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Combining climatic and geo-hydrological preconditions as a method to determine world potential for aquifer thermal energy storage

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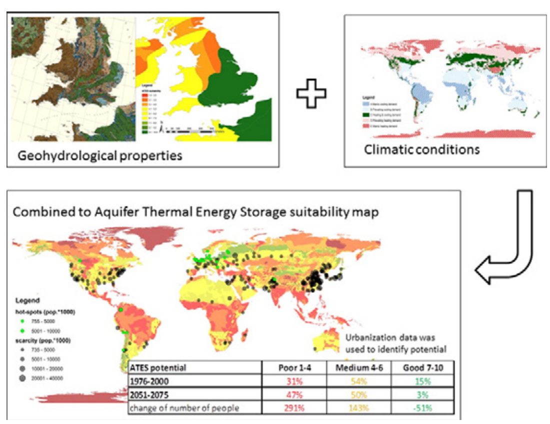
HIGHLIGHTS

- Geo-hydrological and climatic properties are converted to ATES suitability.
- The regions are determined where the potential for ATES is favorable.
- Hot-spots of high ATES potential were identified by including urbanization.
- Shown is where demand for ATES is likely to exceed available space in the subsurface.

GRAPHICAL ABSTRACT



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ABSTRACT

A heat pump combined with Aquifer Thermal Energy Storage (ATES) is proven technology to economically and sustainably provide space heating and cooling. The two most important preconditions for the applicability of ATES are favorable climatic conditions and the availability of a suitable aquifer. This paper shows how these two preconditions can be combined to identify where in the world ATES potential is present, or will become present as a consequence of climate change. Countries and regions are identified where regulation and stimulation measures may increase application of ATES technologies and thus help reduce CO_2-emissions.
Two types of data determine ATES suitability, and their combination with a 3rd identifies potential hot-spots in the world: 1) geo-hydrological conditions, 2) current and projected climate classification and 3) urbanization. Our method combines the data into an ATES-suitability score as explained in this paper. On the one hand the results confirm the suitability for ATES where it is already applied and on the other they identify places where the technology is or will become suitable. About 15% of urban population lived in areas with high potential for ATES at the start of the 21st century, but this figure will decrease to about 5% during the 21st century as a consequence

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of expected climate change. Around 50% of urban population currently lives in areas of medium ATES suitability, a percentage that will remain constant. Demand for ATES is likely to exceed available subsurface space in a significant part of the urban areas.

1. Introduction

1.1. Principle and development of ATES Technology

Buildings in moderate climates generally have a heat surplus in summer and a heat shortage in winter. Where aquifers of sufficient capacity exist, this temporal discrepancy can be overcome by seasonal storage in and extraction of thermal energy from the subsurface. An Aquifer Thermal Energy Storage (ATES) system generally consists of one or more pairs of tube wells, so called doublets that extract and simultaneously infiltrate groundwater to store and extract thermal energy in aquifers by changing the groundwater temperature by means of a heat exchanger (Fig. 1).

ATES is applied worldwide (Blum et al., 2010; Eugster and Sanner, 2007; Fry, 2009; Verbong et al., 2001; Yang et al., 2010); overviews of application of ATES show growth, and in some countries even exponential growth (Bertani, 2005; Bonte, 2013; Lund et al., 2004, 2011; Lund and Freeston, 2001; Sommer, 2015). Adoption is mainly driven by energy saving targets, set by international and national energy saving agreements (EU-Parliament, 2010; SER, 2013). In most countries, however, adoption of ATES technology is limited because of competition by fossil fuels combined with economic recession, preventing people to invest in ATES (Hoekstra et al., in press). Lack of knowledge regarding potential and (future) applicability of ATES is one of the main other important barriers for its application in several European countries (Hoekstra et al., in press; Geo.Power, 2012; Ground-reach, 2007).

Legislation for shallow geothermal energy storage systems, including, ATES and Borehole Thermal Energy Storage[1], varies between countries (Aebischer et al., 2007; Bloemendal et al., 2014; Hoekstra et al., in press; Geo.Power, 2012; Ground-reach, 2007; Haehnlein et al., 2010). Specific legislation was developed in countries where ATES is applied or it was altered to properly govern and/or stimulate the technology. Dedicated legislation is either lacking or poorly substantiated in countries with little application of ATES (Haehnlein et al., 2010), even though it's technical potential may be or will become high. This might result in suboptimal and unsustainable use of the subsurface for ATES or even prohibit application of the technology (Bloemendal et al., 2014). Therefore, it is important for governments to prepare for the potential growth of ATES systems and adapt legislation and groundwater-management practice if needed. A key aspect to such preparation is identification of areas that indicate the suitability for ATES and show potential hot-spots for ATES systems.

Based on developments discussed above and socio-economic developments such as economic growth, sustainable energy targets and high energy prices, it is expected that in the future more buildings can and will rely on ATES in the future for their space heating and cooling, but only when local conditions are suitable and are known to be so.

1.2. Problem statement

Lack of insight in potential, poorly substantiated legislation and/or socio-economic factors are among the main reasons why ATES is not adopted in many countries (Hoekstra et al., in press). These barriers have to be razed to allow ATES to contribute significantly to CO_2-emission reduction. A worldwide overview showing where ATES technology is likely to be, or becomes successfully applicable, may foster the technology. Such an overview would help governments to substantiate their regulation and to stimulate ATES application to meet their energy saving goals.

1.3. Method

Climatic conditions and the availability of a suitable aquifer are the two most important conditions for the applicability of ATES. Geo-referenced climate and geo-hydrological conditions are combined to identify areas with suitability for ATES. ATES suitability maps are combined with projections of population in urban areas[2] to identify ATES hot-spots. Different sources of geographically referenced properties and conditions are combined and evaluated to identify the suitability for any building in a specific area. This method is similar with multi criteria decision analysis (MCDA) as it is often applied in spatial planning (Malczewski, 1999, 2006), however, in our case the evaluation purpose is not decision making. Methods used for MCDA available in literature are, therefore, only partly applicable. Nevertheless, we apply 5 of the 8 steps[3] that were introduced by Ferretti (Ferretti, 2011).

I) Data acquisition. We selected four sources of data that we combined into a world map of ATES suitability: 1) occurrence and properties of aquifers and groundwater (BGR and UNESCO, 2008; Richts et al., 2011), 2) climate classification (Kottek et al., 2006) and 3) urbanization data (Ahlenius, 2014; United Nations, 2008).
II) Problem structuring. The available datasets were not composed with the purpose to identify ATES suitability, their characteristics had to be converted to ATES suitability. The attributes of the data sets were evaluated and their mutual suitability was determined based on the requirements for ATES systems. In Section 2 this done for the geo-hydrological conditions and in Section 3 for the climatic conditions.
III) Comparison. This step consists in the identification of the ATES suitability for each geo-referenced unit relative to others. Each database entry is given an ATES suitability score relative to the other entries of that same property, based on the mutual suitability which was defined in step II.
IV) Standardization & Validation. The obtained relative suitability scores are standardized to a uniform scale to enable combining and comparing different intermediate maps. In the standardization step we introduced an extra step, namely the validation of the suitability score. We do so by applying scale factors, that can be altered to obtain the required result (detailed explanation in Section 2). Because a frame of reference or assessment

[1] Borehole thermal energy systems (BTES) also exists. These systems do not use the groundwater as transport medium, the thermal energy transfer only goes through conduction with a closed pipe in the subsurface. For these type of systems the subsurface conditions are less crucial.

[2] ATES works at low temperature thermal energy, to prevent losses this energy can only be transported over small distances. Therefor ATES is only applied where the building is close by resulting in the fact that demand for heating and cooling with ATES is typically present in urban areas.

[3] Due to the differences in nature and spatial reference of the available data, the super matrices formation was not applicable in this study. The results aggregation is in this study more or less the same step as the standardization and is therefore incorporated in that step. Ferretti questions the applicability of a sensitivity analysis herself. Applying a sensitivity analysis is not common in the field of MCDA because it is complex in a spatial multi criteria evaluation (Ferretti, 2011). In this research the data used for the analysis consist of three different datasets with different composition and/or properties, making it even more laborious.