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Comparative life cycle assessment of renewable energy systems for heating and cooling

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Abstract

Renewable systems for heating and cooling (RES-HC) systems in last ten years have gradually increased their importance and their presence in the global heating ventilation and air conditioning (HVAC) market. Many energetic analysis and impact assessments have been made, which have demonstrated the convenience, respect to traditional HVAC systems, of solutions such as solar thermal or low enthalpy geothermal systems in terms of: energy consumption reduction, renewable energy use increase and emissions decrease.
However, the several analysis made, up to date, only have considered the operation period of such systems, and consequently the comparison has been made only in terms of energy vectors used, omitting materials, components and processes.
This paper aims to give a new perspective, showing how a correct environmental analysis should take into account all the life cycle of a system, from the cradle to grave, also if the system concerns a renewable energy source.
In the specific case, a Life Cycle Assessment (LCA) will be presented, focusing on two currently popular RES-HC systems: solar thermal and low enthalpy geothermal, compared to the same functional unit.
The results of this analysis could be a good starting point for future work on impact assessment of more complex and integrated HVAC systems.

Keywords: Life Cycle Assessment, Geothermal, Solar Thermal, Impact Assessment

1. Introduction

In last 10 years, the presence of renewable energy systems for heating and cooling (RES – HC) has increased among air conditioning market, for many different users: civil, industrial and commercial.

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This is due mainly to two important factors:

- the sensibility for the sustainable development inside the energy policies of industrialized countries and, marginally, of developing ones;
- the increasing costs of fossil fuels, and the parallel increasing difficulty in catching them.

The combination of these two factors has led to an European and global spreading of RES - HC, such us solar thermal and low enthalpy geothermal systems.

Both technologies rarely can cover total buildings energy demand, so that, in most cases, they have to be coupled to electric machines or boilers, such as electric and absorption heat pumps, gas condensing and biomass boilers.

Nevertheless, at present state of technology and raw materials prices, many analysis [1] [2] demonstrated that the adoption of such systems, in addition to traditional thermal power plants, can lead to the following benefits:

- local reduction of equivalent CO_2 emissions;
- global primary energy consumption decrease;
- investments implementation with acceptable pay – back time (generally less than 10 years) [3].

As environmental sustainability and energy efficiency potentials during systems' operation have been thoroughly studied, up to date it has not been done to the Life Cycle Assessment (LCA) of systems' materials and of installation and dismantling processes. This article aims do define a correct procedure for the comparative Life Cycle Assessment (LCA) for the two RES-HC presented

2. The comparative LCA

This work consists in the comparative evaluation, through LCA methodology (ISO 14040 and ISO 14044 [4]) of the environmental sustainability of two RES-HC systems for hot water (HW) production, the first one exploiting geothermal energy, while the other one exploiting solar thermal energy [5]. The production of 400 liters of HW (equal to the needs of a 6 people family house) has been chosen as the functional unit for the comparison and as shared output, to whom normalize all input and output process flows for both systems. The chosen system boundaries include the components production, starting from raw materials, the use stage and the dismantling stage of both systems, along a temporal horizon of 80 years, in a *cradle to grave* analysis.

The two systems have been designed on the basis of the functional unit chosen (production of 400 l of HW), and they are composed by:

- A low enthalpy closed loop system with borehole heat exchanger (BHE), inside which a water – ethylene glycol mixture (22%) flows (figure 1);
- A natural circulation solar thermal system, whose fluid is water – propylene glycol mixture (50%) (figure 2).

Bologna city was assumed as installation place and Milano city was assumed as components production place for both scenarios.

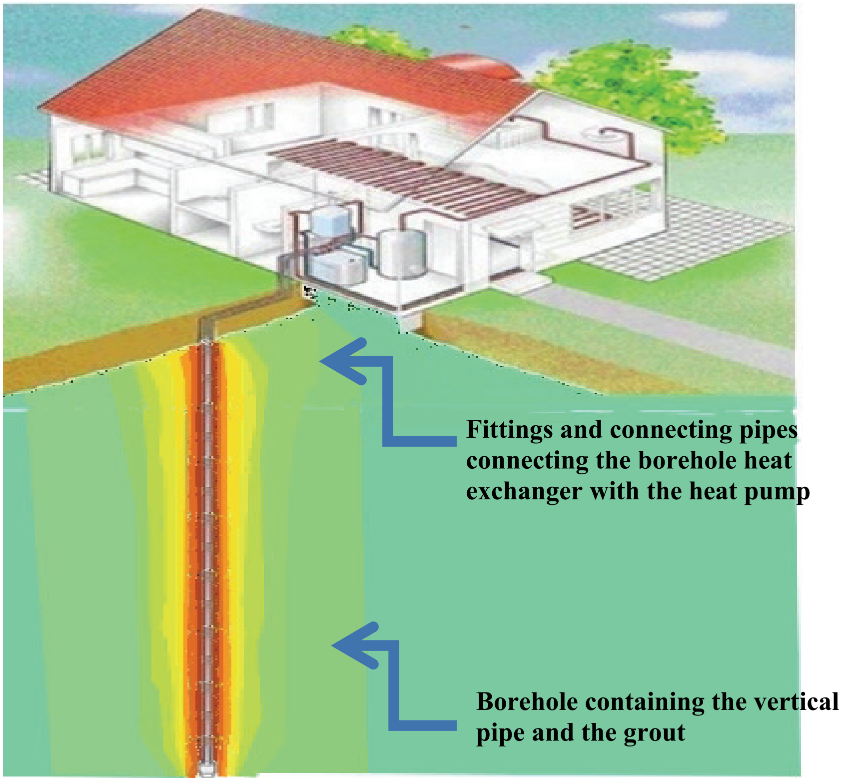

Fig. 1. Scheme of a shallow geothermal system with borehole heat exchanger and heat pump

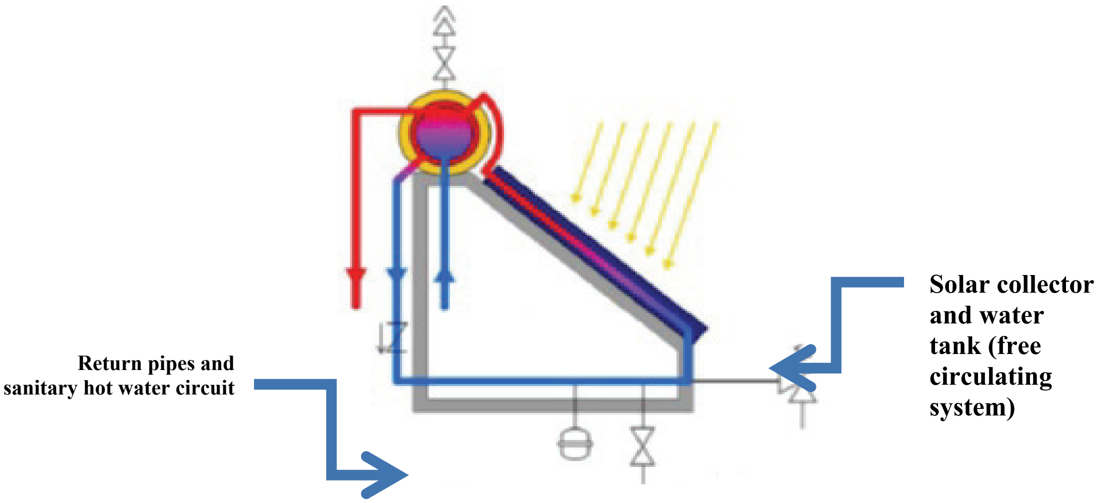

Fig. 2. Scheme of solar thermal system with natural circulation

More in detail, for the geothermal systems have been considered:

- Installation processes:
- Energy (fuel and electricity) and water consumption for the drilling works of the borehole and the insertion of vertical loop;
- Grouting operations of the borehole with concrete – bentonite mixture;
- Transport of the drilling machine to the installation place:
- Transport of all system components from the production place to the installation place.
- Dismantling processes:
- Removal of the heat transfer fluid from the vertical loop and disposal of the glycol;
- Sealing of the borehole;
- Landfill disposal at the end of life of the heat pump.
- Materials:
- High density polyethylene vertical pipes;
- Mixture grout;
- Connection pipes to the heat pump;
- Weight at the bottom of vertical pipe;
- Heat pump.
- Working stage:
- Electrical consumption of heat pump and circulating pumps .
- For the solar thermal system have been considered:
- Installation processes:
- Installation of the collectors on the building roof;
- Transport of all system components from the production place to the installation place.
- Dismantling processes:
- Removal of the collectors from the building roof;
- Landfill disposal at the end of life of the collector.
- Materials:
- Solar collector;
- Supports.
- Working stage:
- No consumption considered.

For both systems testing and maintenance operations have been excluded from the analysis, as well as the HW tank (present in both systems) and distribution pipes of HW to the building terminals.
To compare the two systems, starting from the same functional unit, an allocation procedure has been applied, which permitted to consider the life cycle impacts of the geothermal system only for what it concerns the HW production, id est excluding from the analysis the domestic heating impacts. In fact, a geothermal heat pump system produces heat not only for hot water but also for domestic heating. For the case study considered, the amount of energy for HW is about 40% of the total building needs, on the basis of the following system operational limits:

- Hot water consumption days along one year: 365 d
- Heating hours along one year: 2400 h
- Average seasonal performance factor (SPF) for both HW and heating: 3

The correctness of the calculation made has been verified by *EED 3.0 – Earth Energy Designer* software [I].

Moreover, it is estimated that the lifetime of a solar thermal system is about 20 years, while lifetime for a geothermal system is about 80 years. (except for the heat pump, that has a reasonable lifetime of about 20 years).

To make comparable the systems, LCA for the solar system has been replicated 4 times, while LCA for the geothermal system has been considered only 1 time, with the condition to substitute the heat pump once every 20 years.

3. Discussion on the results obtained

For the evaluation of the impacts the *CML baseline 2000* method [6] has been used, with the aid of the *SimaPro 6.0* software [II].
In all the categories considered by the method, the geothermal system shows a better environmental performance than the solar thermal system; the graph in figure 3 shows the results for the normalization stage.

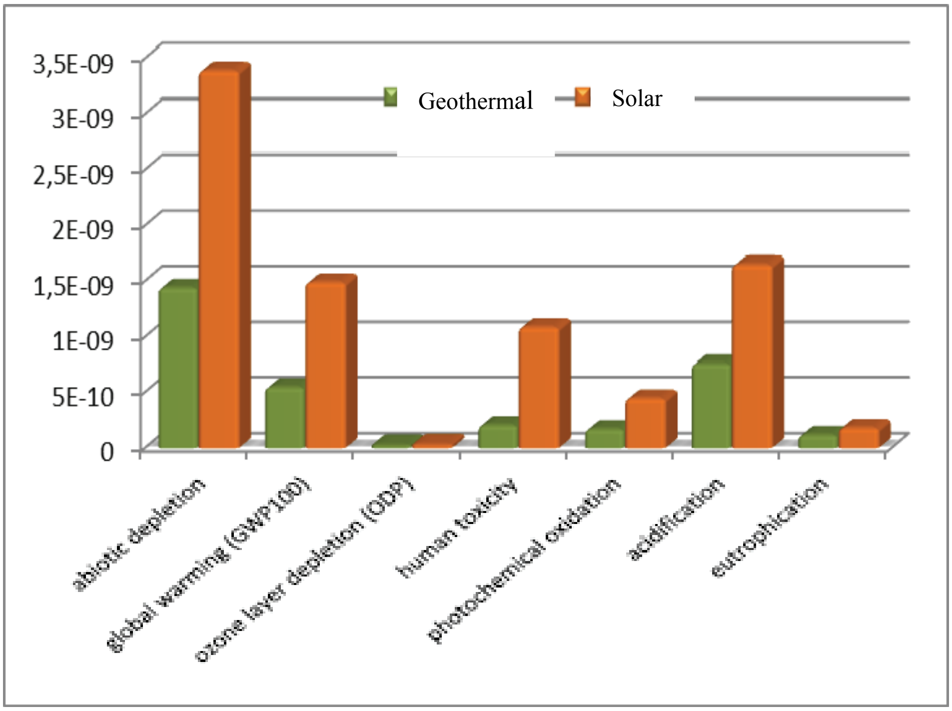

Fig. 3. Environmental impacts of two systems considered

Going into detail of the geothermal system alone, the component with the highest impact for LCA is the heat pump (figure 4). This result agrees with the provision, because the *heat pump* process electric consumptions are considered, as well as the materials. Moreover the model built provides the installation (and so the production) and the dismantling of 4 heat pumps along the lifetime of the geothermal system (80 years).

The graph in figure 4 shows additional and significant information about the important contribution of the drilling stage for the vertical pipes installation. Energy and water consumptions necessary for the working of the drilling machine furnish consistent environmental impacts in all the categories of damage considered by the *CML baseline 2000* method.

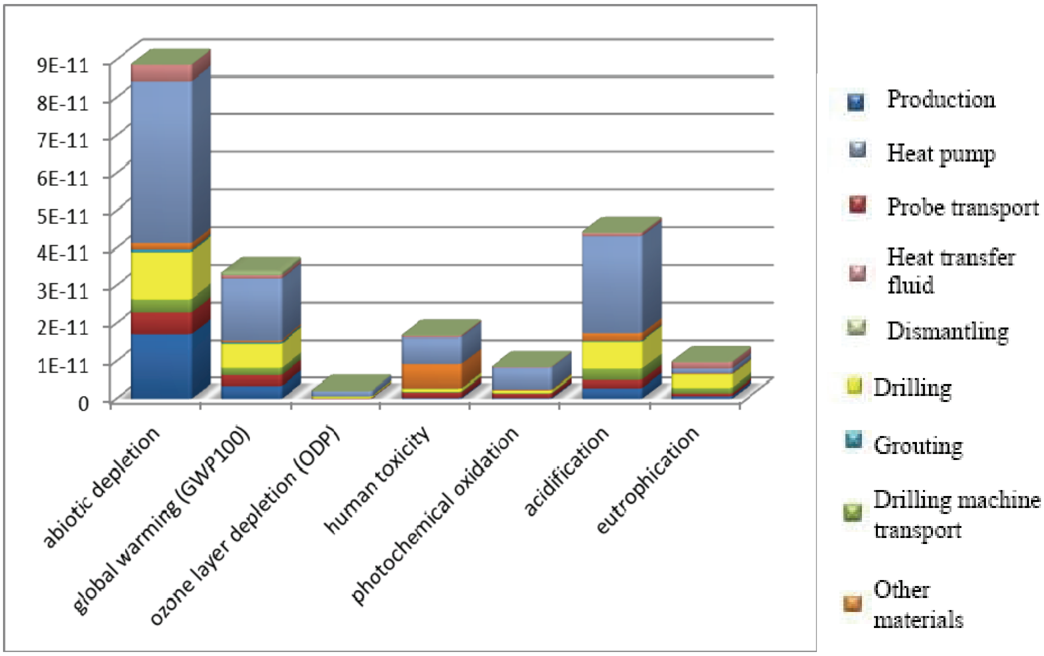

Fig. 4. Environmental impacts of the different processes involved

Focusing on the Global Warming Potential (GWP) category (id est equivalent CO_2 emissions) we can see how the *heat pump* process is responsible for the biggest part of greenhouse gas (GHG) emissions, and how the drilling process contributes with a big part to the equivalent CO_2 emissions from the system along its life cycle.

Considering that drilling machine transport, drilling and grouting are finalized to the installation of the vertical pipes, we can add their contribution to the unique *installation* process.

The graph in figure 5 shows how, excluding the *heat pump* process (and so the energy consumption during the working period), the *installation* process remains the responsible stage for the GHG emissions.

4. Conclusions and future development

The analysis has been the result of a screening study. It has showed how the geothermal system produces less environmental impacts along its life cycle respect to the solar thermal system. Moreover, the analysis has highlighted that the *installation* stage is the most impacting process of the geothermal technology. This indication can be a good starting point to analyze in a more confident way the installation process, with the aim to find more environmentally friendly installation ways

In the future we want to continue the study, taking into account dismantling methods for the solar collectors, alternatives to landfill dismantling, and collecting information on possible ways of recycling for solar collectors' materials.

In parallel we want to expand the boundaries of the system to make an evaluation of the environmental impacts of the integrated thermal plant of an energy efficient building. (Example: hybrid plant solar thermal – condensing gas boiler; geothermal plant for hot water, heating and cooling; distribution networks and fan coils, etc.)

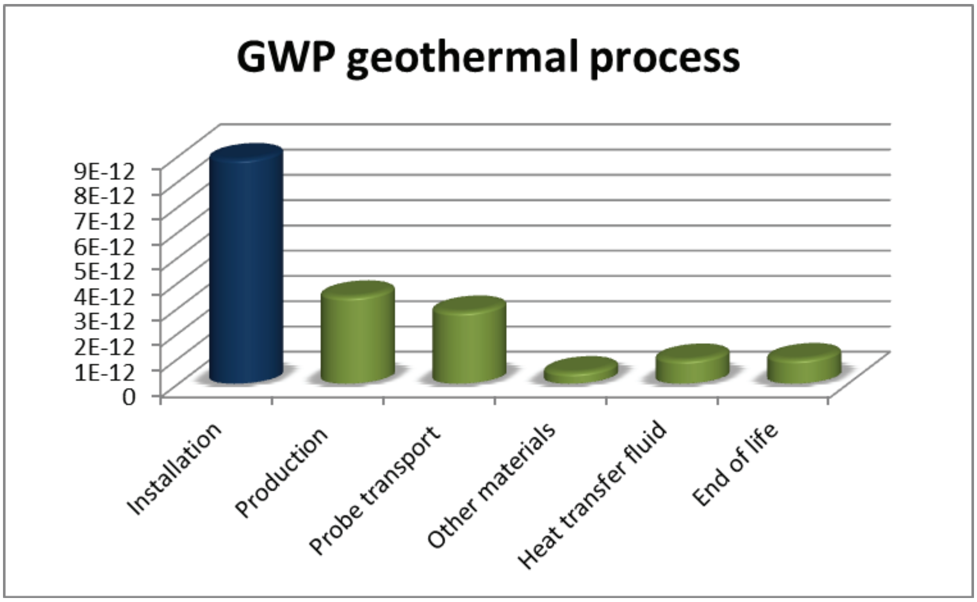

Fig. 5. Environmental impacts excluding the heat pump

Finally, it is useful to underline how the adopted approach of LCA has proved to be a correct way to evaluate the environmental impacts of the RES-HC systems. In fact, evaluations limited to energetic issues, linked only to the working stage of the system, furnish partial information that can be misleading to the real environmental impact index of a system.

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