Renewable Energy 36 (2011) 2474–2483

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

GIS-based energy-economic model of low temperature geothermal resources: A case study in the Italian Marche region

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ARTICLE INFO

Article history:
Received 12 September 2010
Accepted 19 February 2011
Available online 23 March 2011

Keywords:
Low temperature geothermal energy
Decision support system
Geographic information system
Economic indicator

ABSTRACT

This paper presents a computational procedure designed to derive a regional model of the low temperature geothermal potential and its economic exploitability. The model was applied to the Italian Marche region and developed with the support of a Geographic Information System (GIS), which highlights the spatial dependencies in the distribution of geothermic resources. The Low Temperature Geothermal Energy has already gained attention as a renewable energy resource for domestic heating and represents a growing opportunity for investment. Although it is common practice to conduct an accurate evaluation of the geothermal potential and its exploitability on a site during the construction of a single installation, there is not an established practice or guidelines for estimating this resource over large territories. This information could support an institution's ability to conduct regional energy planning and guide private entrepreneurship to meet new economic opportunities. To address these issues, the main contribution of this work is a model that reduces the distance between the physical knowledge of the territory/environment and economic analysis. The model is based on a useful assessment of low temperature geothermal potential obtained from physical parameters on a regional scale, from which a set of economic indicators are calculated to evaluate the actual economic accessibility to the geothermal energy resource.

1. Introduction

1.1. Benefits and costs of exploiting low temperature geothermal energy

Low Temperature Geothermal Energy (LTGE), the energy accumulated in the ground from heat exchange with the atmosphere at low temperature, is an alternative energy source capable of satisfying the energy demand for domestic heating and cooling. In Italy, where over 20% of total energy consumption is due to domestic heating, the use of this renewable energy is being considered to improve the energy performance of buildings. The importance of LTGE is due to the advantages it has over other renewable energies: it allows for the highest savings relative to costs in comparison to conventional energy sources; it is available everywhere at any time; and its exploitation has the lowest environment impact. The advantages of LTGE are due to the manner in which this energy accumulates and regenerates naturally in the ground. The soil has a high thermal inertia, and, at moderate depths, the temperature is not subjected to daily and seasonal temperature fluctuations in the atmosphere and remains constant throughout the year to approximately a few tenths of degree. The basic idea of the exploitation of LTGE is that the heat of soil can be extracted by using heat pumps, taking advantage of temperature differences with the domestic environment.

Although the accumulation of heat in the soil occurs naturally, the crucial consideration is how much of this potential can be practically and economically exploited for heating. In [1], the authors provided a survey of the principal types of installation. A widely used configuration for a geothermal installation consists of one or more vertical wells. In each well, a *Borehole Heat Exchanger* (*BHE*) is installed, which is a U or coaxial heat exchanger circuit that collects energy from the ground. A BHE generally reaches a depth between 80 and 130 m. The main cost driver is the excavation of the vertical borehole, which is proportional to its depth and depends on the thermal efficiency of rocks and the energy demand. The thermal quality of the ground may cause variation of costs up to 50%. The initial investment (t_0) represents the highest part of the costs of an installation, and it is the prime factor influencing project feasibility. The installation of a BHE tends to be a capital-intensive investment, typified by large upfront costs with revenues distributed over a period up to 30 years, which is the average lifetime of an

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doi:10.1016/j.renene.2011.02.014

installation, and requires a careful analysis of convenience. The next section outlines the usefulness for investors and local administrations of a regional study of LTGE, and a practical and innovative model for economic evaluation of this resource is presented in the following sections.

1.2. The need for regional assessments of resources

In Europe, economic analysis of LTGE has been conducted mainly at the national scale and produced statistics that refer indistinctly to entire nations. These include national counting of new installations, nationwide market projections, measurement of geothermal energy produced yearly and its weight in the national energy balance. The statistics reveal that the exploitation of LTGE has reached different levels of progress on the European continent. Currently, Germany is the leading country in developing geothermal heat pumps. In this country, the number of pumps increased 100% in 2006, and since then the number of installations has increased at an average rate of 20% per year, corresponding to approximately 30,000 new units, as reported by [2]. In the same study, it was estimated that LTGE could meet 40% of the energy needs of Germany. Switzerland, with an annual increase of 10% in installations, is in a phase of rapid expansion. In Sweden, LTGE exploitation started to spread decades ago: today, 95% of new houses are built with geothermal installations. In Italy, there is a high market potential [3]. In 2006, the production of LTGE for heating was 640 MW (thermal), and it is expected to grow to 6000 MW by 2020, which is an increase of 17% in the number of pumps. This increase in production roughly corresponds to the needs of about 200,000 houses of 100 m^2 of Climate-House Class "E" [4], with a yearly average consumption of 120 kWh/m^2.

A decisive impulse for the exploitation of LTGE was the European Directives aimed at reducing greenhouse effects, encouraging sustainable development and providing new impulse to the economy. The *EU Emission Trading System* (ETS), which began in 2000, established an EU-wide cap-and-trade scheme for emissions of greenhouse gases. The scheme imposes mandatory maximum allowances for CO_2 emissions from industries. Participants to ETS are encouraged to trade allowances in the form of Renewable Energy Certificates (RECs) to match their actual level of emissions. Within the same frame of directives, local administrations are in charge of making local energy plans and promoting the investment into renewable energies. A regional community can profit from this financial system because a region with no conventional energy resources in its territory could balance its energetic budget with the sale of RECs [2]. The financial benefit is demonstrated by the flourishing of Energy Service Companies (ESCO). These companies assume the risk of the initiative to improve energy efficiency in the buildings of clients, and they share the economic benefits. Although the statistics and the ongoing initiatives for LTGE show a convenient investment scenario, a confident investment and incentives decision activity requires the support of LTGE models at the regional scale, because that is where local administration and investors operate. Typical decision parameters at the regional scale are as follows:

- the total upfront capital to be invested in the BHE installation to satisfy the energy demand for domestic heat of the whole region;
- the overall savings over conventional energy purchases;
- the entire income represented by the RECs;
- the value represented by improvement of energy performance of buildings throughout the region.

Additional decisional parameters for investors are the following:

- the differences in attractiveness of the investment from one site to another;
- the changing in cost over time due to the foreseeable improvements of technology efficiency.

Considering these issues, it has been built an energy-economic model of the LTGE that includes indicators useful for energy planning and decision making at the regional scale. In the next section, it is summarized the state of the art tools and modelling methods for the low-enthalpy geothermal potential. Section 3 describes the construction of a novel model of LTGE for a region and its two components, the physical and economic, which support decision making.

2. Regional energy planning: the background picture

2.1. GIS-based decision support

There are several software platforms that support the design of BHE installation, but there is no specific software for assessing LTGE potential over a region. For this purpose, a highly versatile IT technology known as *Geographic Information System* (GIS) can be used. The GIS stores data in special structures called layers, with each representing the georeferenced measures of a geographical variable. During the past several decades, the GIS has assumed growing importance as a decision support tool for defining regulations for governance of the territory, and it has been used to evaluate the potential of renewable resources, as surveyed by [5]. A *Geospatial Decision Support System (GDSS)* is a GIS implementing a *structured decision procedure*, which is a robust logic-mathematic model designed to resolve a given type of territorial problem and is aimed to simulate human decision making for a given set of territorial variables. The GDSS supports the main stages of decision, which are the following:

1. selection of the geospatial variables that have more influence on the decision;
2. application of the structured decision procedure;
3. presentation of results.

Decision support is said to be *active* or *passive* depending on whether the GDSS provides a direct solution to the decisional problem or a simple decision aid tool, such as a thematic map. A GDSS was designed by [6] to decide what type of heat exchanger was most suitable for each site in Japan based on ground quality and the characteristics of the heat exchangers. In [7], a GIS was used to quantify the LTGE in a small region (a few tens of square kilometres) in Germany, where the decision variable was the thermal power extracted with a BHE calculated based on the thermal properties of the soil within a given depth from the surface. In [8], the *regional energy planning* was studied as a constrained optimisation problem whose objective was the minimisation of the total annual cost of energy and dependence on non-local resources, and the maximisation of the overall system efficiency over the region. Within the framework of EU projects, GDSS have been used in energy planning for a decade, as surveyed by [9].

2.2. Estimation of geothermal potential

The theoretical basis for every physical model of heat flow is represented by *Fourier's law,* which expresses the relationship between the heat flow through a solid body, its thermal conductivity and the temperature gradient. In the ground, the heat transfer takes place by conduction in the solid rock and, at a different rate, through the groundwater that saturates the rock pores. For