Environmental impacts of geothermal, natural gas and biomass used for heat generation at a starch plant

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Introduction

Geothermal energy is a promising renewable energy source and could play an important role in the decarbonization of the energy sector (https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation/). To make sure that geothermal energy does not imply additional environmental impacts, it is essential to determine all the potential environmental impacts of such a technology while considering its entire life cycle. Life Cycle Assessment (LCA) is a standardized tool used to quantify various environmental impacts of a technology or product throughout its entire life cycle (ISO 14040, 2006). LCA can provide very valuable information to ease decision making processes whenever, for example, different energy producing alternatives are compared. As a result, regulations increasingly recommend the use of integrated environmental impact assessment tools to support the decision-making process when comparing different energy pathways (European Commission, 2016; European Parliament, 2014).

Pratiwi et al. (2018) already published an LCA focused on greenhouse gas (GHG) emissions about the Rittershoffen geothermal plant, a heat generation facility classified as an Enhanced Geothermal System (EGS). This preliminary work, including the Life Cycle Inventory (LCI) of the projet, was used as a baseline case study in the GEOENVI H2020 project to build an LCA model compliant with the methodological guidelines developped as part of this research project (Blanc et al., 2020). The application of the new LCA model provides an updated estimate of GHG emissions as well as additional results for several environmental indicators. These environmental impacts for geothermal heat generation are also compared to the heat generated by natural gas and biomass.

Presentation of the Rittershoffen geothermal heat plant

The geothermal heat plant of Rittershoffen located in Northern Alsace (France) has been developed to supply heat to the industrial processes of a starch plant. This industrial user, located in Beinheim, France, totals 100 MWth of thermal needs. The geothermal heat plant, with an installed capacity of 27.5 MWth, has been successfully providing an average of 22.5 MWth and 180 GWh/year of heat to this starch plant since June 2016.

The targeted reservoir is a Triassic sandstone and the top of a fractured Carboniferous granite basement located at 2500 m depth. The first well, GRT-1, was drilled in 2012 and the first testing results after drilling showed a low productivity index. A stimulation program, including thermal, chemical, and hydraulic stimulation, was therefore designed and successfully performed in 2013 (Baujard et al., 2017). Induced micro seismicity activity related to the stimulation tests was very low and virtually undetectable for the surrounding population. The second well, GRT-2, was drilled in 2014. Unlike GRT-1, GRT-2 had a very good initial productivity index during the testing phase after drilling and was therefore not stimulated. The Rittershoffen geothermal power plant is classified as an EGS due to the stimulation program performed on GRT-1 but also because of the total reinjection of the discharged geothermal fluids in the reservoir inducing a micro-seismicity activity at reinjection side during geothermal exploitation.

The geothermal brine is a Na-Ca-K-Cl dominated brine with a Total Dissolved Solids content of approximately 100 g/L and a Non-Condensable Gas (NCG) content, mainly CO_2, of 0.24% in weight mass (Mouchot et al., 2018). As a result, the heat plant was designed with a pressurized geothermal loop: A downhole Line Shaft Pump (LSP) pressurizes the geothermal brine in the surface equipment over the gas break-out pressure to prevent any NCG emission during operation. The production wellhead temperature at GRT-2 reaches 170°C and the flowrate is regulated at 75-85 kg/s, according to the starch plant's heat demand. The geothermal heat is transferred to a secondary loop using several tubular heat exchangers and the brine is fully reinjected without additional pumps at 85°C into the injection well GRT-1. The secondary loop of the heat plant, containing freshwater, is then connected to a 15 km long transport loop to transfer the heat to the starch plant (Ravier et al., 2017).

Figure 1 *View of the Rittershoffen geothermal heat plant (ES-Géothermie)*

Methodology of the reference LCA model

Despite the advantages of being standardized, holistic, multicriteria, and widely accepted, LCA suffers from a lack of guidance when applied to specific energy pathways. When conducting an LCA, the user is faced with a lot of choices that can affect the final results. Practitioners conducting an LCA should be aware of the consequences of methodological choices on the variability of environmental impacts and the limitations regarding the comparability of different studies. To support the use of integrated environmental impact assessment and assist LCA practitioners in performing LCAs of geothermal systems, methodological guidelines specific to geothermal installations have been proposed within the GEOENVI H2020 project (Blanc et al., 2020). These guidelines were applied to build the LCA model of the Rittershoffen geothermal heat plant presented in this work.

The goal of this LCA study was to assess the environmental impacts of the heat production at the Rittershoffen geothermal plant and its supply to district heating providing energy to a starch plant. Following the recommendations of the guidelines, the functional unit of the LCA model is the production of 1 kWh of heat delivered to district heating. The system boundaries include the upstream module, consisting of the secondary data to model background processes, and the core module. The activities of the upstream module are derived from the ecoinvent database v3.6. The core module, on the other hand, includes the construction of the infrastructure, the operation and maintenance of the installation, and its end of life. Figure 2 gives an overview of the different life cycle stages included in the LCA model.

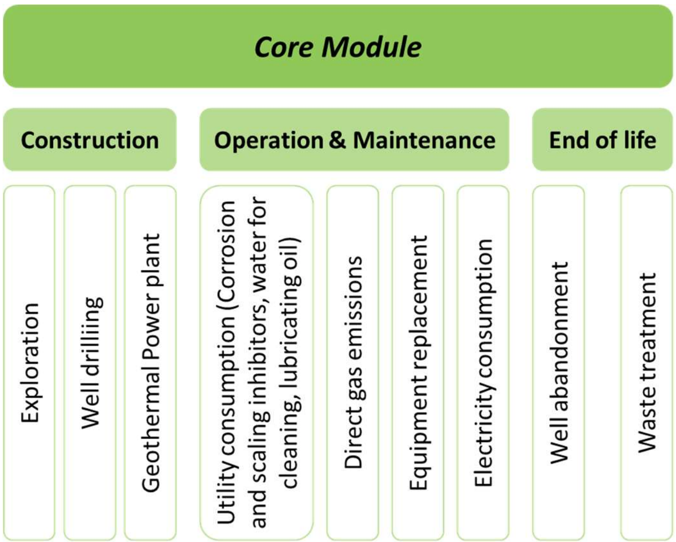

Figure 2 *Phases of the core module included in the modelling of the reference parametrized LCA model adapted from Blanc et al. (2020).*

The LCI developed by Pratiwi et al. (2018) was used as a reference model and completed by new information in collaboration with the plant operator. The use of primary data for most activities, based on real drilling, building and operation, ensures a high data confidence index. The diesel consumption for stimulation and well abandonment was accounted for according to the literature (Rocco et al., 2020), so their confidence level is lower than that of the other steps.

The impacts of electricity consumption estimated by the LCA model are based on the French ecoinvent process *electricity, high voltage, production mix* for 2017, consisting of 75% of Nuclear, 2% of Coal, 6% of natural gas, 13% of Hydropower, and 4% of other renewable resources .

The impacts per kWh of heat of the Rittershoffen geothermal heat plant are compared to the impacts of the two other sources of heat of the starch plant: natural gas and biomass (wood). The models for the heat generation from natural gas and biomass are based on the ecoinvent database v3.6 processes: *heat production, natural gas, at boiler condensing modulating >100kW* and *heat production, mixed logs, at furnace 100kW, state-of-the-art 2014*. In ecoinvent 3.6., no processes specific to the French context were available neither for heat generated from natural gas, nor for heat generated from wood logs. The processes with closest geographies were used instead, namely "Europe without Switzerland" for heat from natural gas generation and "Switzerland" for heat from wood logs.

The impacts of these energy sources were assessed using seven categories of impact proposed in Table 1 of the JRC on the Environmental Footprint v3.0. methodology (2011) and identified with high priority in the methodological guidelines. Two impacts have been added to these indicators: *Human health - ionising radiation* and *Resources - land use*. Indeed, these two indicators, with medium priority level in the methodological guidelines, are showing important variations between the three energy sources compared here.

Results of the Rittershoffen LCA model and discussion

Table 1 and Figure 3 presents the results of the nine impact categories per kWh of heat delivered by the Rittershoffen geothermal plant, natural gas and biomass.

***Table1** Impacts of the Rittershoffen geothermal heat plant, as well as ecoinvent 3.6 process of heat production, natural gas, at boiler condensing modulating >100kW* and *heat production, mixed logs, at furnace 100kW, state-of-the-art 2014.*

Impact category	Reference unit	Rittershoffen geo heat plant	Natural gas	Biomass (wood)
Climate change - Climate change total	kg CO_2-Eq	5,93E-03	2,36E-01	1,62E-02
Ecosystem Quality - Freshwater ecotoxicity	CTU	4,89E-03	5,83E-03	9,58E-02
Ecosystem Quality - Freshwater and terrestrial acidification	mol H+Eq	5,41E-05	1,81E-04	3,60E-04
Human Health - Non-carcinogenic effects	CTUh	9,21E-10	1,57E-09	1,20E-07
Human Health - Carcinogenic effects	CTUh	2,25E-10	2,90E-10	1,11E-09
Human Health - Ionising radiation	kg U_{235}-Eq	1,52E-02	2,41E-03	3,62E-03
Resources - Fossils	MJ	3,75E-01	3,88E+00	1,86E-01
Resources - Minerals and metals	kg Sb-Eq	1,40E-07	6,14E-08	1,33E-07
Resources - Land use	Points	5,05E-02	4,38E-02	3,22E+01

According to the results presented in Table 1 and Figure 3, the potential impacts of Rittershoffen geothermal heat plant are similar or lower than those of the biomass and the natural gas in most impact categories. In particular, the potential impact on *Climate change* is estimated as 5.9 gCO_2eq/kWh for the Rittershoffen geothermal heat plant. This impact is respectively 2.7 and 40 times lower than that of heat from biomass or natural gas. The only exception is the impact category of *Human Health - Ionising radiation*, for which the environmental impact is higher for the Rittershoffen geothermal plant. This impact is indirect, due to the electrical consumption during operation of the geothermal heat plant provided by the French electricity mix, with 75% of nuclear. A mix with a higher share of renewable energy, or a heat plant with on-site self-power generation, would automatically reduce the impact in this category. *Resources - Land use* also present an interesting behaviour, which indicates that geothermal energy may require about 635 less surface than biomass heat generation.

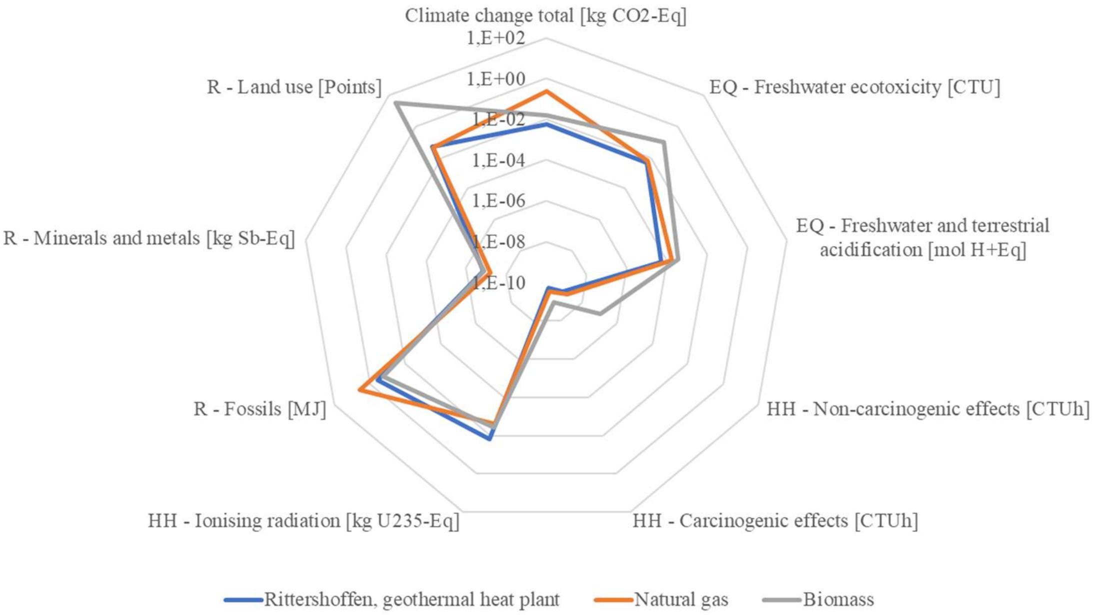

***Figure 3** Impacts of the Rittershoffen geothermal heat plant compared to heat generated by natural gas and biomass*

These results confirm that geothermal energy generated under Rittershoffen's conditions implies lower environmental impacts than the heat generation from natural gas, as well as heat produced from other renewable energy such as biomass. Geothermal energy is a promising renewable energy source for the decarbonisation of district heating and heat used in industrial processes in Europe.

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