Renewable Energy 114 (2017) 805–816

Contents lists available at ScienceDirect

Renewable Energy

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

Impact of technical and economic uncertainties on the economic performance of a deep geothermal heat system

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ARTICLE INFO

Article history:
Received 1 April 2017
Received in revised form
18 July 2017
Accepted 22 July 2017
Available online 24 July 2017

Keywords:
Direct use geothermal
Economic uncertainty
Reservoir uncertainty
Heat
Probability
Techno-economic model

ABSTRACT

This paper presents a techno-economic analysis of a deep, direct use geothermal heat system in a conductive geological setting (Groningen, NE Netherlands). The model integrates the previously discussed uncertainties of the initial reservoir state, geological and operational conditions with the economic uncertainties. These uncertainties are incorporated in the form of probability distributions and 20,000 iterations of the model are performed over a project lifetime of 40 years. A combination of Ex-Ante and Ex-Post criteria are used to evaluate the economic performance of the system based on the Net Present Value (NPV), Levelised Cost of Heat (LCOH) and Expected Monetary Value (EMV). The sensitivity analysis highlights the load factor (effective flowrate) as the most important parameter for the economic performance and energy costs. However, the differences between the NPV and LCOH sensitivities highlight the importance of using both metrics for the economic performance of such systems. The presented project remains economically challenging, exhibiting a 50% probability of marginal revenues over its lifetime. Systematic insights are drawn with regard to potential improvements of technical and economic aspects of such geothermal heat systems.

1. Introduction

District heating and heat energy networks are gaining importance in the provision of renewable energy [1–3]. At the same time market penetration of direct use geothermal energy remains relatively restricted [4] and a large potential for direct use geothermal remains untapped [5].

Geothermal energy is considered as a mainstream technology from a technological paradigm perspective [6]. Implementation of geothermal systems is still expected to accelerate in the near future [7] and possibly saturate by 2030 [6]. The number of direct use installations for geothermal energy and investments in geothermal projects have continuously increased in the 21st century, but the development rates are deemed slow [7].

As the scientific understanding of a diversity of low enthalpy fields and analysis methods are evolving [8–12], the interaction between the technical and the economic aspects becomes more pertinent for successful project implementation and wider dissemination of installed deep geothermal systems for direct use. The importance and impact of technical and economic parameters remains crucial for the realization of planned systems.

Promoting the sustainability agenda within renewable energy projects encourages the efficient use of geothermal resources [13]. Previous research has highlighted points of exergy destruction that are important for optimizing the energetic efficiency of existing systems [14,15]. In order to expand installed geothermal capacity, project level studies are needed to address the complexities and inherent uncertainty of geothermal field development [5,13].

Economic feasibility is identified as the main hindering aspect of direct use geothermal systems, with payback periods extending up to 33 years [16]. Drilling is considered a major cost factor and increasing the success rates would benefit geothermal project developments [16]. Additionally, the economics of geothermal energy production (electricity or heat) are usually addressed in a top down manner [17–19], contrary to the commonly accepted need for project level geotechnical studies. Thus, while the insights from a top down analysis are valuable, they do not clarify the interplay between the geological context, the specific economic conditions of a project and the contextual parameters, such as the regulatory

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http://dx.doi.org/10.1016/j.renene.2017.07.090

framework with its possible incentives and restrictions [3].

Due to the high initial costs and uncertainties related to geothermal development [20], scenario analysis is essential for understanding the economic viability of projects [17,21]. A recent study has analysed the effect of doublet well spacing on the Net Present Value (NPV) of a geothermal doublet in the West Netherlands Basin (WNB) [22]. Moreover, the interference between multiple systems and the related economic impact has also been studied [23]. However, literature on direct use, deep geothermal projects lacks an analysis that incorporates both technical and economic uncertainty to the assessment of energy generation costs. Moreover, there is no clear prioritization between the two in the form of a sensitivity analysis at the project level; no bottom-up cost estimation is presented.

In this paper a techno-economic model is presented based on the Groningen geothermal project (Fig. 1). It builds on previous work regarding initial state, geological and operational uncertainty [24] and incorporates the insights regarding resource efficiency and coupling of a direct use geothermal system to heat networks [25]. In this work economic and project development uncertainties are further included in order to establish a tighter linkage between technical and economic aspects for the Groningen geothermal project.

The analysis employs a novel, bottom-up economic analysis of a direct use geothermal system in a conductive geological setting. The economic feasibility is analysed by means of three economic indexes in tandem, namely the Levelized Cost of Heat (LCOH), Net Present Value (NPV) and Expected Monetary Value (EMV) indexes; it is thus addressing the center of the renewable energy nexus, linking geothermal technology with the policy/incentive framework. Moreover, it includes scenario analysis and project level uncertainties for both the technical, as well as the economic parameters considered. Lastly, it presents a structured, ranked influence of both technical and economic parameters to project economics; it thus generates comprehensive insights regarding the development of direct use, deep geothermal systems in conduction dominated geological settings on a project level.

2. Methods and model description

The results are evaluated using Ex-Ante (beforehand) and Ex-Post (afterwards) criteria. The Ex-Ante criteria (well failure) lead to a project stop. After that point further computations are not carried out. Ex-Post criteria include the LCOH and the project NPV at the end of the project period, as well as the Expected Monetary Value (EMV) of the project.

The model is developed by making use of the Monte Carlo Simulation software GoldSim [26]. Uncertainty regarding any of the technical or financial aspects considered is implemented in the model in the form of probability distributions. This allows for an Ex-

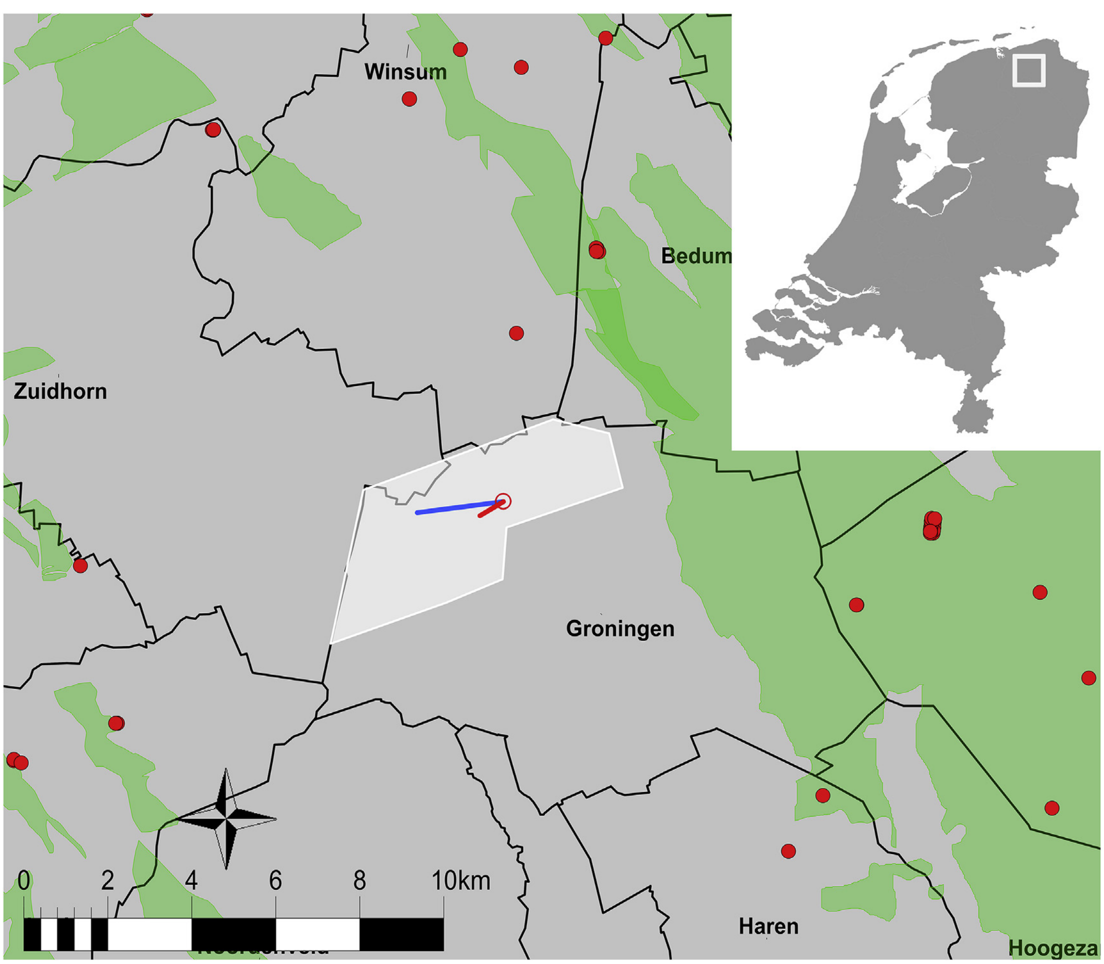

Fig. 1. Location of the Groningen geothermal project. The white shaded area outlines the geothermal concession, the red and blue lines the injector and producer respectively, the green shaded areas are existing gas fields and the red dots represent existing gas wells. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)