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Use rights markets for shallow geothermal energy management

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HIGHLIGHTS

- A trading methodology is presented to manage low temperature geothermal energy.
- A GIS toolset, MetroGeoTher, is developed to implement the proposed energy market.
- Groundwater behavior and underground thermal properties are considered at local scale.
- The size and shape of available plot are taken into account.
- Thermal impacts of exploitations are geographically registered to allocate them.

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ABSTRACT

Due to the growth in demand for shallow geothermal energy, the development of an integrated management system to organize the exploitation of this resource is mandatory to protect both groundwater and the users' rights. This paper proposes a methodology to establish a market of shallow geothermal energy use rights which will represent an advance in the management of this resource. The new concept developed to define the basic unit of management is the thermal plot. It is related to the shallow geothermal potential of a registered plot of land. This methodology is based on a GIS framework (ArcGIS, ESRI) and is composed of a geospatial database (Personal Geodatabase, ESRI) to store the main information required to manage the SGE systems, such as groundwater velocity, thermal conductivity or thermal heat capacity, and a set of GIS tools used to define, implement and control this use rights market. The exchanged heat rate and thermal disturbance are calculated on the basis of analytical solutions of heat transport equation in porous media. Thermal impacts derived from the exploitation of this resource can also be registered geographically, by taking into account the groundwater flow direction and adjusting the thermal impact to the available plot. A synthetic application of this methodology is presented for the Metropolitan Area of Barcelona, Spain.

1. Introduction

In the current scenario of global climate change, sustainably meeting energy needs is a worldwide goal. Several studies have been carried out to demonstrate the viability of substituting fossils fuels when producing power and heat [1–3]. For this reason, renewable energies are being promoted by public and private entities.

Recently, shallow geothermal energy[1] (SGE) has been shown as a feasible option to supply the energy demand for heating and cooling, especially in combination with other energy sources, according to Ozgener [4], Rosiek and Batlles [5], Pärisch et al. [6], Ozgener and Ozgener [7] and Buonomano et al. [8]. SGE has increased in recent years because of its advantages over other renewable energies, such as having a lower environmental impact, being unaffected by weather conditions, decentralized and localized production and economic feasibility [9]. As documented in Lund et al. [10,11], the European Union forecast estimated that shallow geothermal energy would be the energy resource with the most growth from 2009 to 2020 [12].

This continuous growth in the number of SGE installations is leading to conflicts between users due to thermal influences between shallow geothermal exploitations; a problem which has already occurred in cities like Berlin [13], Basel [14] or Zaragoza [15] among others. Urich et al. [16] analyzed the impact of housing

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[1] The shallow geothermal energy (SGE) is the energy stored in the ground in the first 400 m depth available to exchange with an external body, also known as low temperature geothermal energy or low enthalpy geothermal energy.

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Nomenclature

[SGP]	shallow geothermal potential per length of the heat source ($W\,m^{-1}$)
t	time (s)
ΔT	maximum increment of temperature as a threshold (K)
$[v_D]$	velocity of groundwater ($m\,s^{-1}$), known as Darcy velocity
x, y	Cartesian coordinates (m)
[...]	square brackets indicate the spatial nature of the variable (i.e., raster data)

Greek symbols

$[\alpha_{x,y}]$	thermal dispersivity in the longitudinal/transverse direction (m)
$[\lambda_0]$	thermal conductivity of the porous medium ($W\,m^{-1}\,K^{-1}$)
$[\lambda_{x,y}]$	effective thermal conductivity in the longitudinal/transverse direction ($W\,m^{-1}\,K^{-1}$). It can be obtained as: $[\lambda_{x,y}] = [\lambda_0] + [\alpha_{x,y}] \cdot \rho_w c_w \cdot [v_D]$
$[\rho c]$	volumetric heat capacity of the porous medium ($J\,m^{-3}\,K^{-1}$)
$\rho_w c_w$	volumetric heat capacity of water ($J\,m^{-3}\,K^{-1}$), default value: $4.18 \cdot 10^6\,J\,m^{-3}\,K^{-1}$
[...]	square brackets indicate the spatial nature of the variable (i.e., raster data)

patterns on the utilization of shallow geothermal energy for open loop systems by considering the thermal and hydraulic influence distance of each installation. They estimated that this thermal interference can reduce the supply to meet only 10–70% of the demand, according to different scenarios proposed.

Given this situation, it is essential to establish a management system to control the exploitation of this resource in the most efficient manner [17]. Nevertheless, there is a scarcity of SGE management methodologies owing to several factors. Unlike solar or wind energies, that can be easily regulated by administration entities because their benefits and impacts are easily measurable and controlled [18], SGE is difficult to manage because this resource and its impacts are neither visible nor accessible for quantification. Moreover, there exists a great variety of control parameters and thresholds in regulations and legislation which are not scientifically grounded [19]. It is common practice for international legislation to define different parameters to protect this resource, such as the minimum distance from the exploitation point to the next exploitation or the maximum temperature difference for heating and cooling. Most of the time, the given values are merely recommended and constant, which are supposed to apply over a vast territory.

There have been few efforts to define an integrated methodology which overcomes this situation. The first attempt to manage this resource geographically was developed in Stockholm in 2010 through a website where users can apply for a domestic drilling permit for vertical single borehole closed loop systems [20]. When applying, the user can visualize the protected circular areas for existing exploitations on a map, according to an influence radius defined in legislation. Despite this progress, this method does not consider the thermal properties of the geological and hydrogeological media.

Other geographical applications based on Geographical Information System (GIS) have been developed for quantification of SGE at a regional scale. Several authors [21–25] have approached this initial step in SGE management by basing it on map algebra.[2] These methods have progressively incorporated different aspects and properties of geological and hydrogeological media to get more accurate results when estimating SGP. However, none of these GIS methodologies supports an efficient distribution of SGE because they do not take into account local characteristics relating to (1) the behavior of groundwater in the study area; (2) the shape of the plot where energy could be dissipated or extracted from; or (3) existing BHEs and their thermal affections.

To take into account the thermal behavior of the underground media as well as local characteristics, current management methodologies draw upon the numerical modeling, incurring high time and resources costs [22,23,26,27]. The implementation of such numerical models is complicated and requires defining boundary conditions and vertical heat fluxes, which are usually unknown. These disadvantages limit the systematic application of this methodology for use in small exploitations or in poorly defined thermo-hydrogeological conceptual models. As Hähnlein et al. [17] remark in the legal framework they suggest, numerical simulations are required only in complex exploitation systems where thermal influence is expected.

All of these circumstances make it difficult to establish a widespread methodology of management which fits all regulations and legislation, and complicate the definition of a common framework to efficiently manage SGE resources. As a result, so as to avoid being faced with the choice between empirical or weakly justified criteria and advanced numerical modeling techniques, regulations for geothermal energy use in most urban areas are limited to the rule "first come, first served" [14].

To solve this situation, we present a methodology based on the application of use rights markets for geothermal energy, taking the water markets as a reference [28,29]. The resource could thus be managed efficiently by allocating and sharing the shallow geothermal potential (SGP) between neighboring plots, avoiding thermal affections between users. The main objectives of SGE use rights markets would be to: (1) maximize the SGP extracted and, at the same time, (2) minimize the thermal affection between BHE.

To support the implementation and management of a market of SGE use rights, a GIS-based platform, named MetroGeoTher, was developed. This platform supports the decision-making process on the basis of technical criteria based on analytical solutions of the energy transport equation in porous media. MetroGeoTher platform goes one step further in the management of SGE by taking into account geological and hydrogeological properties as well as local characteristics. The proposed methodology would allow for the implementation of a SGE use rights market by providing for (1) the quantification of SGP that can be extracted from a particular plot based on its shape and groundwater direction, and (2) the adequate allocation of new BHEs and their thermal perturbations inside the available plot for each user.

This paper is organized as follows: a description of the proposed market of SGE use rights is presented in Section 2; Section 3 presents the design and functionalities of MetroGeoTher platform;

[2] Map algebra is a GIS technique to work with geographical information at regional scale. It performs algebraic operations with raster data, so input and output variables are discretized in cells.