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THE POTENTIAL OF HIGH-TEMPEATURE AQUIFER THERMAL ENERGY STORAGE (HT-ATES) TO ENHANCE THE TECHNO-ECONOMIC PERFORMACE OF DUTCH DISTRICT HEATING SYSTEMS

Wen LIU*

Energy & Resources, Copernicus Institute of Sustainable Development, Faculty of Geosciences, Utrecht University, Princetonlaan 8a, 3584 CB, Utrecht, the Netherlands

ABSTRACT

The objective of this research is to explore the potential of high temperature aquifer thermal energy storage (HT-ATES) to enhance the techno-economic performance of district heating systems in the Netherlands. Two case studies have been performed for the city of Utrecht and Den Haag. By using modelling tool EnergyPRO, multiple scenarios have been developed for the year 2017 and 2030. This research underlines the importance of local conditions in heat-related projects. First of all, the applicability of HT-ATES depends on the suitability of the underground, which could be different for any locations. Secondly, the local availability of heat sources with low operational costs is crucial for making a successful business case for HT-ATES.

Keywords: district heating, techno-economic analysis, HT-ATES, EnergyPRO, modelling, the Netherlands

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Abbreviations	
HT-ATES	High-temperature aquifer thermal energy storage
DH	District heating
PBP	Payback period

1. Introduction

During the Paris Climate Conference in 2015, a total of 195 countries adopted the Paris Agreement to reduce greenhouse gas (GHG) emissions to mitigate climate change [1]. The Dutch government has set climate goals to enhance energy savings and reduce GHG emissions by 49% in 2030 and between 80-95% in 2050 compared to the 1990 levels [2]. The reliance on low-caloric natural gas is especially high in the Dutch built environment, as approximately 90% of the heat demand of Dutch households is covered by burning natural gas [3]. One of the alternatives for individual gas boilers is using heat from other (more sustainable) sources and supply it via district heating (DH) systems. The main advantage is that DH systems enable the large-scale utilization of alternative heat sources, such as geothermal heat or waste heat streams from industrial processes. One of the challenges for the economic viability of the DH systems is meeting the seasonal mismatch of heat supply and demand. A promising technology that is suitable for the large storage capacities that are required for DH systems is high temperature aquifer thermal energy storage (HT-ATES). HT-ATES is an open system and stores heat from external sources at temperatures higher than 30C° (see Fig. 1).

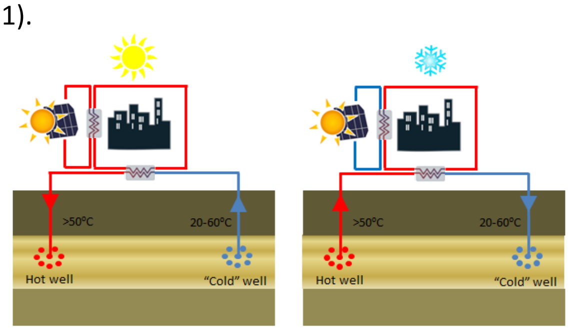

Fig. 1. Schematic diagram of a simple two-well HT-ATES

the objective of this research is to explore the potential of HT-ATES to enhance the techno-economic performance of DH systems in the Netherlands. Case

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studies are carried out in two district heating systems in Utrecht and Den Haag.

2. Methods

2.1 HT-ATES

In order to identify suitable aquifers and their characteristics, the REGIS v2.2 model from the website DINOloket can be used [4]. The theoretical potential of HT-ATES is determined by the total amount of energy that can be stored, which is related to the storage volume and the temperature of the injection and return flow [5]. The amount of energy that can be stored can calculated with the formula below:

$$Q = m * Cp * \Delta T$$

Where m= mass of stored water, Cp= specific heat of water and ΔT= temperature difference.

The technical potential is determined by the technical barriers to fully exploit the storage volume such as the flow rate of water and the thermal recovery efficiency. The economic potential is determined by factors that influence the cost effectiveness of HT-ATES implementation. The economic potential is dependent on a variety of factors, for instance the investment and maintenance costs of HT-ATES, the economic life time of the installation and the marginal costs of heat sources [5].

2.2 Scenario development

Conditions in the year 2017 represent the current situation and the plans for the development of DH systems in two case studies in 2030 are the basis of future scenarios. In order to assess the influence of adding HT-ATES to the DH systems, scenarios with HT-ATES should be compared to scenarios without HT-ATES. Four scenarios are formylated as below.

1. 2017 baseline scenario
2. 2017 baseline + HT-ATES scenario
3. 2030 reference scenario
4. 2030 reference + HT-ATES scenario

2.3 The EnergyPRO model

EnergyPRO is used to assess the techno-economic performance of a DH system in combination with storage capacity. This modelling tool is an input/output model calculating annual productions in time steps of typically 1 hour. The input parameters are fuels, capacities, efficiencies, time series for heat demand and electricity prices, the operational strategy and environmental data. The model derives a dispatch strategy for all heat and electricity production units as well as store utilization based on net heat production costs [6].

EnergyPRO uses the values of the input parameters to determine the net heat production costs of all sources over the year. The heat demand will then be met in the most optimized way. This means that heat sources with low operational expenditures (OPEX) will be used first to satisfy the heat demand, and high-OPEX sources will be used at a later moment when the low-OPEX sources are already fully used.

2.4 Techno-economic inputs

The capacity of heat supply technologies and their efficiency and cost data are presented in Table 1 and 2 [7].

Table 1 Data used in model for DH system in Utrecht

Unit	Fuel	Max Thermal capacity (MW)	Max Electric capacity (MW)	Efficiency (%) Th	el	O&M costs
2017						
Lage Weide	Natural gas	180	250	36	50	4.5 €/MWh
Merwede 12	Natural gas	180	225	36	45	4.5 €/MWh
Boilers	Natural gas	175	-	82		1 €/MWh
2030						
Lage Weide	Natural gas	180	250	36	50	4.5 €/MWh
Merwede 12	Natural gas	180	225	36	45	4.5 €/MWh
Boilers	Natural gas	175	-	82		1 €/MWh
Geothermal	-	30	-	-		2 €/GJ
Biomass boiler	Biomass	60	-	85		1 €/MWh

Table 2 data used in model for the DH system in Den Haag

Unit	Fuel	Thermal capacity (MW)	Electric capacity (MW)	Efficiency (%) Th	el	O&M costs
2017						
CHP	Natural gas	80	110	35	48	4.5 €/MWh
boilers	Natural gas	110	-	82		1 €/MWh
2030						
Waste heat	-	15	-	-		1 €/GJ
Geothermal	-	35	-	-		2 €/GJ
Boilers	Natural gas	110	-	82		1 €/MWh

Natural gas price was 6,5 €/GJ in 2017 and a price increase to 0,31 cents per m3 in 2030 is used, resulting 7,79€/GJ in 2030 [8]. Biomass price was €5,3/GJ in 2017 assumed to be 7,1 €/GJ in 2030 [8].

The historic electricity prices for the year 2017 on the Dutch day ahead market are visible [9]. Based on a study from [8], the average electricity price is expected to increase from 39,31 €/MWh in 2017 towards 44 €/MWh in 2030.

The heat price for residential consumers consists of a fixed annual fee and a price per GJ for the heat consumed. The pricing is based on the NMDA-principle meaning that heat consumers do not pay more compared to a situation when they would have had an individual gas boiler [10]. In 2017, the fix annual price was 309,52€ and the variable part was 24,05 €/GJ. For 2030, it is assumed that the heat price will increase with the same percentage as the natural gas price will increase, resulting in the variable part of heat price of 34,17 €/GJ.

According to [11], the price of CO_2 in 2017 was 5,7 €/tonne. The CO_2 price in 2030 is assumed to be 46,3 €/tonne [12].

2.5 Data analysis and indicators

Indicators are selected to evaluate the performance of district heating system such as energy inputs, CO_2 emissions, and net income. Payback period (PBP) is calculated to evaluate the economic potential of HT-ATES. Because of the space limit, only the results of CO_2 emissions and PBP are presented in the result section.

2.6 Sensitivity analysis

A sensitivity analysis is performed to identify the parameters with a strong impact on the PBP of HT-ATES in the two cases. Multiple input parameters are changed by a decrease of 25% and an increase of 25%.

3. Results

The HT-ATES does not function as a seasonal storage in the 2017 scenario in both Utrecht and Den Haag. The thermal store allows CHP plants to run harder and generate more income at times when electricity prices are high. Increasing the capacity of HT-ATES results in higher incomes through sale of electricity. However, it results in higher CO_2 emissions (Figure 2). The PBP is low for all scenario of Utrecht in 2017 (Figure 3), increasing from 1,4 to 2,8 with an higher installed HT-ATES capacity. In Den Haag, the PBP is relatively low in 2017 increasing from 3,8 to 4,5 with different HT-ATES capacity.

In the Utrecht 2030 scenarios, geothermal heat source and biomass-fired boiler are added to the system. The stored heat from the biomass plant replaces natural gas based heat. The natural gas usage decreases in the HT-ATES scenarios and consequently also the CO_2 emissions. As biomass is a fuel with a high price as well the benefit of substitution is rather small, the PBP ranges from 10,4 to 16 years.

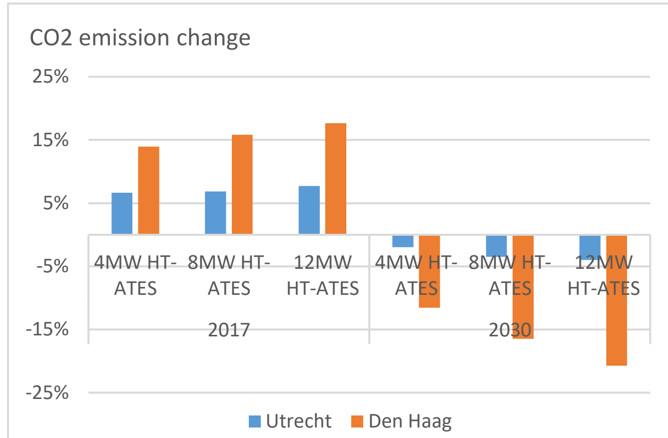

Fig 2. CO_2 emission changes comparing to the sceanrios without HT-ATES

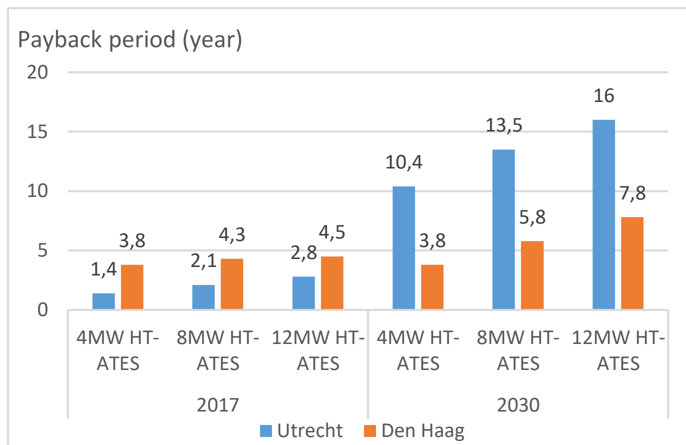

Fig 3. Payback period in each sceanrio

In the Den Haag 2030 scenarios waste heat and geothermal heat are added as heat sources. CO_2 emission reductions are achieved because the usage of low-carbon sources is optimized. Both reductions increase when more storage capacity is installed. Though, the investment costs of HT-ATES increase as well. The PBP of HT-ATES increases from 3,9 years in the 4MW storage scenario to 7,3 in the 12MW scenario.

The results of the sensitivity analysis are shown in Figure 4 and 5. It can be seen that the biomass and natural gas price have the large influence on the PBP in both Utrecht and Den Haag.

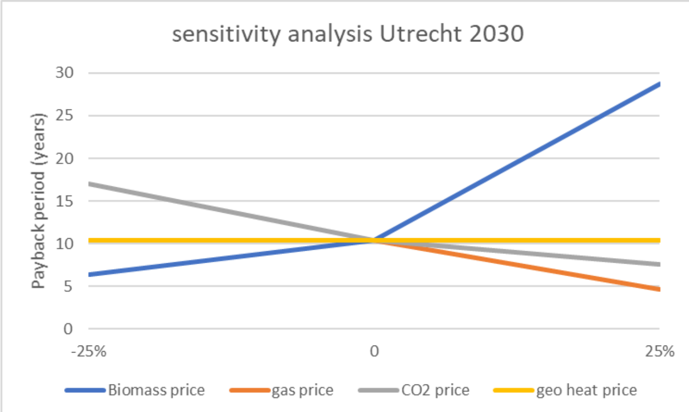

Fig. 4 sensitivity analysis Utrecht 2030 4MW storage scenario

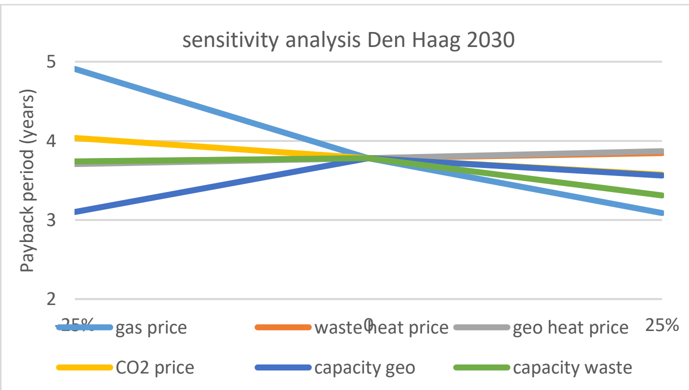

Fig. 5 sensitivity analysis Den Haag 4MW storage scenario

4. Conclusion

In order to assess the potential of high temperature aquifer thermal energy storage (HT-ATES) to enhance the techno-economic performance of DH systems in the Netherlands, two case studies have been carried out with help from modelling tool EnergyPRO. By using the hourly heat demand data from the DH systems in both Utrecht and Den Haag and characteristics of different heat sources, multiple scenarios have been developed for the year 2017 and 2030.

Results show that HT-ATES can improve a DH system's techno-economic performance by lowering the overall production costs of heat and reducing the CO2 emissions involved in the production. Furthermore, this research underlines the importance of local conditions in heat-related projects. First of all, the applicability of HT-ATES depends on the suitability of the underground, which could be different for any location. For both Den Haag and Utrecht an aquifer has been identified which allows a decent water flow. Secondly, the local availability of heat sources with low operational costs is crucial for making a business case for HT-ATES.

In the 2017 scenarios for the DH systems of both Utrecht and Den Haag, application of HT-ATES positively influences the economic performance of CHP plants when electricity prices vary over time, as the plant could anticipate on high electricity prices, resulting in a relatively low payback period. Though, HT-ATES did not function as seasonal storages in these cases. In the 2030 scenarios of Utrecht and Den Haag the heat sources in the DH systems became more diverse and sustainable. It has been found that HT-ATES has the largest potential in situations where low-OPEX heat sources have an overcapacity during summer and this heat could substitute more expensive heat from a different source at a later time. In the two case studies this condition mostly applies to the future scenario of Den Haag. In Utrecht the capacity of the geothermal source is already fully used and it appeared to not be financially attractive to store heat from the biomass boilers, resulting in a relatively high payback period.

The results of the sensitivity analysis show that the prices of natural gas and biomass have the highest influence on the PBP of HT-ATES, as the operational costs of heat mostly depends on the fuel price.

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