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Medium Deep Borehole Thermal Energy Storage Pilot Plant

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ABSTRACT

Borehole thermal energy storage (BTES) is eminently suitable for seasonal storage of large amounts of excess heat. However, water authorities regard the associated thermal impact on shallow aquifers as critical. Medium deep borehole heat exchangers (BHE) tap into larger depth and allow for the use of thermal insulation in the topmost section of the boreholes. As a result, the thermal load on topmost aquifers is significantly reduced and shifted to the rock volume below. Numerical simulations have shown, that these medium deep BTES systems can store heat on a large scale and effectively protect critical drinking water reservoirs. However, the existence of modern district heating grids and the large system size required for efficient operation raises the capital cost. As a consequence, medium deep BTES systems have not been put into practice so far.

We present the concept of the first pilot plant for a medium deep BTES system to be built on the campus of Technische Universität Darmstadt. The array consists of four coaxial BHEs, which tap into a crystalline reservoir rock underneath a sedimentary cover of approximately 50 m thickness. All BHEs are to be equipped with flowmeters and fiber optic cables for depth-dependent temperature measurements. In close vicinity, wells with multi-parameter probes will complete the extensive monitoring setup. Experiments are run using mobile heating and cooling units, which simulate charging and discharging cycles and allow for full control of the storage operation. Together with geophysical exploration data from the construction phase we expect the pilot plant to provide comprehensive data for the validation of our numerical experiments and to proof the concept of medium deep BTES.

1. INTRODUCTION

The decarbonization of the heating sector by utilizing renewable solar heat and excess heat from industrial processes or heat and power plants heavily relies on the possibility of seasonal thermal energy storage. Seasonal variations in both the heating load and the heat production potential result in an offset of heat demand and supply. Facilities, which are capable to cover the heat demand in winter, would be oversized during summer and represent an overcapacity. Hence, only storage of large quantities of heat on a seasonal scale can provide a resource-efficient solution.

As heat demand correlates with population density, the demand for seasonal heat storage is concentrated in urban areas. However, sensible heat storage requires very large volumes to provide sufficient capacities for seasonal loads. Thus, on-surface solutions like water tanks are often infeasible as space is very limited in densely populated areas. Yet, the subsurface offers an almost unlimited volume for sensible heat storage. Arrays of BHEs have already been used for BTES multiple times, but these systems usually only tap into the shallow subsurface (e.g. Lundh and Dalenbäck, 2008; Reuß, 2008; Sibbitt *et al.*, 2012; Bauer *et al.*, 2013; Sørensen *et al.*, 2013). During summer, hot fluid is circulated through the BHEs to transfer excess heat from the surface to the ground. In winter, operation is reversed and cool fluid is circulated through the BHEs to extract thermal energy from the previously heated subsurface.

Shallow systems, however, typically access the topmost aquifers, which are also used for drinking water extraction. Many authorities regard excessive heating of this valuable resource as critical (Haehnlein *et al.*, 2010). Furthermore, BTES in shallow aquifers are also often prone to heat losses: ground water flow velocities above 1 m a^{-1} result in significant heat losses in BTES systems (Welsch *et al.*, 2016). To bypass these problems, Welsch *et al.* (2016) propose to drill medium deep BTES systems instead. Heat is stored in a deeper, less permeable reservoir and the extended depth allows for thermal insulation in the borehole grouting of the uppermost sections (Schulte *et al.*, 2016a). On top of that, medium deep BTES systems require less space compared to shallow systems of equal capacity (Figure 1), which is another advantage in urban areas.

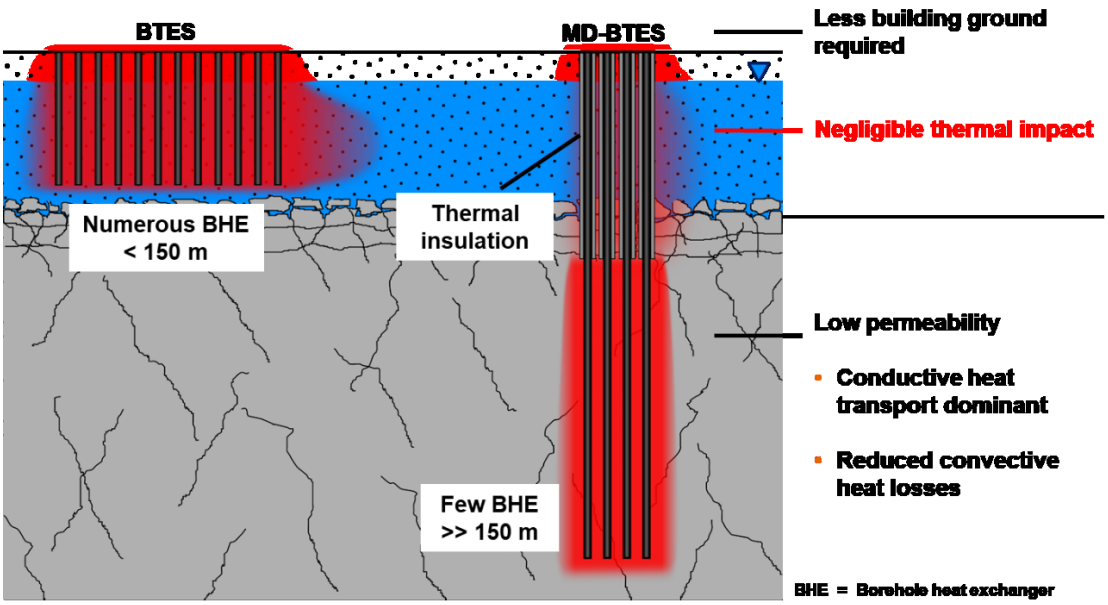

Figure 1: Heat storage can impose a critical thermal impact on aquifers. Medium deep borehole thermal energy storage circumvents the problem by accessing a less vulnerable storage reservoir in larger depth; modified after Schulte et al. (2018).

2. DESIGN OF THE EXPERIMENTAL BTES SYSTEM

So far, medium deep BTES systems have only been investigated by means of numerical simulations (Welsch *et al.*, 2016) and mathematical optimization (Schulte *et al.*, 2016b), but they have not been put into practice. At the Technische Universität Darmstadt Campus Lichtwiese (Figure 2), the Chair of Geothermal Science and Technology plans to build a demonstrator for such a system to prove the concept of medium deem BTES systems for seasonal storage of solar heat and excess heat, and to gather data for validation of the existing numerical models. Ultimately, the experimental BTES demonstrator is supposed to show the economic viability of industrial scale BTES systems in district heating grids.

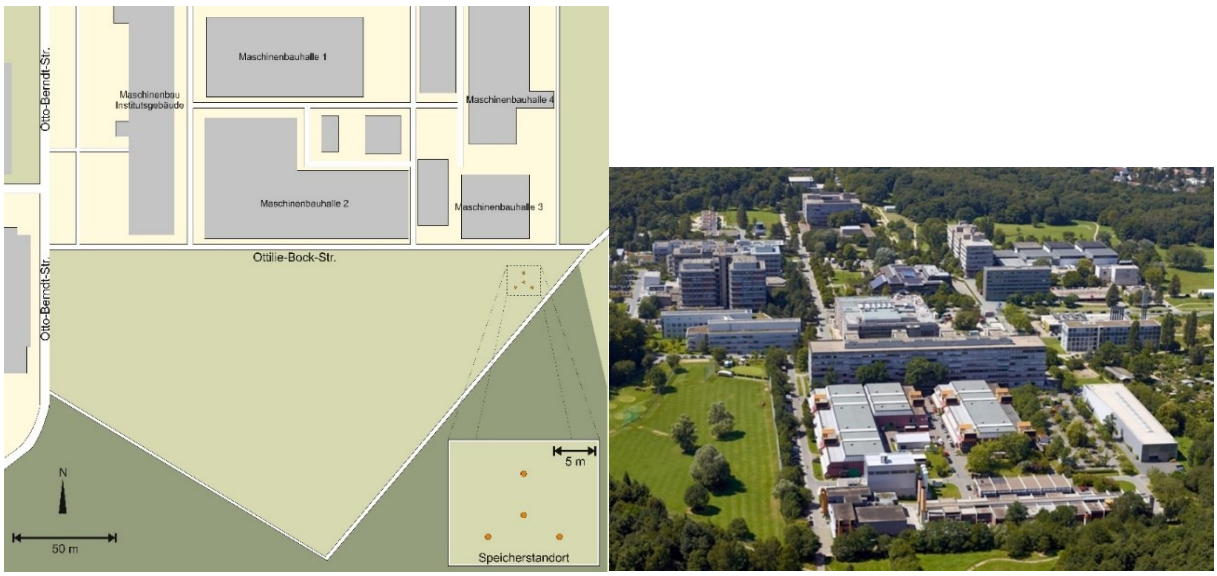

Figure 2: Map view illustrating the location and arrangement of the four coaxial BHEs on Campus Lichtwiese (left) and an aerial view of the campus (right).

The planned experimental BTES system will consist of four coaxial BHEs of 750 m depth. One BHE will be in the center, whereas the remaining three will be positioned in equal distance of 5 to 6 m to the central BHE in a triangular arrangement (cf. Figure 2). Three monitoring wells in the vicinity will monitor hydro-chemical changes in the upper aquifer (depth estimated to be approximately 50 m). All BHEs will be equipped with flowmeters and fiberoptic cables for mass flow measurements and depth-dependent temperature measurements, respectively (Figure 3).

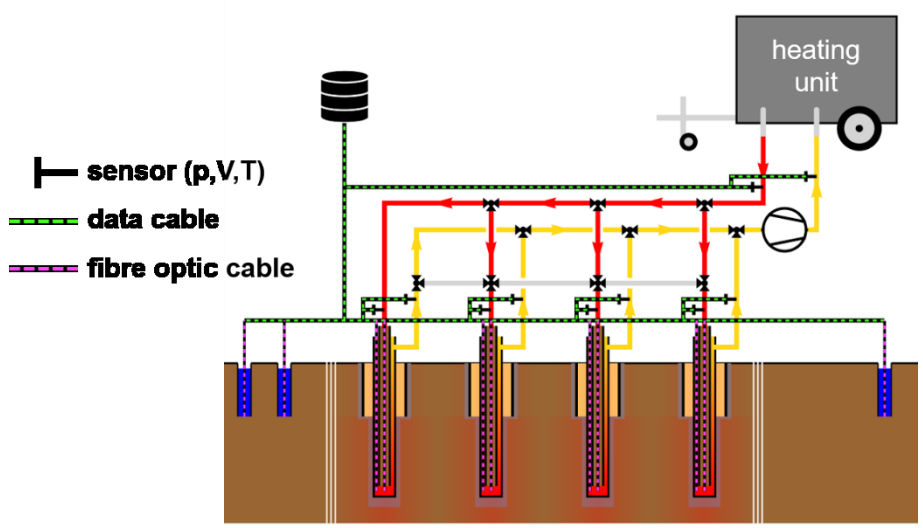

Figure 3: Schematic of the experimental BTES demonstrator showing the four coaxial BHEs with their hydraulic connection, the three monitoring wells and the installed measurement equipment.

3. EXPERIMENTS

In order to run experiments undisturbed from fluctuations in the existing district heating grid, the demonstrator will not be connected to the grid at first. Instead, heating and cooling will be provided by mobile units, which allow for full control of the operational boundary conditions. The demonstrator will be used for three subsequent experiments, beginning with a geothermal response test (GRT) at the central BHE to determine the borehole resistances and effective thermal conductivities. Due to the length of the BHEs, the GRT will be run for six weeks. A priori numerical simulations indicate that it takes much longer for the system to reach thermal equilibrium in close proximity of the medium deep BHEs than for usual GRT with regular, shallow boreholes.

The GRT is followed by an attenuation phase of a few months. Depth-dependent temperatures will be continuously recorded. The data can be used to calibrate existing subsurface parameters of numerical models before the subsequent experiments of thermal energy storage. First, four cycles with constant charging and discharging power will simulate storage of heat from a cogeneration heat and power plant (CHP) during summer, as the thermal load from a CHP is rather steady (Figure 4). The last experiment will simulate fluctuating heat storage from a solar thermal collector field (Figure 5).

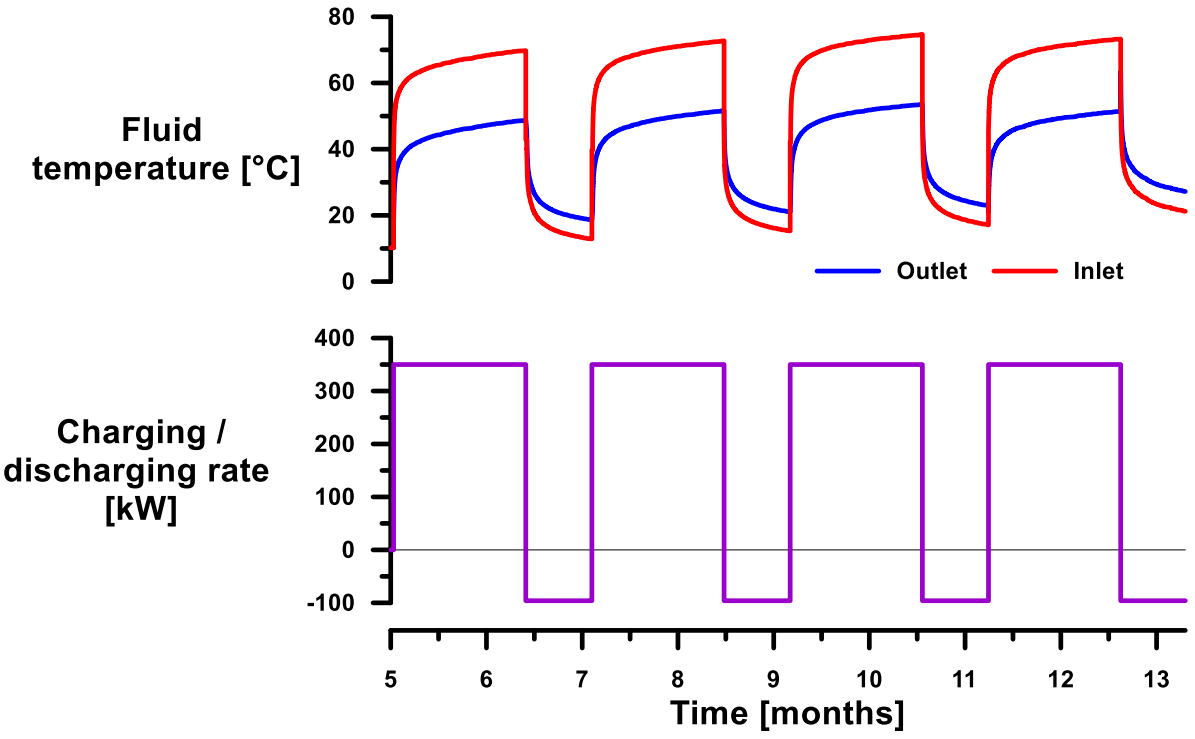

Figure 4: Heating and cooling load and corresponding inlet and outlet temperatures of the BTES system during simulated heat storage from a CHP.

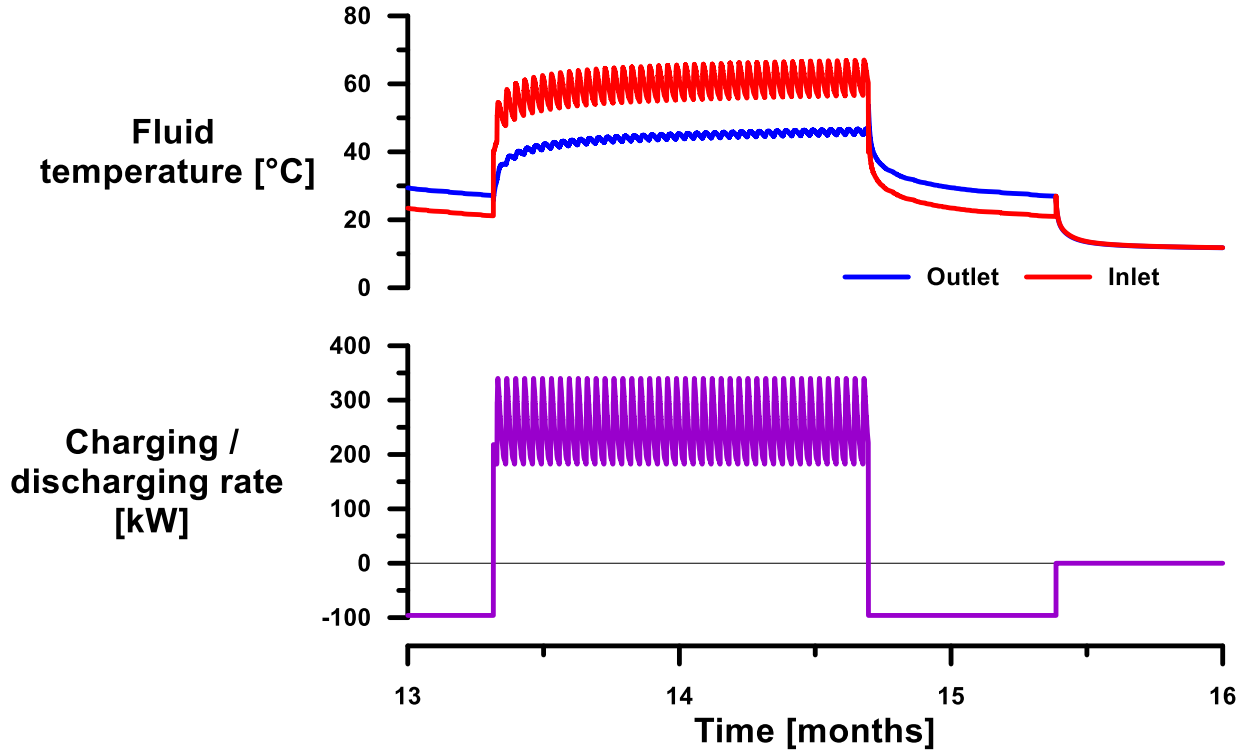

Figure 5: Heating and cooling load and corresponding inlet and outlet temperatures of the BTES system during simulated heat storage from a solar thermal collector field.

The results of the experiments will provide data for validation of simulations that also consider the on-surface facilities and their interdependent thermal behavior. Validated models can then be used to simulate and investigate upscaled systems.

4. OUTLOOK

The Technische Universität Darmstadt aims to reduce its carbon emissions at the Campus Lichtwiese considerably. Renovating its building stock plays a major part in this plan as it facilitates a significant reduction of the heat demand. More importantly, heating systems of renovated buildings have lower temperature requirements, which allows for a reduction of temperatures in the district heating grid. Renewable energy sources typically cannot provide temperatures as high as combustion processes. Thus, a reduction of grid temperatures helps to utilize more renewable heat to replace fossil fuels and subsequently makes BTES more attractive to be used in the grid. Figures 6 and 7 show the results of simulations of a hypothetical campus district heating grid including solar thermal collectors and a BTES system with high grid temperatures (status quo) and reduced grid temperatures and their influence on the potential share of solar and BTES-provisioned heat.

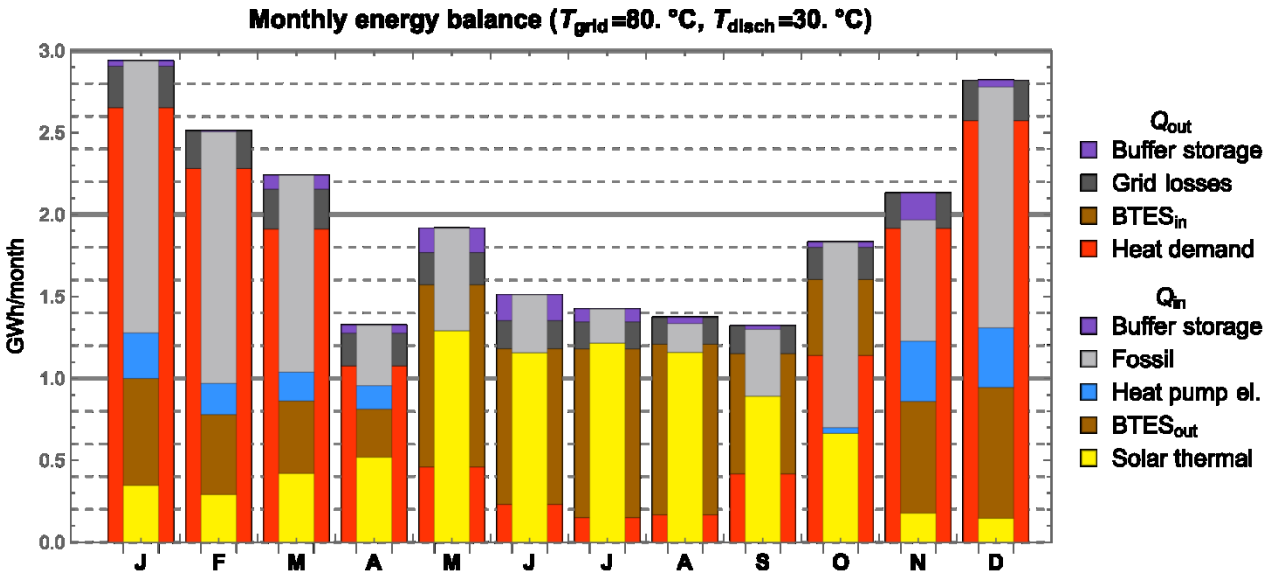

Figure 6: Monthly energy balance of the campus district heating grid with high grid temperatures based on simulations.

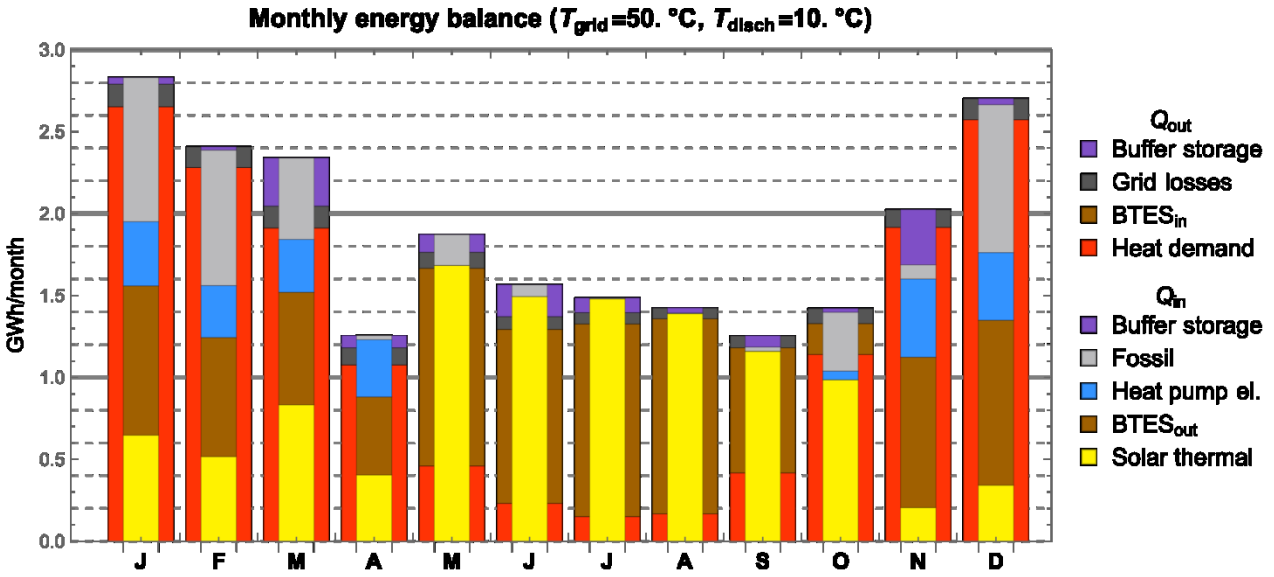

Figure 7: Monthly energy balance of the campus district heating grid with reduced grid temperatures based on simulations.

A reduction of the grid temperature turns out to be very beneficial. Grid losses decrease by more than 50%, whereas the share of renewable heat (solar + BTES) can be improved from 40 % to 67 % in this particular case. Welsch et al. (2018) investigate these effects in a comprehensive economic and environmental study in terms of the possible reduction of global warming potential (GWP) and the associated levelized cost of heat (LCOH) for a district heating grid with an annual heat demand of 25 GWh. They show that under certain boundary conditions solar thermal collector fields with BTES systems can significantly reduce the GWP in fossil fuel-powered district heating grids at competitive cost (Figure 8).

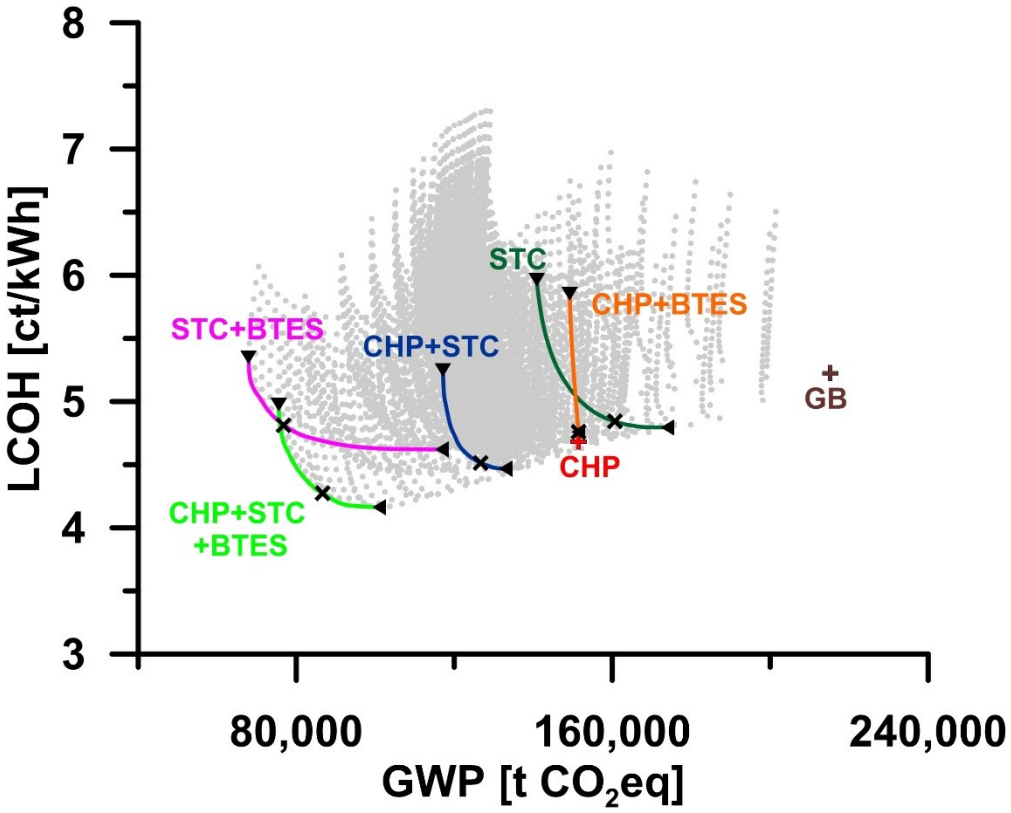

Figure 8: Comparison of Pareto fronts for different system compositions considering existing subsidies in Germany and assuming a progressive-prognostic development of the share of renewable energies in the electricity mix as well as increasing energy prices; GB: gas boiler (reference scenario), STC: solar thermal collector, BTES: borehole thermal energy storage, CHP: combined heat and power plant (Welsch et al., 2018).

Provided that the construction of the BTES demonstrator and the experiments will be successful, this indicates that the demonstrator could be economically extended to an industrial scale and connected to the campus district heating grid to allow for the utilization of solar heat in order to replace fossil fuels and to cut carbon emissions.

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