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Ground heat flux and power sources of low-enthalpy geothermal systems

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Geothermal heat pumps commonly extract energy from the shallow ground at depths as low as approximately 400 m. Vertical borehole heat exchangers are often applied, which are seasonally operated for decades. During this lifetime, thermal anomalies are induced in the ground and surface-near aquifers, which often grow over the years and which alleviate the overall performance of the geothermal system. As basis for prediction and control of the evolving energy imbalance in the ground, focus is typically set on the ground temperatures. This is reflected in regulative temperature thresholds, and in temperature trends, which serve as indicators for renewability and sustainability. In our work, we examine the fundamental heat flux and power sources, as well as their temporal and spatial variability during geothermal heat pump operation. The underlying rationale is that for control of ground temperature evolution, knowledge of the primary heat sources is fundamental. This insight is also important to judge the validity of simplified modelling frameworks. For instance, we reveal that vertical heat flux from the surface dominates the basal heat flux towards a borehole. Both fluxes need to be accounted for as proper vertical boundary conditions in the model. Additionally, the role of horizontal groundwater advection is inspected. Moreover, by adopting the ground energy deficit and long-term replenishment as criteria for system sustainability, an uncommon perspective is adopted that is based on the primary parameter rather than induced local temperatures. In our synthetic study and dimensionless analysis, we demonstrate that time of ground energy recovery after system shutdown may be longer than what is expected from local temperature trends. In contrast, unrealistically long recovery periods and extreme thermal anomalies are predicted without account for vertical ground heat fluxes and only when the energy content of the geothermal reservoir is considered.