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Conceptual market potential framework of high temperature aquifer thermal energy storage - A case study in the Netherlands

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ABSTRACT

High temperature aquifer thermal energy storage (HT-ATES) can contribute to the integration of renewable energy sources in the energy system, the replacement of fossil fuel-based heat supply and the utilization of surplus heat from industrial sources. However, there is limited understanding on the drivers, barriers and conditions of HT-ATES implementation. The objective of this study is to partly fill this knowledge gap by developing a methodological framework for a quick scan on market potential of HT-ATES. Based on the application of this framework to a case study in the Netherlands, it is concluded that the proposed method is suitable for a pre-feasibility analysis on the HT-ATES market potential. The investigated case study has a planned district heating system with geothermal energy as the heat source. HT-ATES is found to be cost-effective compared to a reference technology, i.e. a natural gas boiler, in the scenarios under existing and more sustainable alternative policies. The lifetime of HT-ATES and the size of heat demand have a strong influence on the market potential.

1. Introduction

Global warming, geopolitical concerns and other drivers initiated a global transition from a fossil fuel-based energy system towards a sustainable energy system [1]. The renewable energy sources (RES) required for this transition bring new challenges. Large-scale RES integration in the energy system potentially results in a mismatch between energy supply and demand. Increased flexibility of the energy system is required to manage such mismatches [2].

A technology capable of contributing to the flexibility of energy systems is seasonal thermal energy storage. Applications of seasonal thermal energy storage facilitate the replacement of fossil fuel-based heat supply capacity by renewable thermal energy sources (RTES) and enable utilization of excess heat from industries. This is particularly the case in district heating (DH) networks, where inefficient, expensive and carbon intensive peak capacity from heat-only boilers is often needed on cold winter days [3]. During the summer season, renewable thermal energy sources such as solar and geothermal installations may have surplus capacity. Surplus heat can be stored and utilized in winter in a DH system with the application of seasonal thermal energy storage. Thermal storage in combination with DH networks can further provide competitive flexibility to the electricity system through system integration, e.g. through power to heat options.

An excellent place to store large amounts of thermal energy over seasonal timespans is the subsurface. In addition to having good isolating properties, the subsurface provides a large potential storage volume while keeping interference with other surface activities at a minimum. This makes underground thermal energy storage particularly suitable for urban environments [4], where most of the potential for thermal storage lies due to concentrated heat demand.

A promising technology that is suitable for the large storage capacities required for both DH networks and for balancing supply of RTES with the demand is *high temperature aquifer thermal energy storage* (HT-ATES). HT-ATES is based on the same principles as regular aquifer thermal energy storage (ATES), but differs on a few points. Firstly, the temperature of stored water is higher. While the hot well injection temperature of regular ATES typically reaches up to 30 °C [5], HT-ATES is characterized by a minimum hot well injection temperature of 50 °C (and maxima up to 150 °C in pilot projects) [6]. A second difference is that HT-ATES systems only store heat, while ATES systems generally store both heat and cold. As

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indicated in Fig. 1, a HT-ATES system consists of both a hot and a cold well, but the cold well does not contain water for cooling purposes. In summertime, formation water from the “cold” well is heated with surplus heat and stored in the hot well; in wintertime the formation water in the hot well moves through a heat exchanger back into the cold well. Depending on the DH network and well depth, the cold well temperature can be higher than the aquifer ambient temperature. Unlike a typical ATES, energy balance is unlikely to be achieved, resulting in a long-term increase in subsurface temperature. As a result of these differences, HT-ATES wells are typically (but not necessarily) located in deeper aquifers than ATES wells to reduce environmental impacts, the risk of interference with drinking water reserves or surface activities. The main advantage of HT-ATES compared with regular ATES (<30 °C) is that retrieved heat can be directly used for heating purposes without the need for upgrading (e. g. with heat pumps). The storage of water with higher temperatures can also increase both the energy storage capacity and overall energy efficiency [4,5]. In addition, HT-ATES enables the utilization of various higher temperature heat sources, e.g. geothermal heat and wasted heat from CHP plants.

Despite many advantages, a limited number of HT-ATES projects operate worldwide. The first development of HT-ATES technology dates from the 1970s. Pilot projects started in the 1980s and were mostly unsuccessful. To the authors' knowledge, only two operational HT-ATES systems exist, both in Germany: the Reichstag Building in Berlin, where water is stored at 70 °C [7], and the HT-ATES system in Neubrandenburg, where water is stored at 80 °C [8]. The main explanation of limited implementation of HT-ATES is that it is more complex as compared to regular ATES. The technical and operational challenges include minerals precipitation, corrosion of components in the groundwater systems and low recovery efficiency due to thermal advection under high buoyancy forces induced by density contrasts [5,6]. In the period 1985–1995, much research aiming to resolve these problems was done. To date, most of the technical challenges that hampered the early growth in implementation of HT-ATES systems have been solved and proven solutions are available, such as appropriate water treatment and materials selection to prevent minerals precipitation and corrosion [6,9,10]. The use of low permeability aquifers [8] and the use of salinity contrast for density difference compensation [11] are proposed to improve the thermal recovery efficiency.

Other points of concern which are important for the feasibility of HT-ATES are the impact on the ground water and legal aspects. The potential impacts mainly induced by the change of temperature on the composition of groundwater include mobilization of organic carbon, increase of mineral solubility, algae growth and shifting of materials [12]. The impact on groundwater geochemistry and microbiology is still not fully known [5]. Application of HT-ATES in the shallow subsurface (<500 m) is now prohibited in most European counties and also countries outside Europe because of legislation [12,13]. Regulated threshold values for groundwater temperatures are county-specific. The most commonly applied maximum absolute groundwater temperature for heating is 25 °C (25–30 °C in the case of the Netherlands depending on province) [12,14]. The current HT-ATES in the Netherlands are pilot projects. The purpose of pilot projects is to gain practical experience and more insights on the technical performance and environmental impacts. Monitoring of groundwater quality, energy efficiency, hydrothermal effects, geo-chemical effects and effects on microbiological populations in the subsurface is therefore being executed. Knowledge from these pilot projects and monitoring programs can be used for the revision of the regulatory framework for HT-ATES [8].

As discussed above, the focus of the scientific studies on HT-ATES is about technical design, operation and environmental impacts. Challenges need to be overcome in these areas but there is also a need to gain more insights on the market potential aiming to present the influence of policies on its application and the influence of technical, economic and social contexts on its business case. A review of studies assessing the market potential of energy technologies (see Table A1 in the appendix) shows that technical and economic potentials of energy technologies have been widely assessed while market potentials are assessed less. Particularly limited literature is available on the market potential of ATES and HT-ATES. In order to promote HT-ATES in the sustainable energy transition, it is crucial to understand the drivers, barriers and conditions for its implementation. The objective of this study is to partly fill this knowledge gap by developing a conceptual methodological framework for a screening assessment of the market potential of HT-ATES in a DH system and to showcase a part of this framework in the form of a techno-economic case study in the Netherlands. With this objective in mind, the conceptual methodological framework of the market potential assessment is discussed is section 2. The case study and its main characteristics, data and assumptions are also presented in section 2. The results of implementing the framework in the case study are interpreted and discussed in section 3 and 4. Finally the conclusions are drawn in section 5.

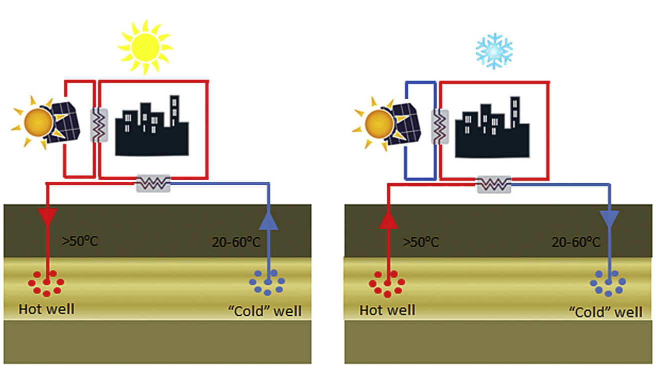

Fig. 1. Schematic diagram of a simple two-well HT-ATES operating in a district heating network with solar thermal as its main heat source. In summertime (left) more solar heat is produced than required and therefore part of the produced heat is injected into the HT-ATES hot well. In wintertime (right) less solar heat is produced than required and therefore additional heat from the HT-ATES hot well is produced. (Note that the cold well in this diagram is not used for cooling, but is used to store formation water from the hot well after it has passed through the heat exchanger. Optimal injection and production temperatures can strongly vary per project.)

2. Method

Theoretical and technical potentials of a technology are generally assessed at a regional or country level to quantify the potential energy production of this technology within this area in a target year. Economic and market potentials are generally assessed at the local level or for a specific project. The application of the proposed framework facilitates a quick scan for identifying the feasibility of a HT-ATES case taking into account technical, economic and market conditions. In this study an exemplary case study is performed to show how a part of the market potential framework can be quantified.

2.1. Conceptual assessment framework of market potential

The developed preliminary market potential assessment framework is represented by Fig. 2. Each step contains a different set of prerequisites and key parameters affecting the assessment,