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Life cycle analysis of a geothermal heatpump installation and comparison with a conventional fuel boiler system in a nursery school in Galicia (Spain).

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Abstract. Within the work lines in sustainable energy field of the EnergyLab Technology Centre (Vigo, Spain), associated with the technologies that are under investigation by this centre, it is developed a study about the Life Cycle Analysis (hereinafter, LCA) over a geothermal heatpump (hereafter, GSHP) installation in a nursery school in the province of Pontevedra (Galicia, Spain), and its comparison with the fuel boiler system prior to GHP. Thus, with the use of computer tools and following specific rules about the calculation of LCA, assessing the environmental impact of each system, and perform the appropriate comparison in order to quantify the savings emissions and the improvement in sustainability related to the replacement of diesel boiler system by the GSHP system.

1 Introduction

With respect to the problems regarding the preservation of the environment and sustainability related to human activity, there are several methodologies to evaluate and quantify the environmental aspects of products, processes or services generated by this human activity.

Among these methodologies highlights the LCA, which has emerged as a reference for the study of environmental impacts throughout the entire life cycle of a product, process or service, that studies the environmental aspects throughout this cycle through the collection and evaluation of inputs, outputs and potential environmental impacts, in order to reduce their impact on the environment. The analysis comprises the extraction of raw materials to its end as waste or possible reuse or recycling, taking into account also those intermediate stages such as manufacturing, transportation, distribution, use, etc.

2 Objectives

The main objectives of this study, in which is performed a LCA comparative between a fuel oil boiler and a GSHP system in a nursery in the province of Pontevedra (Galicia), are:

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- To evaluate and quantify the environmental impacts of the two heating systems, fulfilling equivalent functions, throughout the life cycle considered and comparison of environmental impacts.
- To identify and evaluate opportunities to reduce these environmental impacts along the life cycle.
- To analyze the potential environmental benefits of GSHP facilities.

3 Description of the installation and start-up data

The facility under study is a nursery located in the town of Baiona, in the province of Pontevedra (Galicia), which consists in one building with 800 m^2, heated by radiant floor, with one level which houses classrooms, toilets, offices, kitchen and the boiler room. The thermal demands to satisfy are heating and hot water (hereinafter, DHW). The usual occupation of the school is 85 children and 10 workers.

Until the end of 2009 the school met their needs through a 90 kW conventional fuel oil boiler with a historical average economic fuel consumption of 6.000 €/year.

In November 2009, work began on replacement of the fuel oil boiler by a GSHP system. So that, in December 2009 starts the new system based on a 52 kW GSHP and a thermal buffer tank with 1.500 liters capacity which allows its use to the system as a primary heating and an instant production system of DHW. The catchment area consists of 5 geothermal drilling depth of 120 m and 140 mm diameter each.

Because this facility is part of a demonstration project of GSHP systems in public buildings in the autonomous community of Galicia (Spain), the installation of GSHP has been monitored in order to analyze the behavior, performance and energy consumption of the GSHP system. The results obtained in monitoring the installation of GSHP during the year 2010, are the basis for consideration of performance, consumption and thermal demands to be considered over the period of use of the facility in obtaining the LCA and subsequent comparisons (Table I). In terms of total operating hours of the geothermal system, was obtained 1.269 hours over the year 2010. Dividing the annual energy demand at 63,4% for heating and 36,6% for DHW.

Table I. Seasonal indicators recorded in the facility throughout the year 2010 (considering: 0,11 €/kWhe and 0,270 kg CO2/kWhe (Source: Gas Natural Fenosa)).

Measure	**Units**	**2010 (only GSHP compressor consumption)**	**2010 (GSHP compressor and circulation pump consumption)**
SPF	-	4,10	3,93
Electric consumption	kWh	16.498,56	17.040,92
Electric costs	€	1.814,84	1.874,50
CO_2 emissions	kg CO_2	4.454,61	4.601,05

4 Methodology

The general methodology of LCA considers a number of interrelated work stages that follow a defined sequence. So that, according to the UNE-EN ISO 14.040 and UNE-EN ISO 14.044, LCA consists of four main phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Results Interpretation.

Active and dynamic phases, in which are collected and assessed data, are the second (Inventory Analysis) and third (Impact Assessment). The first phase (Goal and Scope Definition) and fourth (Results Interpretation) can be considered static phases.

Regarding the Goal and Scope Definition, at this stage is defined the subject of study and establishes the functional unit, and this is one that describes the main function of the analyzed system. In this case, the amount of supplied heat energy (kWh) by the heat generating system to meet the needs of the building heating and DHW during a considered use period of 10 years.

In the Inventory Analysis phase, are quantified all inputs and outputs of unit processes defined within the limits of the system, considering:

- Inputs: energy, raw materials and auxiliary materials.
- Outputs: products, by-products, waste, air emissions and discharges to water and soil.

The structure of the Impact Assessment phase is determined by the standard UNE-EN ISO 14044, which defines mandatory and optional aspects to be considered in an LCA study. Aspects being considered as mandatory, are:

- Selection of impact categories, category indicators and characterization models.
- Classification, which is the allocation of data from the Inventory Analysis phase in each impact category depending on the expected environmental effect.
- Characterization, consisting in modeling, using the factors characterizing of the inventory data, for each of these categories of impact.

5 Inventory analysis

The processes that have divided the LCA of the analyzed thermal systems were: manufacturing, transportation, implementation of the installation, operation, transportation and dismantling. So that, for each thermal system, are analysed the raw materials, materials and energy consumed in each process under consideration.

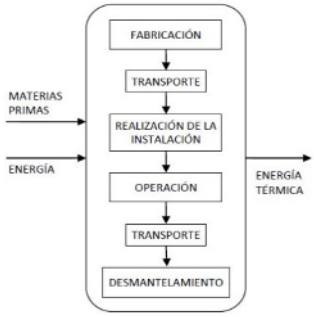

Fig. 1. Processes diagram considered for the LCA of the analysed thermal systems.

6 Impact assessment. Results

The purpose of this phase is to interpret the inventory analysis, analyzing and evaluating the impacts of environmental burdens identified. The commercial tool used for the determination of the LCA in this study includes several impact assessment methods, using all of them the characterization procedure which calculates the relative contribution of a substance to a particular impact category.

Thus, among the methods most suited to the project selection criteria, was decided to use the IMPACT 2002+ method, mainly because:

- The effects considered are: human health, ecosystem quality, climate change and resources.
- The method is a compilation of several previous methods and is recognized internationally.
- The method makes no stage of weighting.

Table II shows the results of the characterization of both thermal plants as a result of the introduction of the data for the inventory analysis phase of the tool used to calculate the LCA. To better manage the results, the tool used allows a standardization of the results based on a units unification (Pt), which allows a simple treatment of the data (Table III and Fig. 2).

Table II. Environmental profile characterization of the thermal plants under study.

Damage category	Units	GSHP system	Boiler system	Units	GSHP system	Boiler system
HUMAN HEALTH				DALY	0,106	0,263
Carcinogénicos	kg $C_2H_3Cl_{eq}$	444	6,89E3	DALY	0,00124	0,0193
No carcinogénicos	kg $C_2H_3Cl_{eq}$	1,5E3	692	DALY	0,00424	0,00194
Respiración inorgánicos	kg $PM_{2,5eq}$	141	344	DALY	0,099	0,241
Radiación ionizante	Bq C-14_{eq}	6,17E6	2,75E4	DALY	0,0013	5,78E-6
Reducción capa de ozono	kg CFC-1_{eq}	0,0262	0,198	DALY	2,75E-5	0,000208
Respiración orgánicos	kg C_2H_{4eq}	45,1	334	DALY	9,62E-5	0,000712
ECOSYSTEM QUALITY				PDF·m^2·año	2,8E4	1,75E4
Ecotoxicidad acuática	kg TEG agua	1,79E7	2E7	PDF·m^2·año	896	1,01E3
Ecotoxicidad terrestre	kg TEG suelo	3E6	1,25E6	PDF·m^2·año	2,37E4	9,9E3
Acidificación y eutrofización terrestre	kg SO_{2eq}	2,73E3	6,37E3	PDF·m^2·año	2,84E3	6,62E3
Ocupación del terreno	m^{2}cultivable	448	11,4	PDF·m^2·año	488	12,5
Acidificación acuática	kg SO_{2eq}	979	3,57E3	-	-	-
Eutrofización acuática	kg $PO_{4\text{-}lim}$	2,38	0,394	-	-	-
CLIMATE CHANGE				kg CO_{2eq}	1,06E5	2,32E5
Calentamiento global	kg CO_{2eq}	1,06E5	2,35E5	kg CO_{2eq}	1,06E5	2,32E5
RESOURCES				MJ primaria	2,11E6	3,24E6
Energías no renovables	MJ primaria	2,11E6	3,24E6	MJ primaria	2,11E6	3,24E6
Extracción de minerales	MJ extra	3,2E3	38,9	MJ extra	3,2E3	38,9

Table III. Environmental profile characterization of the thermal plants under study, based on standardized final results.

Damage category	Units	GSHP system	Boiler system
Human Health	Pt	14,9	37,1
Ecosystem Quality	Pt	2,04	1,28
Climate Change	Pt	10,7	23,4
Resources	Pt	13,9	21,3
TOTAL	Pt	**41,6**	**83,1**

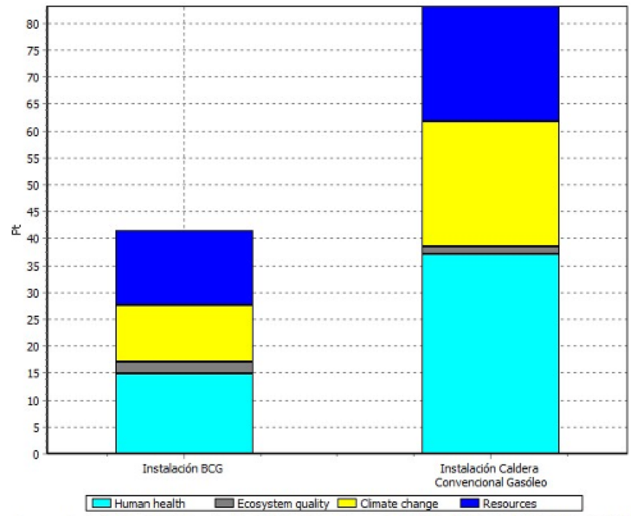

Figure 2. Environmental profile characterization of the thermal plants under study, based on the final results normalized and divided into categories of damage.

Overall, the environmental impact of the GSHP system is measured in 41,6 Pt, while the boiler system is quantified in a total of 83,1 Pt. Making clear that, with the GSHP system, the environmental impact is reduced on the order of a half about the oil boiler system.

As to the process diagram of the life cycle of the heating boiler system, Fig. 3 and Fig. 4 show the environmental loads generated in each process. Having fuel oil consumption during operation, as the process more unfavorable to the environment.

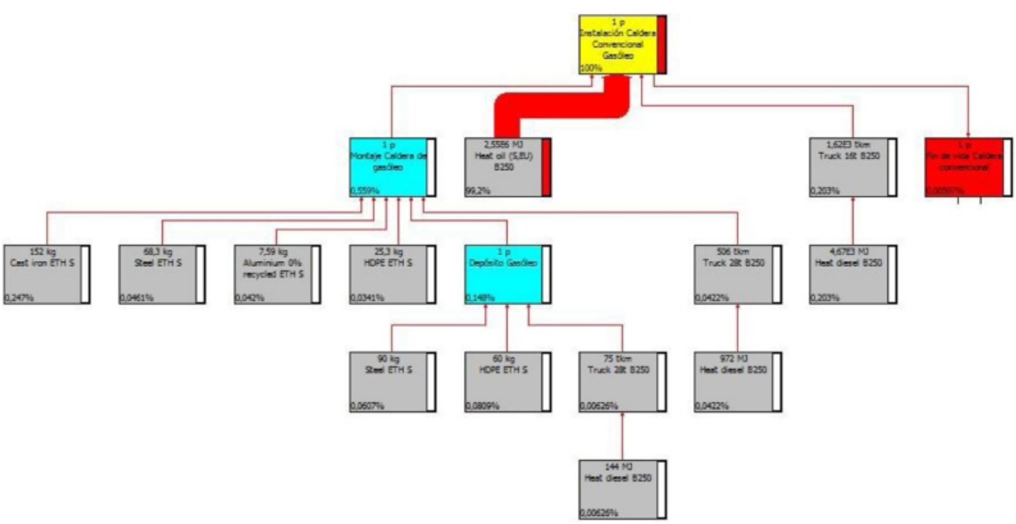

Figure 3. Life cycle processes diagram of the boiler heating system.

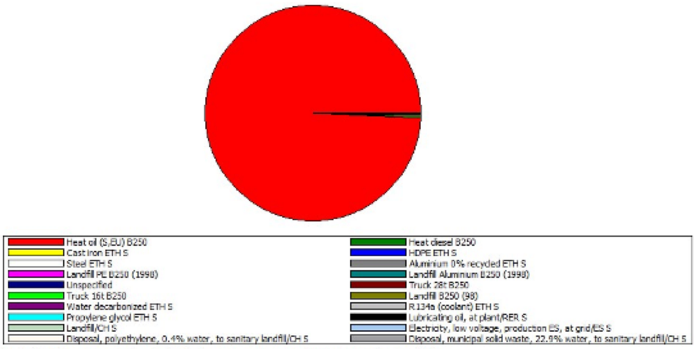

Figure 4. Contribution of each process considered to the total environmental impact of the boiler heating system.

For its part, environmental loads generated in each process corresponding to the heat system with GSHP, are shown in Fig. 5 and Fig. 6. Again, in this case, the most unfavorable process for the environment corresponds to the energy consumption of the GSHP system during operation.

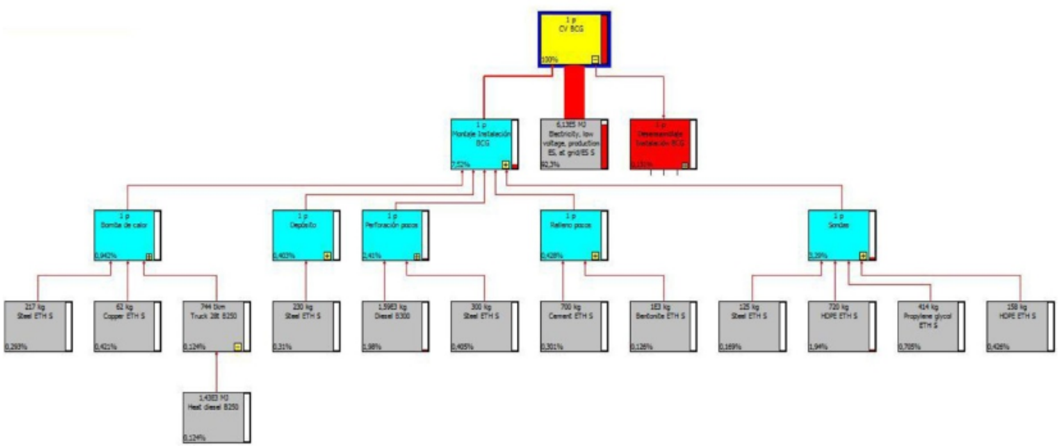

Figure 5. Life cycle processes diagram of the heating system with GSHP.

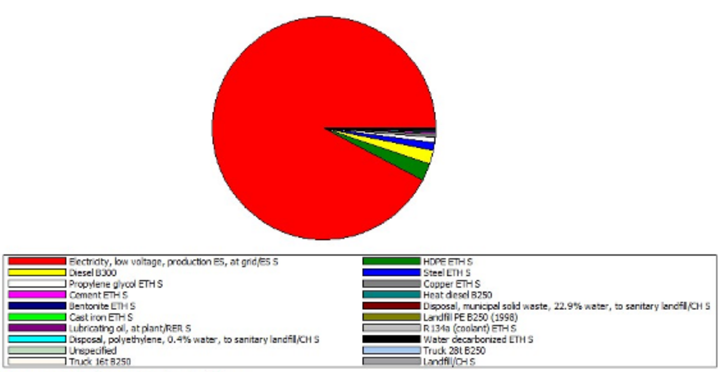

Figure 6. Contribution of each process considered to the total environmental impact of the GSHP heating system.

Moreover, is done a detailed analysis of the environmental impact relative to the installation phase of the thermal systems analyzed (Fig. 7). Obtaining a greater impact on the installation phase of the GSHP system, mainly due to the implementation of catchment geothermal field. Phase which involves, among others, issues related to drilling equipment and materials used for the geothermal heat exchanger.

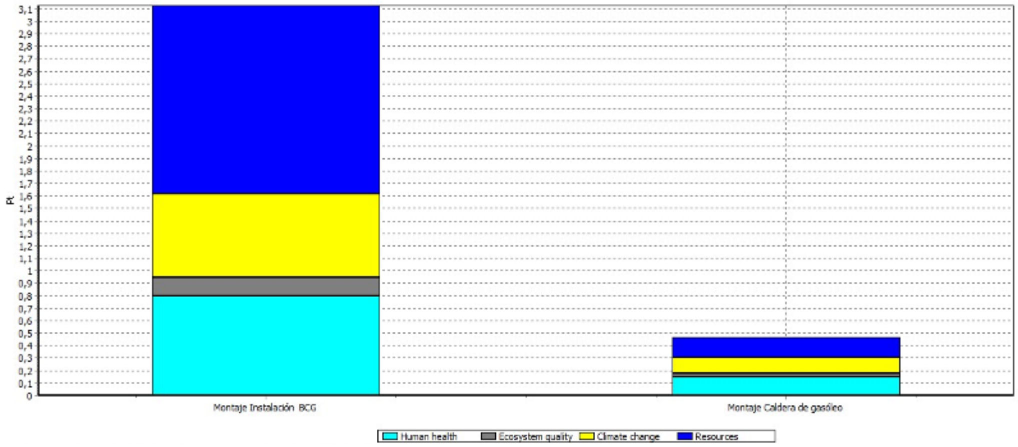

Figure 7. Environmental profile characterization of the thermal plants under study relative to the installation phase, based on the final results normalized and divided into categories of damage.

Finally, is done a sensitivity analysis in order to analyze the environmental impacts for the GSHP system in case that the electricity consumed by the system were generated entirely from renewable sources at a rate of 60% from wind power, 30% from mini hydro schemes and 10% from solar PV. The result, as shown in Table IV and Fig. 8, is that under this assumption the GSHP system powered by electrical energy from renewable sources is, by far, which would involve a reduced environmental impact.

Table IV. Environmental profile characterization of the thermal plants under study, including GSHP system powered by electricity from renewable sources, based on standardized final results.

Damage category	Units	GSHP system	Boiler system	GSHP system (with R.E.)
Human Health	Pt	14,9	37,1	1,3
Ecosystem Quality	Pt	2,04	1,28	0,5
Climate Change	Pt	10,7	23,4	0,7
Resources	Pt	13,9	21,3	2,0
TOTAL	Pt	**41,6**	**83,1**	**4,5**

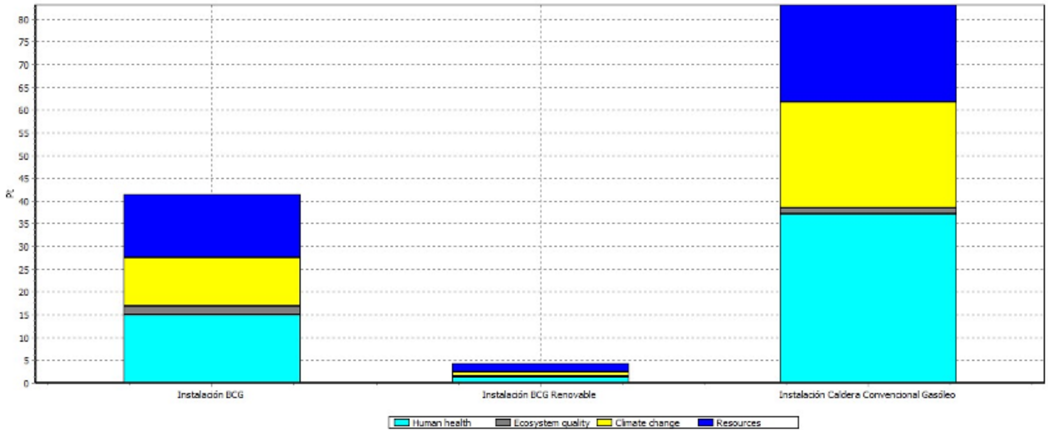

Fig. 8. Environmental profile characterization of the thermal plants under study, including GSHP system powered by electricity from renewable sources, based on the final results normalized and divided into categories of damage.

7 Conclusions

According to the results of the study, based on the considerations and framework of LCA applications in the analyzed thermal plants, it can be concluded that:

- The GSHP system has less environmental impact than conventional diesel boiler installation, with associated emissions of CO_2 for each system and for the considered life cycle, of 106,0 t CO_{2eq} for the GSHP system, and 232,0 t CO_{2eq}, for diesel boiler system. Representing savings of CO_2 emissions to the atmosphere of 54.3%.

- The damage categories, according to the methodology of impact assessment considered, with greater influence on the final environmental impact are Human Health, Climate Change and Resources.

- The process with greatest influence on the environmental impact of both systems is the energy consumption for the operation phase of the installation. Which, for the GSHP system, is 92,3%.

- In the implementation phase of the thermal system, the GSHP system has a greater impact than the boiler system, mainly due to fuel consumption of the drilling machines and to the construction of geothermal probes.

- In the event that electric power consumed by the GSHP were originated from renewable sources, the corresponding environmental impact would suffer a marked decline, making it the best option from the environmental point of view. In this case, CO_2 emissions associated with this system for the considered life cycle are of 9,6 t CO_{2eq}. Representing savings of CO_2 emissions into the atmosphere, compared to oil boiler system, of 95,8%.

- Therefore, we can say that the combination of the GSHP system with renewable electric power generation is a very favorable scenario for the environment conservation, to satisfy the thermal demands in buildings in an efficient and sustainable way and to achieve the international goals scored in terms of reduction of pollutant emissions into the atmosphere.