How will geothermal energy transform the environmental performance of the heating mix of the State of Geneva from a lifecycle perspective?

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The State of Geneva in Switzerland is determined to increase the share of renewable energy in its heating mix to reduce its dependence from fossil fuels and their greenhouse gas emissions. Geothermal energy from shallow and medium depths is identified as one of the new renewable energy sources to meet the high heat demand in urban areas of Geneva in combination with the district heating network. The program GEothermie 2020, led by the local utility Services industriels de Genève (SIG) and the State of Geneva, aims to understand the characteristics of the State's subsurface to allow for sustainable use of geothermal energy, while considering the technology's environmental impacts.

In this study, the environmental impacts of different geothermal heating systems for groundwater extraction in the State of Geneva were quantified using Life-Cycle Assessment (LCA). A systematic literature review revealed that most studies of geothermal LCA until now focused either on shallow geothermal applications with heat pumps or on high-enthalpy systems for electricity production. There was a lack of LCA studies for geothermal systems involving groundwater extraction from shallow and medium depth, even if the number of these systems is growing internationally.

In the first phase of our LCA study, we built six scenarios, integrating the geothermal subsurface characteristics and the district heating designs at the surface. We built a model to simulate material and energy flows and create life-cycle inventories. Critical parameters such as temperature, flowrate, well depths, and the seasonal heating demand of residential buildings were used as the input parameters. For each scenario, we defined upper and lower limits for geothermal production and material intensity, and a reference case representative of an existing or ongoing project in Geneva.

In the second phase, we quantified the ranges of environmental impacts of the scenarios using the Ecoinvent 3.6 database and ReCiPe 2016 Midpoint characterization factors. We performed hotspot analysis to understand the contribution of life-cycle steps to selected environment impacts. Subsequently, we introduced other heat sources such as electric heating, waste incineration with district heating, and gas boilers into the reference cases, and analyzed their impacts. We compared these impacts with those of other heat systems such as oil boilers, ground
source heat pumps, waste incineration, and centralized gas boilers.

We found that all of our scenarios of shallow-to-medium geothermal heating systems were less detrimental to the environment than oil boilers and centralized gas boilers in terms of global warming, air pollution, fossil resource scarcity, and acidification impacts. The ground source heat pumps were less detrimental than our geothermal scenarios in most cases, except for acidification. The hotspot analysis identified the operation phase as the activity that contributed the most to the environmental impacts in most cases, followed by the activities for the subsurface development or heating system construction. The latter became increasingly dominant when the heat production output was higher. Lastly, we found that introducing centralized gas boilers and waste heat into the district heating system increased these impacts, whereas the opposite was true when the low-carbon Swiss electric heating was introduced instead.