	13	4
Munich	5	2	11	3	1	3	12	30	13	6	16	4

7. Conclusions

The performed LCA returns an EI99 equal to 198.19 EIP for the DSHWS with traditional glazed panels and equal to 18.28 EIP for the unglazed one. With respects to the whole functional unit, for the traditional DSHWS, the 93% of the impact comes from the panel production. For the DSHWS with unglazed panel, the impacts of the accumulation tank and the panel production are more balanced, 54% and 44% respectively. Finally, the impact of the end of life phase is lower than 2%, for both the systems. The use phase of the DSHWSs has been taken into consideration through the calculation of the payback times of the DSHWSs under energy, CO_2 and economic points of view. The performance of the systems in three different locations (Rome, Madrid and Munich) was simulated, in order to evaluate the influence of local climate on the solar panels yields. Moreover, all the payback times took as basis of comparison the two competitive technologies: the natural gas and the electrical boiler. The EPT ranges between 2-12 months, while the CO_2PBT ranges between 1-30 months. The unglazed solar thermal panels always have both EPT and CO_2PBT shorter than the glazed ones. The different national costs of commodities play an important role in the €PBT and can offset the amount of energy saving. As the cost of electricity is higher than that of natural gas in the analyzed locations, the €PBT with natural gas boiler is two/three-times longer than the one with electrical boiler. Compared with natural gas boiler, €PBT of all DSHWSs ranges between 8-13 years, while compared with the electrical one, the €PBT ranges between 3-4 years.

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