Using cooperative control to manage uncertainties for Aquifer Thermal Energy Storage (ATES)

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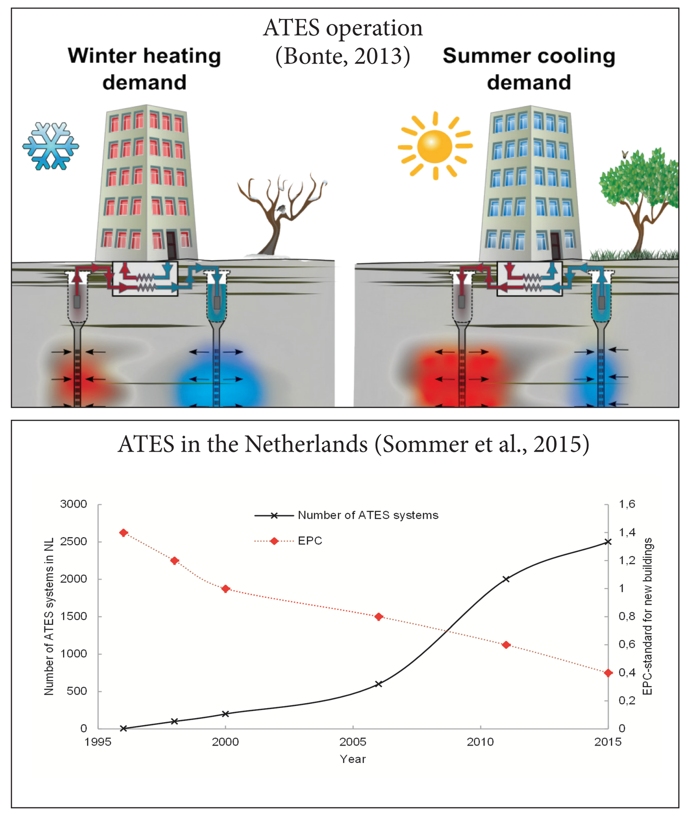
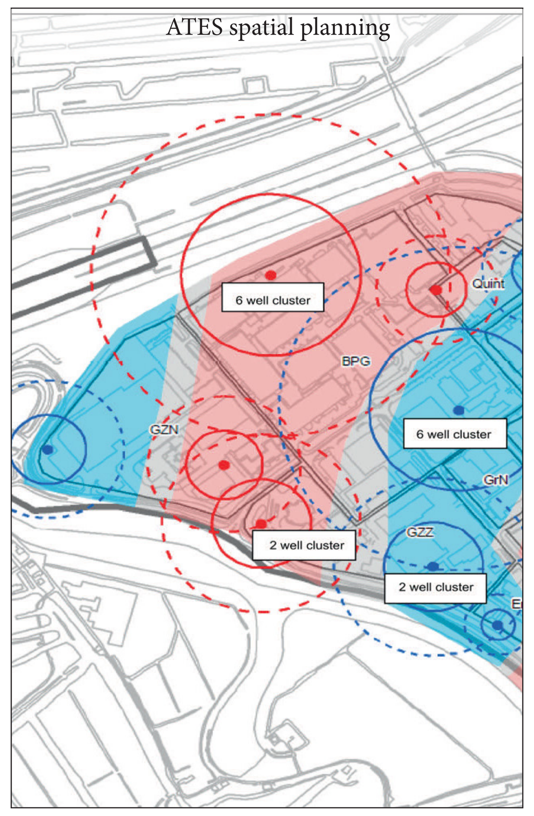
1. Background

Aquifer Thermal Energy Storage (ATES) can significantly reduce energy use in the built environment, using seasonal energy storage in aquifers for the heating and cooling of buildings. ATES systems have experienced a rapid uptake and can reduce energy consumption in buildings by more than half. However, the overall performance of ATES systems still remains below expectations – largely due to the limitations of current methods for the planning and operation of urban systems, which need to address a wide range of operational uncertainties. This will require improvements in control systems, but also in permitting and management policies.

A project on ATES Smart Grids at TU Delft therefore aims to evaluate advanced control systems (e.g. Distributed Model Predictive Control) to improve the performance of ATES systems. This poster presents results from an idealized case study, using a coupled simulation environment to test different ATES control designs, and their impact on ATES performance.





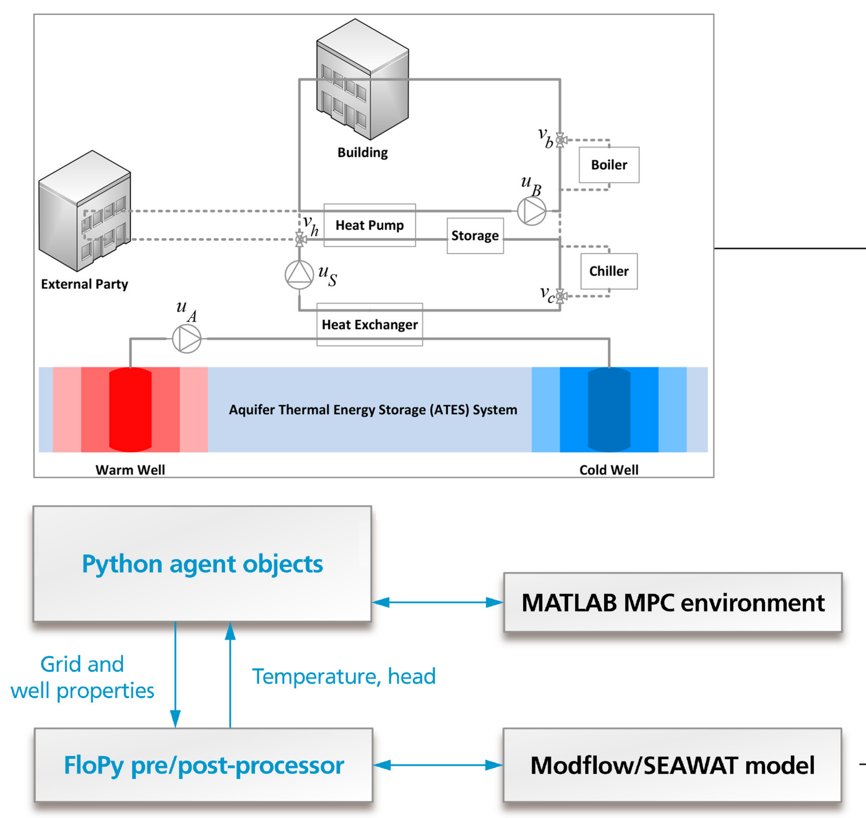
2. Research problem

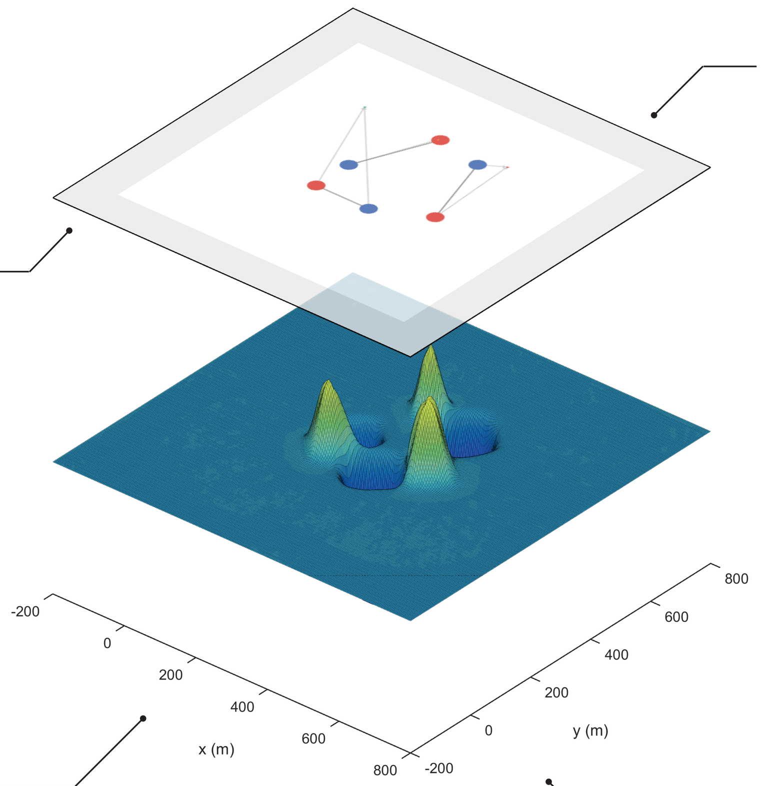
- Current practices for ATES planning and operation limit the performance of urban ATES systems
- Operational uncertainties (e.g. variable building energy demand and ATES use) are not fully acknowledged in ATES planning; in the Netherlands, only 40-50% of the planned system capacity is typically used (Willemsen, 2016), leading to an artificial scarcity of space in some areas
- Uncertain well flows can lead to unexpected thermal interactions between neighboring systems, and a loss of performance; thermal imbalances (e.g. excess heating or cooling demand) can also cause undesirable long-term changes in aquifer temperature distributions

Can cooperative control mechanisms improve the management of thermal interactions and imbalances for urban ATES systems?

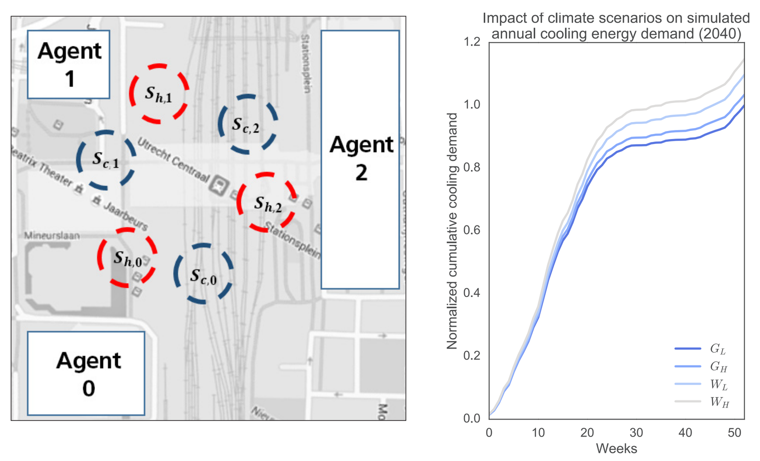
3. Model setup

- Coupled geohydrological/control simulation used to link ATES operation and groundwater dynamics
- Individual building control compared to a centralized control scheme with full information exchange

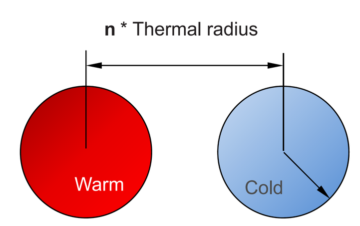




- 3 simulated office buildings based on typical ATES use in Utrecht; synthetic energy demand profiles, with 8 replications * 4 KNMI climate scenarios over the 2035-2040 period



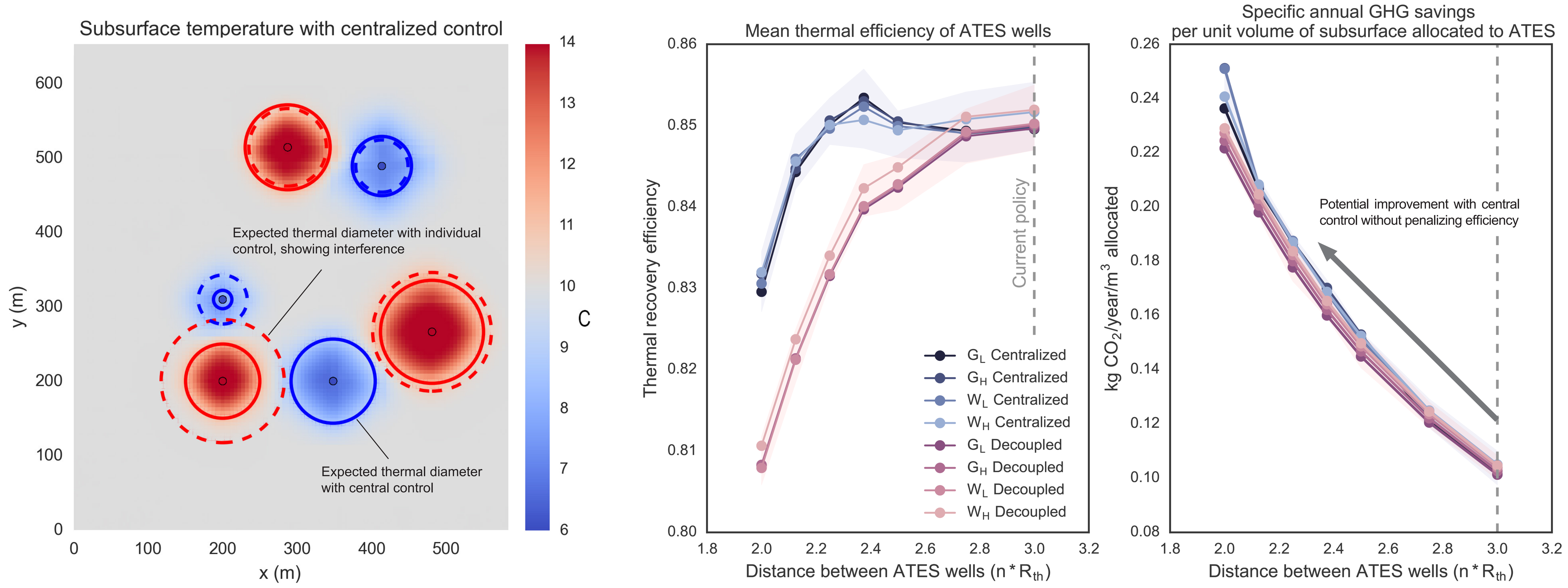
- Finite-difference simulation of temperature distributions in a confined aquifer, with typical properties for ATES use in the Netherlands
- Weekly time resolution (5 years total runtime)
- 7 layout policies tested, based on relative distance between neighbouring ATES wells



- Individual case imposes contraints on individual ATES well storage volumes and thermal balance over time (control design presented in Rostampour et al., 2016)
- Centralized case introduces additional coupling constraints on the volume stored in neighboring wells to avoid overlap, assuming perfect information:

$$V_{\mathbf{h},i}(k)+V_{\mathbf{c},j}(k)\le \bar{V}_{\mathbf{hc},ij}, \quad \forall j\in\mathcal{N}_{-i,\mathbf{c}},$$
$$V_{\mathbf{c},i}(k)+V_{\mathbf{h},g}(k)\le \bar{V}_{\mathbf{ch},ig}, \quad \forall g\in\mathcal{N}_{-i,\mathbf{h}}, \quad \forall i\in\mathcal{N}$$

4. Results

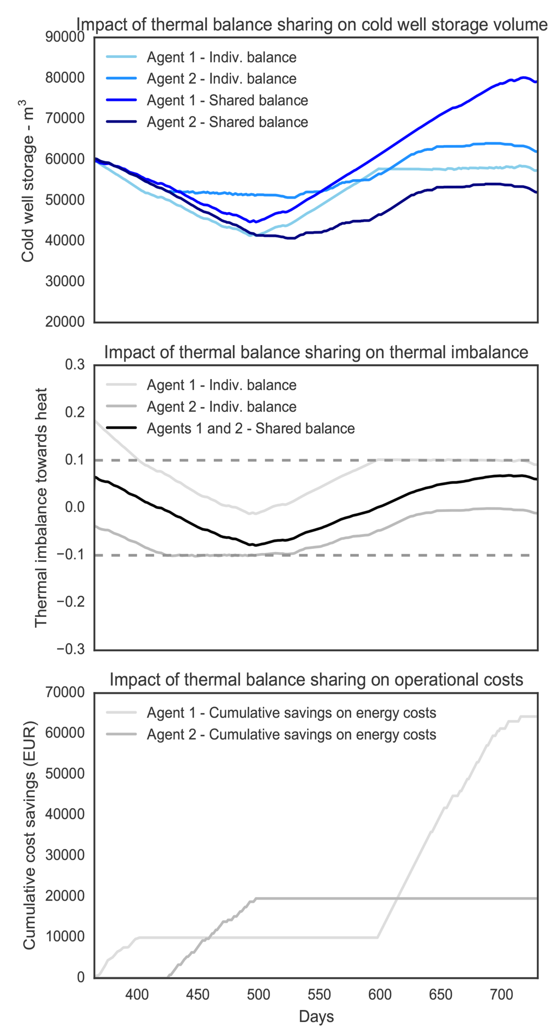


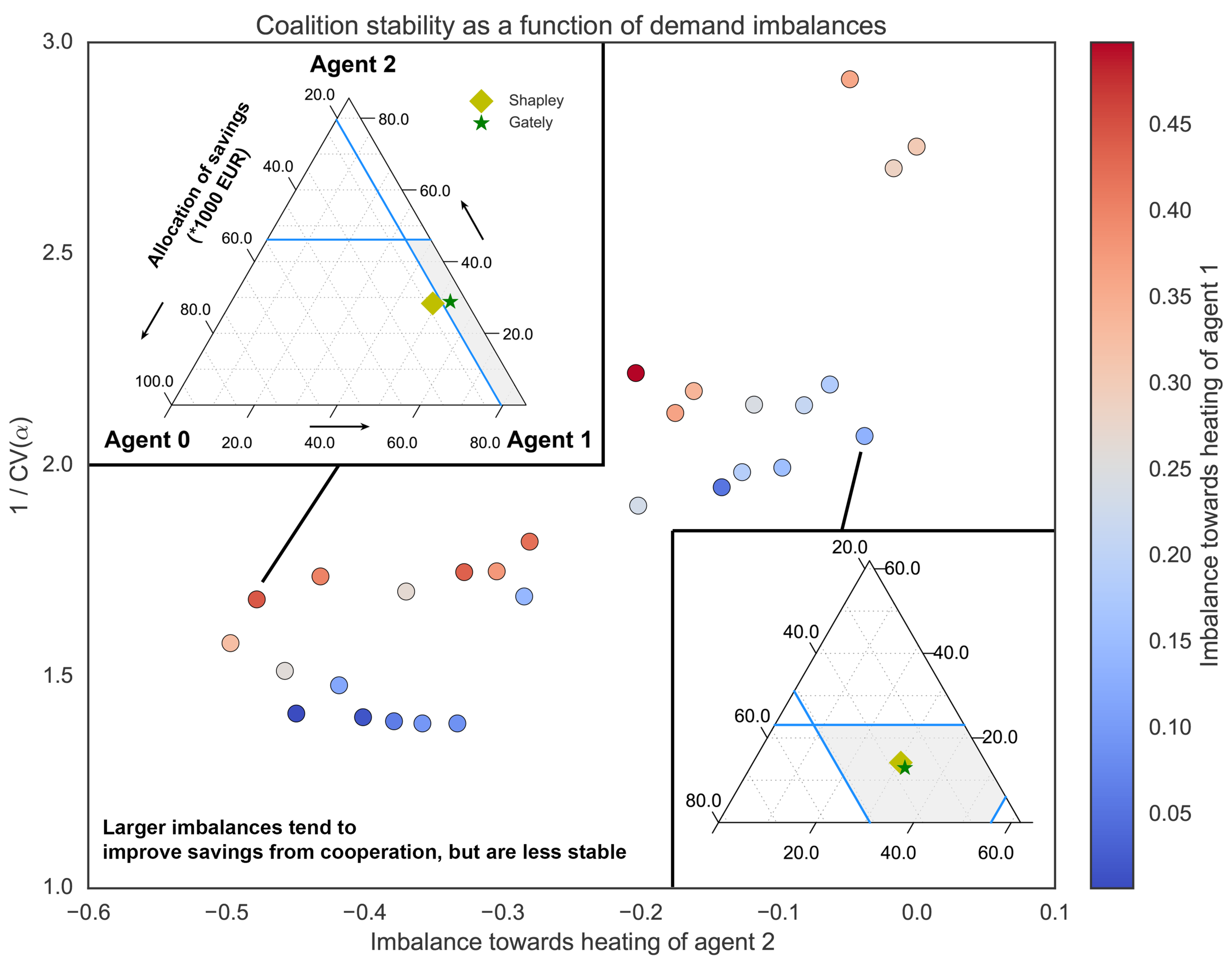
- The centralized controller successfuly manages thermal interactions between wells at smaller distances, which could support denser spatial planning to increase the adoption of ATES in urban areas without reducing the performance of systems

Thermal balance

- Information exchange could also be used to better manage thermal imbalances between heating and cooling, if we assume that individual ATES system constraints on thermal balance (as currently applied) can be replaced by a constraint on the average balance of neighboring systems
- Cooperative game theory can then help assess the conditions under which cooperation would be beneficial/stable

- The graphs on the left show a shared +/- 10% balance constraint, under which agents 1 and 2 compensate for their individual imbalances; by letting the agents operate their ATES systems more flexibly, the shared balance constraint reduces operating costs
- The figure on the right uses 32 scenarios to simulate operational variations by adjusting the baseline demand of agents 1 and 2, in a range of 0-50% towards heating and cooling respectively
- The inset ternary plots show how savings from cooperation on thermal balance could be allocated with Shapley values. The calculated stability of the coalitions is based on the variation of the Shapley-Shubik power index across agents





5. Conclusions and next steps

- The exchange of information between neighbouring ATES systems could help cope with operational uncertainties such as building energy demand, and allow operators to better manage thermal interactions and imbalances between neighbouring systems
- A combination of denser spatial planning and cooperative operation could significantly improve the efficiency at which subsurface volume is allocated for ATES systems, and increase future potential for ATES adoption in dense urban areas
- The simulations will be extended to account for multiple building operators with heterogenous and time-varying control strategies