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Shallow geothermal energy under the microscope: Social, economic, and institutional aspects

Konstantinos P. Tsagarakis

Business and Environmental Technology Economics Lab, Department of Environmental Engineering, Democritus University of Thrace, 67100, Xanthi, Greece

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ABSTRACT

The design and operation of Shallow Geothermal Energy (SGE) systems have been continuously increasing in scientific research over the past years. What hinders the wide penetration of SGE systems in most countries are issues mostly related to high installation costs, administration, stakeholders' awareness, and marketing. On top of this, SGE systems lack an in-depth economic evaluation, which is often limited to the financial inputs, and thus omitting the non-market monetized environmental benefits. This paper consists of a primer for conceptually improving understanding in regions with low levels of SGE penetration. It provides guidance to project evaluation and discusses the social and institutional strategies to assist SGE systems penetration.

1. Introduction

Shallow Geothermal Energy (SGE) systems have been technically improved with several applications [1] and advances in design [2] and control [3]. However, there are still many aspects to be taken into account in scientific research, due to the numerous parameters involved for their application. Compared to the other Renewable Energy Sources (RES), SGE employs more uncertainties regarding the high impact of the local and site conditions. Parameters like geology [4,5], soil properties [6], hydrogeological properties [7], climate [5,8,9], and weather [10] are amongst the most studied ones. Energy output differs in favour of regions with higher needs for heating and cooling compared to the ambient temperatures. The energy output, however, may vary within same regions and countries, according to the microclimate and other conditions of the respective locations.

In principle, the term 'financial analysis' would reflect estimations that do not include environmental and social non-market costs and benefits. New approaches involve the inclusion of external costs and benefits due to CO_2 emissions reduction, compared to other renewable or conventional systems of energy production [11,12]. No matter the technical inputs regarding the evaluation of an SGE system, the suitability depends on classic investment criteria, such as net present value [13,14], internal rate of return [13–15], or payback period [13–17]. Economic analysis for individuals is typically limited to financial inputs [18], while, most of the times, the analysis fails to include environmental and economic externalities. Economic analysis that will also include opportunity costs will lead to different end-values regarding project evaluation indicators [19].

Noorollahi et al. [8] undertake an analysis based on the total annual economic cost to prioritize regions for installing Ground Source Heat Pumps (GSHP). An objective criterion for comparison is that of the levelized cost of energy [14,20–23], which is measured in 'cost value per KWh', comparable with energy produced from fossil fuels or other RES [24]. The Levelized cost of energy is more useful for comparison among other production alternatives, resulting in a monetary criterion [25], but all standard financial project indicators can be used for additional inputs in the feasibility stage [26]. Deliverable 2.2 of the 'REGEOCITIES' EU funded project [27], concludes on barriers for the penetration of SGE, which can be summarized in lack of economic incentives, legal framework [28], organizational support, and stakeholders' information. In a similar concept, barriers of SGE applications have been reported by the US Department of Energy [29], mainly including technological, economic, institutional, and market barriers, as well as lack of awareness and experience. Recent and ongoing projects [30,31] and networks [32] have come to similar conclusions regarding the bottlenecks of SGE intrusion, indicating the need towards the

E-mail address: ktsagar@env.duth.gr.

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implementation of a sustainable institutional framework.

Following this Introduction, three critical groups of factors regarding SGE penetration are reviewed, by shedding light to economic, social, and institutional parameters. Section 2 discusses the economic evaluation of SGE systems, while sections 3 and 4 proceed with analyzing the social and institutional aspects, respectively. Finally, section 5 consists of the overall conclusions and further research suggestions.

2. Economic evaluation

Cost estimations for SGE systems bring additional uncertainties compared to other established renewable energy technologies due to site specific characteristics. This section discusses the parameters and procedures that could suggest that an SGE system could be economically assessed. In the majority of systems, these are small decentralized installations ranging from household to building scale. Any case or site specific characteristic may bear proportionally high construction or operational costs in the implementation stage. Like in all renewable energy systems, reported historical or statistically derived costs of energy are not a panacea, and may result in wrong reference values. It is apparent, however, that renewable energy costs decrease with time due to "technology learning" [33–35], and estimated costs per technology in different markets or technology may be outdated within six months or one to two years (see Ref. [36] p. 26). The case of SGE with exponentially increasing penetration rates can be similar regarding cost outdated data. Therefore, any costs published by national or international agencies should be considered with caution.

The principal advice before proceeding further is that each case is different and should not be generalized. Project evaluation criteria use the same input variables for calculating a critical value for the comparison with competitive projects. According to the nature of the decision maker, different criteria or input values are used. If, for example, a private operator is installing a system for profit, it is very important that the investment is paid back as soon as possible, so that the initial capital can be re-invested. On the other hand, a house owner would be more interested to install an affordable system that would provide the cheapest source of energy for his household needs in the long-run.

Notable interdisciplinary teams have created advanced reference documents for calculating the per unit cost of energy in the lifetime of the project. The International Renewable Energy Agency provides annual reports for the Levelized Cost of Energy (LCOE) comparisons among all well established renewable energy technologies [36]. Rhodes et al. [37] estimate the LCOE for 12 technologies in USA, also including monetary values for environmental externalities. The methodology behind these calculations is detailed in a White Paper by the Energy Institute of the University of Texas at Austin [38], which can give insights for such calculations in other countries. Tsiropoulos et al. [39] provide a review of capital costs for the most established renewable technologies as well. The Sustainable Energy Initiative provides an online tool for calculating the LCOE [40]. Another important online tool by Beckers et al. [41] assists in calculating the LCOE for Enhanced Geothermal Systems based on several technical financial and macroeconomic variables [42]. With the exception of the annex of the IPCC special report on RES [43], in the previously mentioned documents and online tools SGE is not considered as a major renewable energy power source globally. However, methodologies and principles employed to those reports and tools can be of benefit to the economic analysis of SGE systems. Another reason for not having SGE systems reported in renewable energy reports, is their collective inclusion as energy resulting from heat pumps together with aerothermal and hydrothermal systems [44].

As a result, technologies typically employed in buildings and infrastructure, such as ground heat exchangers, groundwater wells, or energy piles, are underestimated in the macroscopic economic and policy analyses so far. This is partially justified by the small global renewable energy share, but their importance at local level signifies the need for better attention. Such need has been addressed by several research projects worldwide, and the establishment of national and international geothermal associations and research networks as well.

Evidently, in recent years we see SGE economic and market issues in Geothermal Thematic publications [24,45–47] as a result of their increasing worldwide penetration [48]. Nevertheless, cost estimations and economic analysis can be characterised by the lack of systematically recording data due to the recent (and ongoing) development of the sector and the diversity due to the site specific costs.

A simple criterion to communicate energy producing technologies is the Total Annual Economic Cost (TAEC), which assigns a cost to the unit of energy produced, taking into account the construction cost, the Operation and Maintenance (O&M) cost, the project lifetime, and the opportunity cost of capital [49]. Before further discussion, it should be pointed out that different SGE technologies have pros and cons. The purpose of this work is to give an independent overview, and provide further suggestions for the inclusion of all parameters affecting the cost of each kWh produced.

Open or closed horizontal/vertical loop systems have different land requirements; a factor that is often missing or underestimated in the economic analysis of energy related projects [50,51].

For those SGE systems that require space below surface at the vicinity of the building or structure, this may impose change of land use. Eventually, this change of land use may imply loss of income. The opportunity cost of land should be used to value this loss [52,53]. For example, a horizontal SGE system that prevents the surface above ground and at the periphery of it (pipe safety zone) from being used for agricultural applications (eg. crop trees) bears additional costs to the system. The opportunity cost of land should then be calculated to value the cost of the forgone agricultural income [19,54]. Similar is the case on any other use change [55–58]. The cost of land should be estimated not only for the present but for the whole lifetime of the project (a few decades), which brings additional uncertainties to the estimations [59]. Any space restriction may also alter the value of land in urban areas [60], including necessary space for infrastructure networks [61,62]. It is proposed that typical land requirements (in m^2) per SGE system are reported in renewable energy reports per generation capacity and annual energy output (see examples for other geothermal systems in Ref. [63], p. 420). Since economics of land use planning [64] is an essential parameter in the urbanising environment, any restrictions and changes bring new challenges for urban economists and city planners [65].

Underground properties [66] and drilling costs [67] result into high installation costs of SGE systems [68–70], which may be a serious factor against their selection. Since the scale of such projects is relatively small, up to household/building level, collective actions are necessary. On the other hand, the O&M costs are quite low compared to other RES. In technology evaluation, the O&M cost is often simplified as a fraction of the individual equipment [71] or by referring to as 2.0% of the investment [24], 2.5% [21] or 4% [22] of the total equipment cost.

Vertical loop systems have higher installation costs, compared to horizontal ones, but fit better in residential areas or where land availability is scarce or expensive. The horizontal loop counter parts cost less for installation, but occupy more land. However, the cost of land could be negligible and could be set aside for systems that require limited space. To assign the capital cost in each year of the