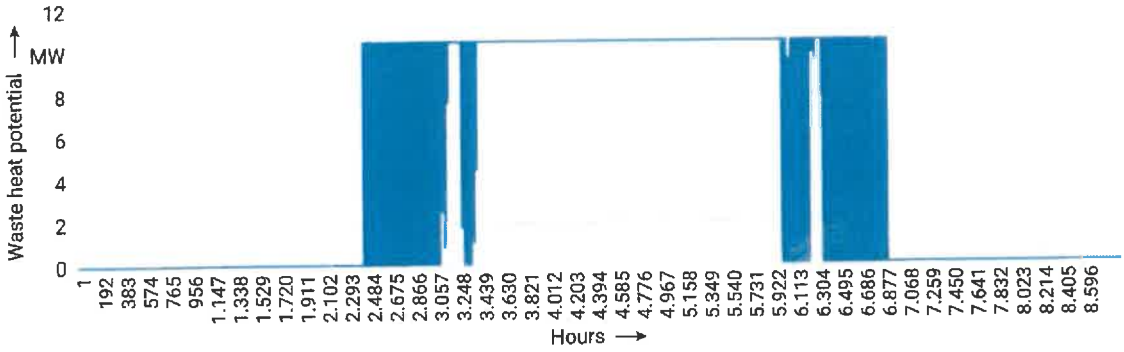

Figure 1. Assumption of waste heat availability at 95 °C in a weather situation like 2007

Assessment of a Seasonal Cavern Thermal Storage for District Heating in the City of Graz

In the exploratory project CityStore the state of the art of energy storages for urban areas were investigated. The central question was: Which storage technologies can best contribute to the energy transition in cities? As a result, it can be concluded that seasonal thermal storages for district heating systems are increasingly requested.

Due to increasing urbanization the need for energy and resources is more and more concentrated on congested areas, which calls for local solutions. In this respect, urban energy storages can play an important role for the energy transition. While conventional storage systems (storage hydropower plants, gas storages) are more likely to be found in rural areas, it remains to be seen what contribution urban storage solutions can make. For this purpose, stakeholder interviews and model calculations on possible applications of storage technologies were conducted. In consultation with local stakeholders, storage solutions were investigated by means of energy system model calculations. In Austria, two use cases were identified, one for the city of Weiz (11,7000 inhabitants) on photovoltaic combined with battery storage and one for the city of Graz (325,000 inhabitants) on the seasonal thermal storage for district heating.

Background

In Graz district heating plays not only currently a major role in the heat supply but also for the future energy transition and security of supply in the city. The energy 2050 vision [1] also includes the city's district heating targets for 2050. The aim is to provide the whole district heating from renewable energy resources. The use of seasonal thermal storages is therefore gaining a key role in storing excess heat, since excess heat in the summer has so far remained unused. At a stakeholder meeting on urban storage technologies in Graz, the idea of a cavern storage system was discussed in more detail. The main advantage of this rather unknown technology is that it does not require free spaces, as it is the case for a pit thermal energy storage. Since the storage facility is built into the mountain (underground), there is no competition with land use in the city.

Cavern heat storage

In cavern heat storage systems energy is stored as hot water in an underground cave. These systems have a very high storage capacity

Possible structures for this storage facility are abandoned mines, tunnels or rock caves, natural karst structures and artificially built caves for example with tunnel boring machines [2].

Aim of the model-based simulation

In the following, the first model-based simulation of a possible future application of a seasonal cavern thermal storage is presented. Industrial waste heat intended for district heating in Graz needs to be stored. The estimations of the investment costs of a cavern storage facility are fluctuating quite a lot depending on the rock layer (between €70 and € 140 /m³ storage volume). The aim of the simulations was to obtain an initial estimation of how high the investment costs for the cavern may be to enable an economical operation of a seasonal cavern storage in Graz. The storage facility was considered to be run economically, if the storage costs – with depreciation over 60 years and an assumed interest rate of 5% – can be covered by the district heating revenues in winter.

Modell description

For the simulation it has been assumed that between April and September 40 GWh of waste heat with a temperature of 95 °C from industry is available. In winter, this waste heat is already used. From April to September, depending on the weather, there is an unused waste heat potential of 10.5 MW thermal output (figure 1). The year 2007 was used as the basis for simulation of this case study since weather data were available for this year. Figure 1 shows the assumed course of the temporal availability of waste heat of 40 GWh over the year. In table 1 important model parameters for the cavern storage simulation are summarized.

Figure 2 shows a schema of the simulated cavern storage system. The heat pump (HP) can reheat the water in the cavern to a maximum of 95 °C. Since district heating flow temperatures arise up to 120 °C in Graz, it is assumed that when water is extracted from the cavern the heat pump must reheat the water to the required flow temperature. If the heat pump uses the water in the cavern as a heat source in winter, it can cool the water in the cavern down to 5 °C by removing the heat. In this case, the river Mur is in summer warm enough to heat the 5 °C

Investment costs	
Cavern	€70-€140 /m³
Heat pump without heat source	€800 /kW(th)
Heat exchanger for waste heat connection to the cavern	€85 /kW(th) at 5 °C TTD[1)]
Heat exchanger for extracting heat from the cavern	€86 /kW(th) at 5 °C TTD
heat exchanger from extracting heat from the river	€87 /kW(th) at 3 °C TTD
Depreciation	
Interest rate	5% (WACC)
Depreciation period cavern	60 years
Depreciation period heat pump	15 years

[1)] TTD: Terminal Temperature Difference

Table 1. Model parameters

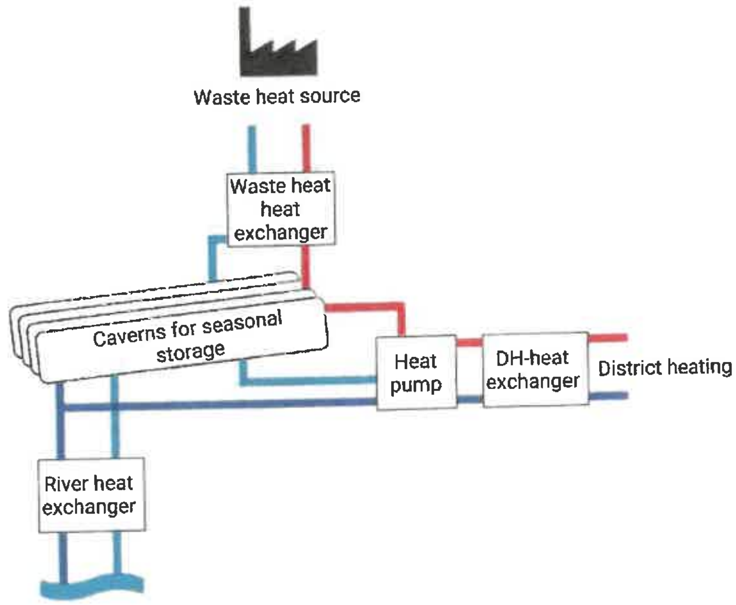

Figure 2. Schema of the simulated cavern storage

cold water in the cavern back to 10 to 15 °C before the waste heat from the industry increases the water in the cavern to 90 °C. To separate the cavern water from the district heating and the river water, appropriate heat exchangers would have to be installed and paid for. This is optimized in the simulation to maximize the revenue of the cavern. Since no resources were provided for the thermodynamic simulation of the rock in the project, the heat losses and gains through the heat conduction in the rock are missing in this first assessment.

Heat input	[MWh]	Heat extraction	[MWh]
Waste heat	39,070	Direct use of storage heat at flow temperature ≤90 °C	9,898
Heat pump electricity purchase	25,742	Provision with heat at flow temperature >90°C	185,766
Heat pump losses	-3,805		
Caching	129,763		
River water	4,894		
Total	195,664	Summe	195,664

Table 2. Overview simulation assumptions and results

Simulation results

Four scenarios with cavern sizes between 200,000 and 700,000 m^3 and variations in the district heating marginal costs have been simulated. The simulations showed that the cavern may cost between €50 and €120 /m^3 (depending on the scenario) to enable an economical operation of the cavern storage facility. In one of the four scenarios a cavern size of 500,000 m^3 was simulated. Table 2 shows a comparison of the components of heat input and heat extraction for this simulation. Since the heat pump supplies the system with additional heat using electricity, this – minus the heat pump losses – contributes around 22 GWh of usable heat.

The river water can contribute around 5 GWh of heat in summer. The cavern is used in winter – after removing the seasonal stored heat – in a large part (130 GWh) as a compensation storage for district heating. Energetically the cavern storage facility achieves nine storage cycles per year.

Conclusion

In this analysis, a first rough evaluation of a possible operation of a cavern storage facility for district heating in the city of Graz was realized. Four scenarios were simulated. The target costs for the cavern, to achieve the economic viability of the seasonal storage, amounted to €50 to €120 /m^3, depending on the scenario-specific assumptions. From a cavern size of around 400,000 m^3 in an optimized operation scenario 40 GWh of available waste heat can be stored. The cavern is also used as an intermediate storage for district heating and as a seasonal storage for river water heated in summer.

However, this exploratory study on urban energy storage has not performed a thermodynamic simulation of the rock. Thus, the heat losses and gains due to heat conduction in the rock and the feedback between the storage and the district heating generation are missing in this first analysis. These issues remain open and can be investigated in follow-up projects.

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