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Impact of climate change on the thermoeconomic performance of binary-cycle geothermal power plants

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INTRODUCTION

The IPCC Special report on renewable energy sources and climate change mitigation [1] states that climate change will not affect geothermal energy because geothermal energy is influenced only by the structure and physical processes within the Earth's interior. Other research [2] is more alerting: climate change could affect the availability and productivity of geothermal resources. Changes in rainfall patterns and prolonged droughts may affect groundwater levels and slow down recharge rates of wells. Further, climate change could affect the efficiency of the heat rejection systems in nuclear, thermal and geothermal power plants, causing reductions in electricity generation. Geothermal power plants would be affected the most because they operate with smaller temperature differences between the heat source and heat sink.

This aim of this work is to quantify the impact of climate change on the thermal and economic performance of a binary cycle power plant using an air cooled condenser. The analysis is performed for two representative climate change scenarios: the intermediate (SSP2-4.5) and the extreme scenario (SSP5-8.5), over the period from 2021 to 2100.

METHOD

Figure 1 shows the single stage Rankine cycle configuration with isobutane as the working fluid. The geothermal fluid flows from the production well with a temperature of 160 °C, a pressure of 25 bar, and a mass flow rate of 225 kg/s.
The thermodynamic model applies mass and energy conservation equations to the major components in the binary cycle (heat exchangers, pumps and turbine). The economic model calculates the levelized cost of electricity (LCOE) and the specific installation cost (SIC), including the costs of capital, operation and maintenance arising for a greenfield geothermal project, and expresses them in present day US$ (2023), adjusted for inflation [2]. This cycle configuration achieves a gross and a net power output of 12.1 MW and 10 MW, with a net cycle efficiency of 11.6% when the ambient air temperature is 8 °C. In this case, the LCOE is 75.7 US$/MWh and the SIC is 5014 US$/kW.

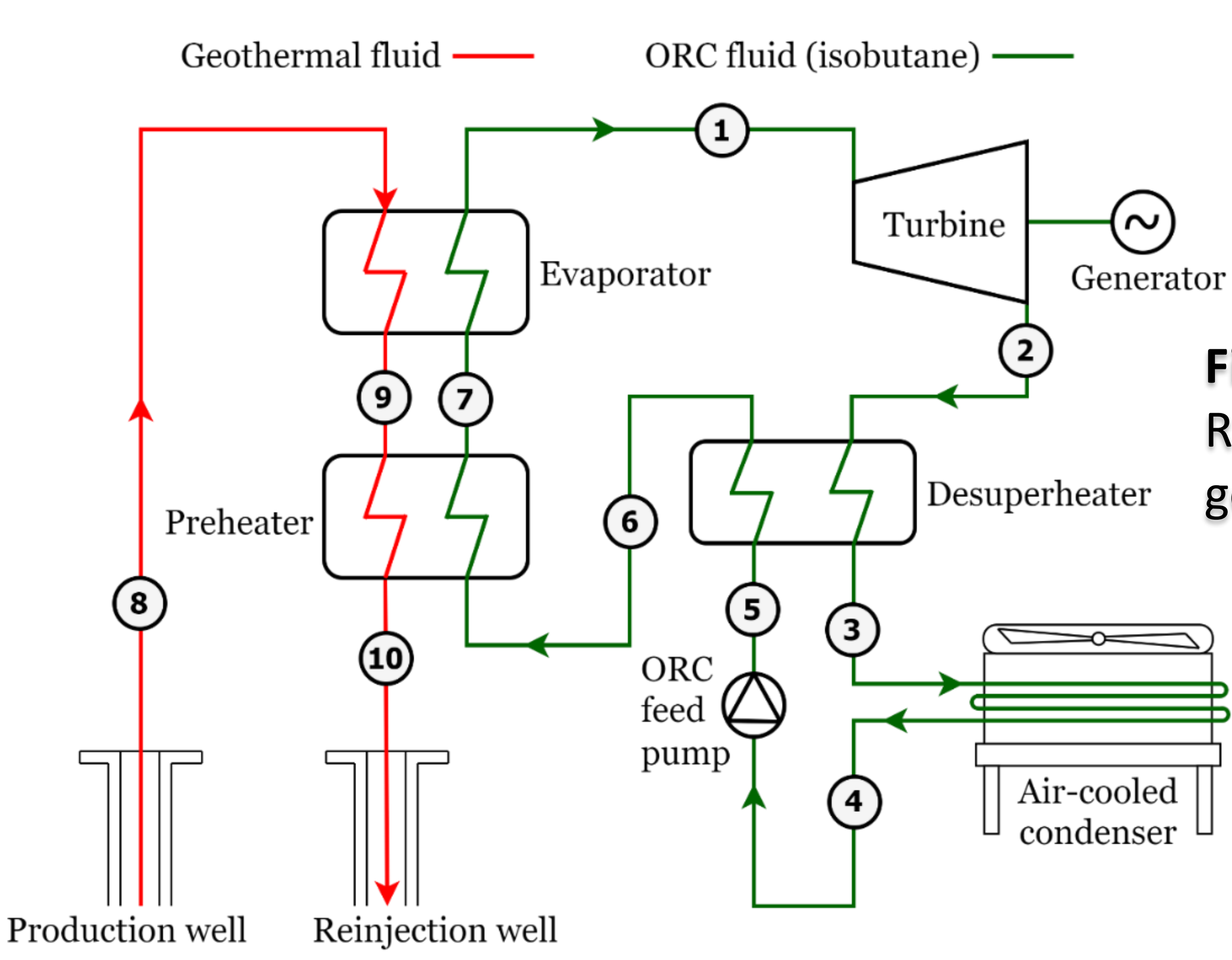


Figure 1. The single-stage Rankine cycle of the geothermal power plant

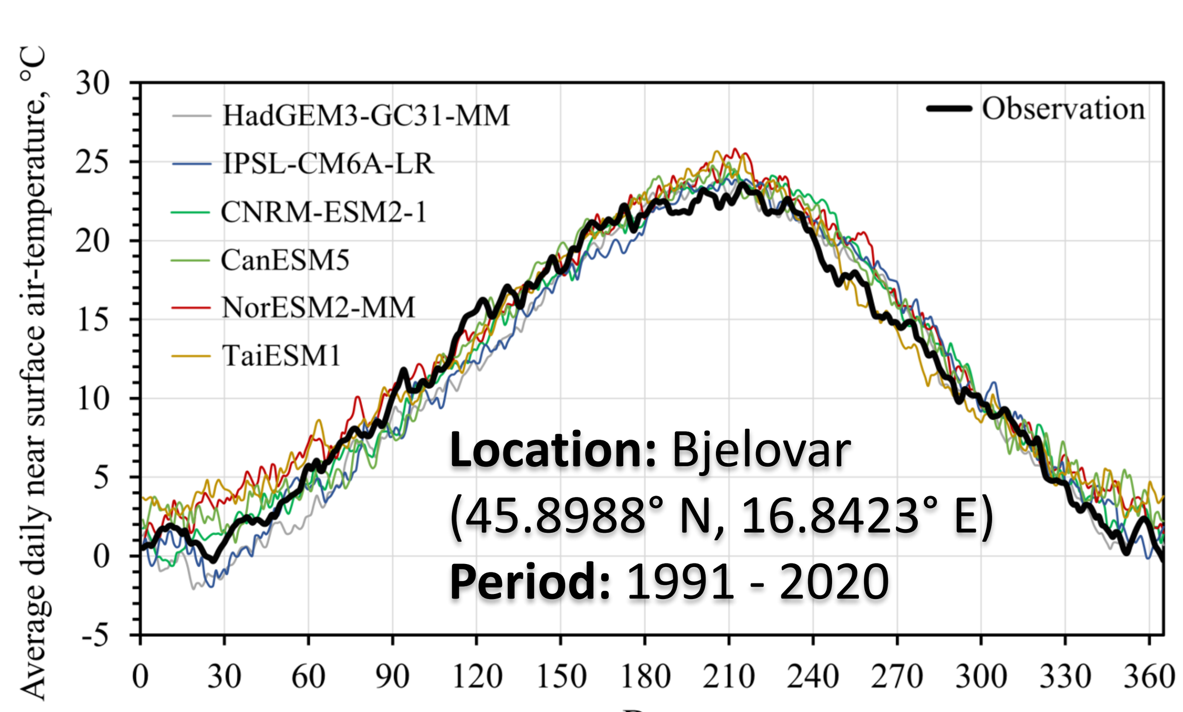
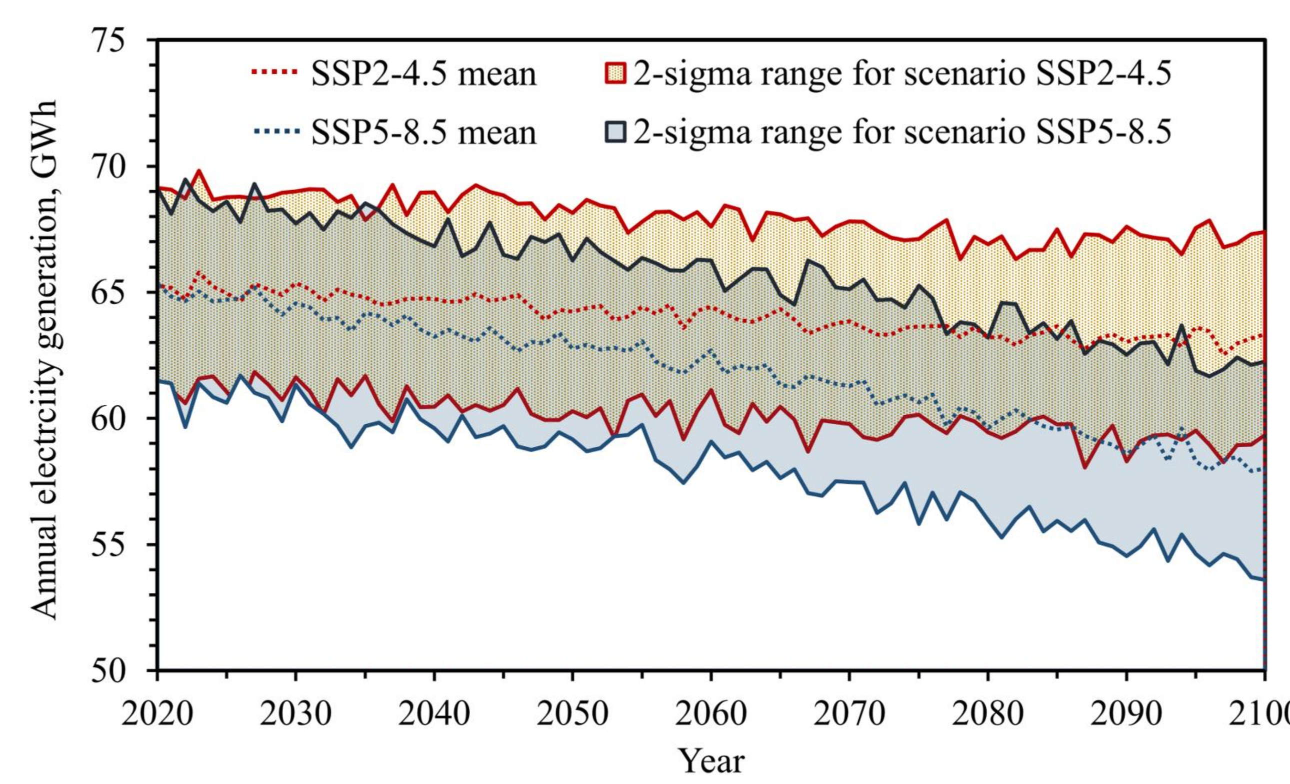


Figure 2. Comparison between observed and predicted near-surface air temperatures. Results from the six best performing CMIP6 climate models.

Climate data for the location of Bjelovar, Croatia (45.8988° N, 16.8423° E) was obtained from the Climate Data Store [3]. Predictions from climate models developed within the Sixth Phase of the Climate Model Intercomparison Project (CMIP6) are compared against observed near-surface air temperatures. Figure 2 shows the comparison between observed and predicted daily averaged near-surface air temperatures, over the reference period 1991-2020.

RESULTS & DISCUSSION

Figures 3 and 4 show the annual electricity generation (AEG) and the LCOE in the observed geothermal power plant as predicted by the multi-model means and their respective 2-sigma ranges (95.4% intervals). The assumed capacity factor is 80% (7000 full load hours) and is equally distributed throughout a year. The AEG of geothermal power is expected to decrease between 0.5% and 2.9% in the intermediate climate change scenario (SSP2-4.5), and between 2.0% and 8.7% in the extreme scenario (SSP5-8.5). The LCOE will increase between 0.4% and 1.8% in the intermediate scenario, and from 1.3% to 5.6% in the extreme scenario.



Period	SSP2-4.5	SSP5-8.5
Reference	65.2 GWh/year	65.2 GWh/year
2021-2050	-0.5%	-2.0%
2051-2070	-1.7%	-4.8%
2071-2100	-2.9%	-8.7%

Figure 3. Impact of climate change on the AEG of the geothermal power plant

Period	SSP2-4.5	SSP5-8.5
Reference	79.2 US$/MWh	79.2 US$/MWh
2021-2050	+0.4%	+1.3%
2051-2070	+1.1%	+3.0%
2071-2100	+1.8%	+5.6%

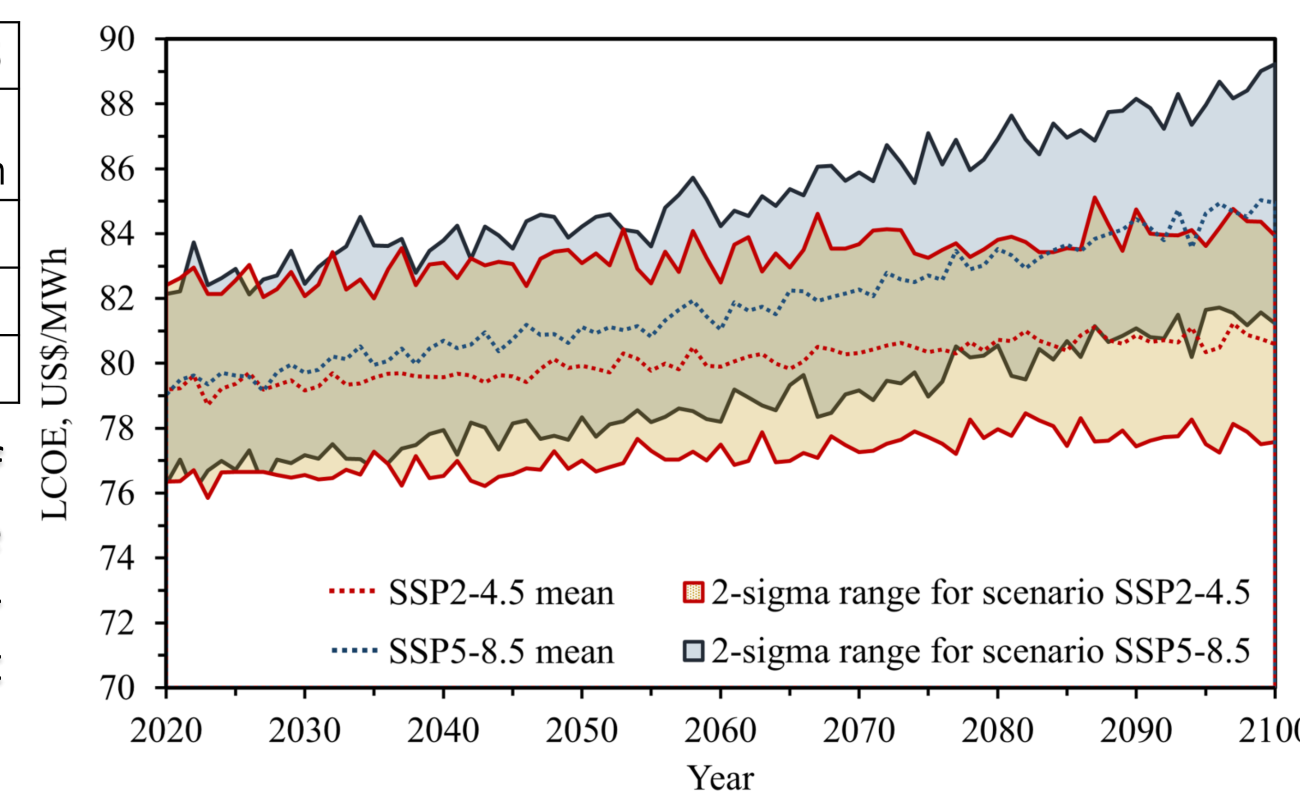


Figure 4. Impact of climate change on the LCOE of the geothermal power plant

FUTURE WORK / REFERENCES

Although CMIP6 climate models exhibit a certain variability in the predictions, they agree on the general trend: climate change will reduce the efficiency of heat rejection systems in geothermal power plants. As consequence, the annual electricity generation will decrease and the cost of electricity will increase, especially in the extreme scenarios of climate change. Future work should extend the analysis on other binary-cycle configurations (e.g. single- and dual-pressure), different cooling tower types (e.g. evaporative, adiabatic, spray), on other geothermal reservoir conditions and to locations with different climates.

[1] IPCC, 2011: Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, United Kingdom & New York, USA, 2011.
[2] Arbula Blecich, A.; Blecich, P. Thermoeconomic Analysis of Subcritical and Supercritical Isobutane Cycles for Geothermal Power Generation. Sustainability 2023, 15, 8624. https://doi.org/10.3390/su15118624
[3] Copernicus Climate Change Service, Climate Data Store, (2021): CMIP6 climate projections, Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.c866074c (Accessed: May 2, 2024)