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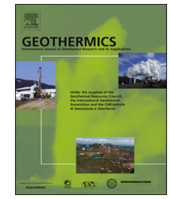

Life-cycle climate-change impact assessment of enhanced geothermal system plants in the Upper Rhine Valley

A. Pratiwi*, G. Ravier, A. Genter

ÉS-Géothermie, 26 Boulevard du Président Wilson, F-67000 Strasbourg, France

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ABSTRACT

In this study the greenhouse gas (GHG) emissions of the Rittershoffen geothermal plant in France – an operating EGS (Enhanced Geothermal System) project developed in the Upper Rhine Valley are analysed and quantified. In this study a similar analysis for the forthcoming EGS in Illkirch Graffenstaden (Strasbourg) is also presented. Life cycle inventory is constructed based on a real project. Five different scenarios comprising a heat plant, power plants and cogeneration plants are developed respecting LCA (Life Cycle Assessment). Contribution of each phase and material type towards GHG emissions is studied using hot spot analysis. In this study some site-specific approaches to potentially reduce of GHG emissions are also assessed. This study is a useful reference towards LCA studies of EGS as it analyses the first EGS utilization for industrial heat.

1. Introduction

1.1. EGS development

Despite having comparatively higher efficiency and stability, the growth of power supplied by geothermal sources has been surpassed by that of wind and solar power. Solar PV is the leader in renewable energy growth with a growth rate above 200% since 2010, while the growth of geothermal utilization remains below 20%, seeming to be the least competitive form of renewable energy (Fig. 1).

The main reasons for the slow growth of geothermal power generation vary in different regions and different countries, from high initial investment, long payback and construction time or difficulty in the assessment of resources. Therefore, innovations in geothermal technology are needed to speed up geothermal growth (Li et al., 2015).

The innovations in deep geothermal technology in Europe, where geothermal reservoirs are mostly of low or medium enthalpy, has enabled a more efficient utilization of geothermal resources to fulfil the renewable energy demand in this region. One of these innovations is called EGS. The currently used term ‘enhanced or engineered geothermal system’ (EGS) has its roots in the early 1970s when a team from Los Alamos National Laboratories began the Hot Dry Rock (HDR) project at Fenton Hill, USA (Breede et al., 2013).

This concept inspired the initiation of an EGS research project in the Upper Rhine Valley region (France) starting in 1987, namely, Soultz-sous-Forêts, where a total of five wells has been drilled and three of them reach a depth of 5 km, penetrating the granitic basement (Genter et al., 2010). To date, Soultz-sous-Forêts wells are supplying thermal energy to commercially produce 1.7 MW_{el}. They use an ORC (Organic Rankine Cycle) system thanks to its success in improving the productivity of the wells through several enhancements. While the project did not establish a perfect underground closed loop system as initially intended in the HDR concept (as the maximum rate of injection recovery observed was 26% (Sanjuan et al., 2016)), Soultz-sous-Forêts is acknowledged as a successful EGS project. Furthermore, it was also discovered that a network of pre-existing fractures channelling natural brine exists in this basement (Gérard et al., 2006) and thus the project has achieved an improvement in its natural permeability. Following this and some other developments, the EGEC (European Geothermal Energy Council) defines EGS as an underground reservoir that has been created or improved artificially (Dumas and Angelino, 2015). EGS is an umbrella term for various other denotations, such as Hot Dry Rock, Hot Wet Rock, and Hot Fractured Rock (Rybach, 2014).

Since that development, several EGS projects have been initiated in the same area. The first example is Landau, which had a 2.9 MW_{el} capacity in 2008 (Hettkamp et al., 2013). However, due to a major surface deformation, the production stopped in March 2014 for safety reasons and geological investigations (Heimlich et al., 2015). The next one is Bruchsal which started in 2009 with a 550 kW_{el} capacity (Breede et al., 2013), followed by Insheim which started in 2012 with a 4.8 MW_{el} capacity (Teza et al., 2016). At the same time, EGS is also being developed in other parts of the world. This includes Habanero in South Australia which has a capacity of 1 MW_{el} since 2012 (Larking and Bendall, 2013). This plant is currently closed (Fedorowytsch, 2016)

* Corresponding author.
E-mail address: astu-sam.pratiwi@es.fr (A. Pratiwi).

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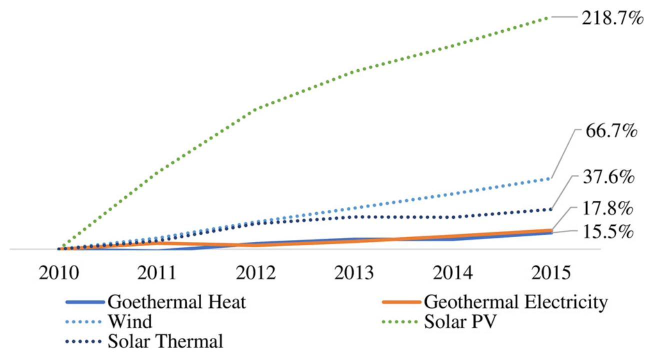

Fig. 1. a) Growth of geothermal energy in Europe. b) Growth of different renewable energy sources in Europe (Observ'ER, 2012, 2014, 2016).

because it faces challenging economic viability (Humphreys et al., 2014). The other projects are the Eden and United Down projects in the UK which envisage a total of 4 MW_{el} capacity (Batchelor et al., 2015) and a pilot EGS project in Pohang, South Korea which, despite several different problems, still progresses towards achieving a plant of 1 MW_{el} (Song et al., 2013).

1.2. Geothermal development in the Upper Rhine Valley

In the Upper Rhine Valley, after the accomplishment of the Soultz-sous-Forêts project, the utilisation of EGS energy in this region has once again been demonstrated to be highly feasible thanks to the Rittershoffen plant that has been successfully providing heat for the starch manufacturing process in the Roquette Frères factory since June 2016. This project was accomplished within the ECOGI (*Exploitation de la Chaleur d'Origine Géothermale pour l'Industrie*) project. It's the first industrial deep geothermal project in France aiming to supply high temperature water. Rittershoffen geothermal heat contributes to up to 25% of the required energy in the Roquette Frères factory, the leader in starch production in Europe and ranked number four worldwide (Baujard et al., 2017).

Not far from Strasbourg, in Illkirch-Graffenstaden, a seismic acquisition was also obtained in 2015 for evaluating the structure of the fault that will be used for a potential EGS cogeneration plant (Richard et al., 2016). The objective of this plant is to provide electricity and to supply heat to the district heating network for the surrounding community by 2020. The geothermal heat will be obtained from two wells of approximately 3-km depth and it is predicted to have a production temperature of 150 °C at the rate of 300 m^3/h.

Still in the Strasbourg area, in the city of Vendenheim, another geothermal plant is being developed and provisioned to come on line in 2019. This plant is projected to provide 6 MW_{el} and 40 MW_{th}. The drilling of one of the wells, over 4 km in depth, has started as of mid-2017 (Simon, 2017). A similar development is also taking place in Eckbolsheim, France. There, a cogeneration plant producing electricity and both high- and low-temperature heat for space heating and agriculture purposes will utilize a geothermal potential of 46 MW (Fonroche Géothermie, 2017).

1.3. Geothermal environmental impact in Europe

Still on the subject of energy generation, the European Commission has determined the 20-20-20 goal, which means achieving a 20% share of renewable energies, 20% energy savings and 20% CO_2 emission reduction by 2020 (Danish Energy Agency, 2015). Furthermore, its low-carbon economy roadmap suggests that by 2050, the EU should cut greenhouse gas (GHG) emissions to 80% below the 1990 levels, with the power sector being one of the main sectors where action is needed (European Commission, 2011). Therefore, it is necessary to assess the environmental impact of geothermal energy production to justify that this state-of-the-art energy production is in accordance with the whole scenario of climate-change mitigation.

Indeed, to date, there are numerous existing studies which estimate the GHG emissions of geothermal power plants. However, unlike wind and PV technologies where the CO_2 emission rate does not significantly vary around the world, the environmental impact of geothermal plants varies for the same technology. For instance, while it is known that geothermal binary technology emits low CO_2, this is not reflected by cases in Turkey. The binary plants in Turkey with a capacity of approximately 7 MW_{el} emit approximately 400–1100 gCO_{2eq}/kWh; potentially exceeding the CO_2 emission rate of a bituminous coal power plant (Layman, 2017). This high CO_2 emission rate is due to carbonate-dominated metamorphic rocks in the reservoir (Haizlip et al., 2016). This indicates that the environmental impact of a geothermal plant is geographically and geologically dependent and therefore it is valuable to perform a study based on actual cases. This current study begins with the high quality dataset of the unique case of the Rittershoffen geothermal plant and will expand its scope to study the geothermal plant in Illkirch-Graffenstaden.

2. Method

To quantify GHG emissions, this study follows the LCA method (Life Cycle Assessment) laid out by ISO 14040 as the framework and ISO 14044 as the guideline, both issued in 2006. LCA addresses the environmental aspects and potential environmental impacts throughout the product life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal.

2.1. Goal and scope

2.1.1. Goal definition

The goal of the study is to precisely estimate the climate change impact of electricity and heat production from an existing geothermal plant, Rittershoffen, and from the future geothermal plant in Illkirch. The study is aimed to meet two main objectives:

- Quantify the GHG (Greenhouse Gas) emissions in gCO_{2eq}/kWh_{th} and gCO_{2eq}/kWh_{el} for the different geothermal plant scenarios described in Table 1. The functional units are kWh_{el} and kWh_{th}.
- Analyse and identify the configurations that emit less GHG emissions and identify opportunities for GHG emission reduction.

S1 represents the actual Rittershoffen plant which provides heat to Roquette Frères (which will be referred to as the *heat user*) by transporting hot softened water at 160 °C. S2 is based on a hypothetical case of building an ORC (Organic Rankine Cycle) plant to produce electricity instead of supplying industrial heat, employing the geothermal heat from the same wells. S3–S5 are based on the Illkirch project whose geothermal potential has been studied and for which well drilling will commence in 2018. S3 considers producing purely electricity using ORC, S4 and S5 consider producing electricity using ORC and district heating with different distributions. More details for the parameters are stated in Table 1.

2.1.1.1. Elaboration of S1: actual Rittershoffen plant. The Rittershoffen EGS geothermal plant utilizes one production well having a true vertical depth (TVD) of 2708 m (GRT-2) and one reinjection well of 2508 m (GRT-1) to provide a closed cycle of geothermal fluid, the first loop. As well enhancement approach, a series of thermal, chemical and hydraulic stimulations was carried out to increase the efficiency of the natural fractures. Stimulations were only carried out on one of the wells (GRT-1) which later was decided to be the reinjection well.

By means of heat exchangers, the geothermal heat is transferred from the first loop to the second loop; the transport pipes containing softened water. The heated softened water travels 15 km away to the