Where and when do energy benefits from EGS outweigh induced seismicity risk? Findings from private and social cost benefit analysis

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ABSTRACT

Enhanced geothermal systems (EGS) harness thermal energy from the deep underground to produce renewable and low-carbon electricity and heat. The literature has repeatedly drawn attention to the dilemma of siting EGS projects in terms of induced seismicity and EGS profitability (Giardini, 2009; Majer et al., 2012; Trutnevyte and Wiemer, 2017). On the one hand, siting EGS projects in remote areas away from populated spaces and buildings can reduce exposure and thus induced seismicity risk, but the waste heat from these projects often remains unused due to the absence of large heat consumers. On the other hand, heat sales, especially to a district heating network in densely populated areas, make EGS projects more economically viable and the price of electricity more competitive as well as reduce CO_2 emissions. However, the induced seismicity risk is higher.

Motivated by ambitious EGS targets and hence complex siting decisions in Switzerland and elsewhere, we use cost-benefit analysis (CBA) to quantify the trade-off of siting EGS of different capacities in remote or in densely populated areas (Knoblauch and Trutnevyte, 2018). We conduct CBA from two perspective: private and social CBA (European Commission, 2014). *Private CBA* reflects the viewpoint of the EGS operator and thus includes private Net Present Value (NPV), internal rate of return (IRR), and levelized cost of electricity (LCOE). *Social CBA* (social) reflects costs and benefits to society as a whole, including damage risk due to induced seismicity, CO_2 savings, and heat and electricity benefits, in order to quantify social NPV and benefit-to-cost ratio (B/C ratio). Among all parameters that could be varied for CBA, we put primary emphasis on the trade-off between benefits of producing electricity and supplying geothermal heat to residential buildings and avoiding CO_2 emissions from fossil fuel heating versus induced seismicity risk to the same residential buildings. As both the benefits of selling heat and induced seismicity damage to residential buildings can be monetized, CBA is an adequate tool for quantifying the siting trade-off.

For the case of Switzerland, we analyze 12 hypothetical scenarios combining different EGS size (water circulation rates of 50, 100, or 150 l/s) and siting (0, 1'000, 10'000, or 100'000 residents nearby). We model the EGS plant and its heat and electricity production in detail and couple it to a purposely developed model of induced seismicity hazard and risk that is adequate for first order-of-magnitude estimates, given the high uncertainties and lack of data for induced seismicity. We bound uncertainties using Monte Carlo and sensitivity analyses. The full analysis is available in a forthcoming publication (Knoblauch and Trutnevyte, 2018).

Since the electricity generation costs in current EGS are not competitive at the current market prices, we assume the price of electricity of 0.32 USD/kWh$_{el}$ that would make EGS investment in most of our scenarios worthwhile to investors. In terms of the private perspective of investors (*private CBA*), we find in Figure 1 that large EGS (150 l/s) near a large population (10'000 or 100'000 residents), enabling high heat sales, are most profitable. EGS at 50 l/s or in very remote areas are not profitable and exhibit negative private NPV even at an assumption of 0.32 USD/kWh$_{el}$.

With the same assumptions, *social CBA* shows that the most profitable EGS scenarios for society according to the social NPV (including direct and indirect costs due to electricity and heat generation, CO_2 savings, and damage due to induced seismicity) are the scenarios with mid- or large-size circulation rate (100 or 150 l/s) combined with siting near some but not too many residents (10'000 or 100'000 residents). Among eight EGS scenarios with positive social NPV, the most profitable from Figure 1 is EGS scenario, wherein EGS is located near a considerable number of residents (10'000) combined with highest circulation rate (150 l/s). Mid-range profitability can be expected from EGS scenarios near some residents (1'000 or 10'000 residents) in combination with the small circulation rate (50 l/s) and EGS scenarios located near no residents combined with medium circulation rate (100 l/s). Regarding negative social NPV, EGS scenarios located near an especially large number of residents are unattractive investments from the social perspective. This can be attributed to extensive risk due to damage due to induced seismicity. Also, EGS scenarios surrounded by no residents show negative NPV for the smallest circulation rate (50 l/s). In this scenario, EGS produces too little electricity to compensate for high upfront investment (50 l/s).

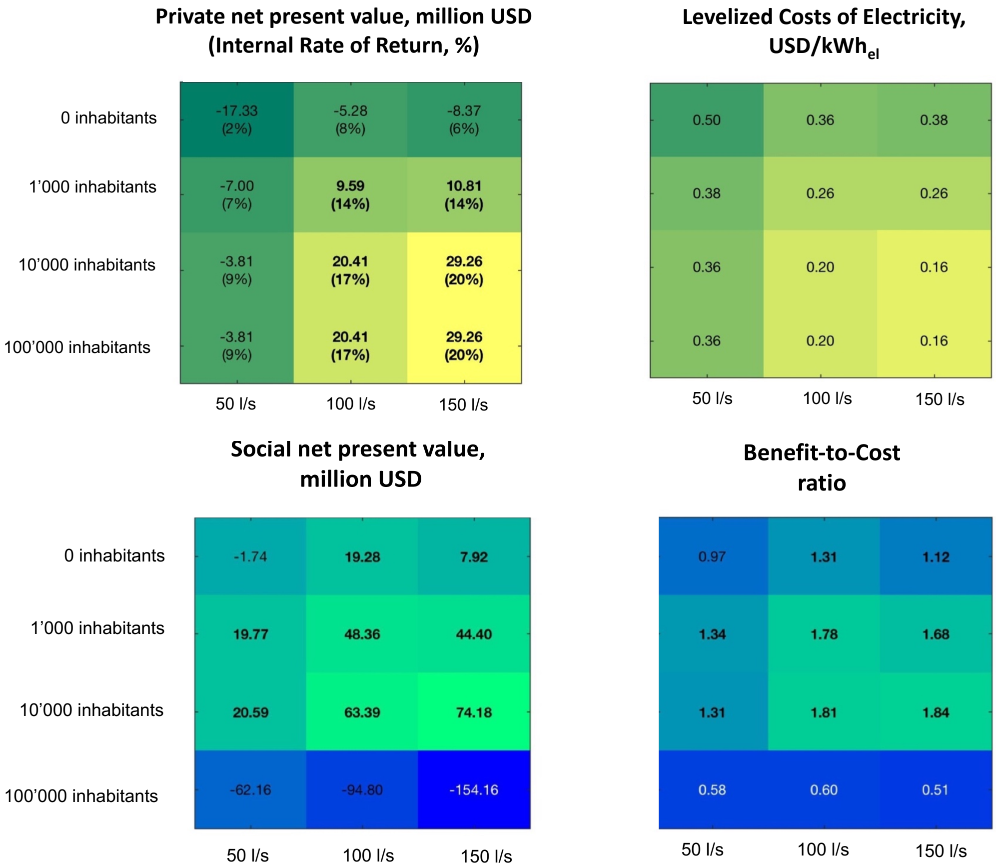

Figure 1. Private NPV, IRR and LCOE (top) and social NPV and social Cost-to-Benefit ratio (bottom) for the EGS scenarios analyzed in terms of water circulation rates of 50, 100, or 150 l/s and siting near 0, 1'000, 10'000, or 100'000 residents. Positive NPV indicates the scenarios that are profitable from the investor's perspective (private NPV) or the societal perspective (social NPV). These results have been calculated using a high electricity price of 0.32 USD/kWh$_{el}$, private discount rate of 10%, social discount rate of 3%, and assuming 30 years of EGS operation.

After conducting extensive Monte Carlo analysis to bound uncertainties inherent to EGS and model limitations, we conclude that even at an electricity price as high as 0.32 USD/kWh$_{el}$ that would make EGS a viable project to investors, our results do not necessarily support the claim to site EGS in remote areas to avoid induced seismicity risks due to lacking benefits from remaining heat (Giardini, 2009; Majer et al., 2012). Considering CBA from the private and social perspectives jointly, EGS should rather be sited where considerable heat can be sold but damage due to induced seismicity remains limited but not necessarily zero. In addition, EGS need to be carefully designed in order to generate sufficient revenues from electricity and heat sales in order to pay off high upfront investment costs.

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