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Life cycle impact assessment of a solar assisted heat pump for domestic hot water production and space heating

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Abstract

Solar heat pumps (SHP) are a class of heating systems combining solar thermal technology with heat pumps. In this article the life cycle impact assessment (LCIA) of a SHP system used to produce domestic hot water (DHW) and space heating (SH) for single family dwellings is presented. This study intends to evaluate the environmental impacts of the energy and material used in a serial SHP installation and identify areas for improvement by applying a "cradle-to-grave" approach when analysing the system. This includes the installation materials both in their manufacturing and disposal phases as well as the energy consumption for DHW and SH throughout a service life of 20 years. In addition, it provides a comparison against two other residential heating systems operating with the same life expectancy. In this LCIA, two environmental related indicators are used, one associated with depletion of non-renewable energy resources (CED_{NRE}) and the other with climate change (GWP). The impact of the type of electricity used was also investigated by defining, in addition to the European supply mix, an alternative supply mix with electricity deriving from renewable sources. This study shows that SHP have lower environmental impacts than systems operating on electricity only. Installations with large solar collector surfaces are also seen to lead to lower energy consumption related impacts. If the electricity used by these systems derives from renewable sources, the environmental performance improves. However, under these conditions, the SHP impact (material and energy consumption) related to climate change will be of the same order as that of the electric system due to a higher contribution of the infrastructure content of these systems.

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Keywords: Life cycle impact assessment; Heat pump; Thermal solar collectors; Heating; Residential; GWP; CED_{NRE}

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1. Background

In Switzerland, SH and DHW are responsible for more than 40% of the total final energy consumption and CO_2 national emissions. Households represent about 65% of the heating demand [1]. In order to reduce building's heating requirements and come about with a sustainable geographic strategy for residential heating, the Swiss government is working on new energy policies that encourage the use of renewable energies, foster optimisation of building envelopes and promote solar thermal and heat pumps (HP) technologies.

The potential of coupling a HP with solar collectors for heating single family dwellings as already been demonstrated in a previous study [2]. However, their environmental impacts in terms of operational energy consumption and materials used have not been addressed to objectively compare different heating systems. More recently, a SHP research project [3], developed within the framework of Task 44/ Annex 38 (T44A38) of the International Energy Agency (IEA) [4], has defined, among other objectives, to evaluate the environmental impacts of a serial SHP system and to compare with those of different residential heating technologies. The work presented here is part of this investigation.

Nomenclature

CED	Cumulative energy demand
DHW	Domestic hot water
GWP	Global warming potential
HP	Heat pump
LCIA	Life cycle impact assessment
NRE	Non-renewable energy
SC	Solar collector
SH	Space heating
SHP	Solar heat pump

2. LCIA Methodology

This LCIA includes the installation materials both in their manufacturing and disposal phases as well as the energy use for DHW and SH throughout an operational period of 20 years. The methodology applied in this study was elaborated according to the ISO standards 14040 [5] and 14044 [6]. Data on material constituents of system components was determined from an industrial partner or based on experience. All impact values were taken from the Ecoinvent database v2.2 [7] that contains a large number of processes for production of goods and provision of services with a focus on European production chains. These include:

- Component materials (extraction, transportation, manufacturing and disposal)
- Existing facilities such as heat pumps (manufacturing and disposal)
- Energy carriers and requirements for system operation

All hydraulic components were also considered in this study (e.g. valves, circulators and expansion vessels).

2.1. System boundary

In this study the following life cycle stages are considered: extraction of raw materials, transport to the manufacturer site, components fabrication, assembly and disposal. The use phase is taken into account by