ABSTRACT

Context

In order to meet climate goals and provide energy security, geothermal energy can play an important part in Belgium's energy production portfolio. A major part of the final energy demand is heat, and deep geothermal systems provide thermal energy that can be used directly as a heat source for district heating networks and industrial applications.

Working with deep subsurface data introduces large uncertainties, leading to high financial risks. Considering these risks in decision making at project or policy level is essential but not straightforward. Especially linking numerical geothermal reservoir simulations to economic and environmental assessments, while taking into account uncertainties and flexibilities is challenging.

Objectives

The goal of the DESIGNATE project is to create interdisciplinary tools for integrated forecasts under uncertainty for deep geothermal systems in Belgium, including applications in abandoned mines. More specifically, the objectives are to:

- Develop techno-economic assessment (TEA) tools that incorporate geological uncertainty and are based on real options analysis (ROA) and the PSS simulator.
- Develop a framework for dynamic life cycle assessments (LCA) considering timing of emissions and their effects over time.
- Develop analytical or other fast reservoir simulations that can be directly connected or integrated in the TEAs and LCAs.
- Create a first basis for analysing subsurface interference effects of deep geothermal projects.
- Demonstrate the application of the developed tools and workflows to several case studies within Belgium.

Methods

Five case studies are selected: the Balmatt doublet project in Mol developed by Vito, the Turnhout-NW doublet project which is in early development by the GEO@Turnhout consortium, the hypothetical Deep Mons doublet project, a hypothetical single well application in the Cretaceous in the Flemish Region, and a hypothetical heat-cold storage application in the former Péronnes-lez-Binche coal mines. Geological uncertainties are first characterized, and decision trees are built to map flexibility options.

In order to integrate reservoir simulations in Monte Carlo-based economic and environmental analyses, fast simulation time is needed. An analytical solution for a geothermal doublet is developed and calibrated for the Balmatt project. Lookup tables without and with interpolation are developed for the single well and Deep Mons project, respectively. An operational solution for the mines case is not yet finalized.

After a review of available life cycle assessments of deep geothermal projects, a dynamic LCA method is developed, which takes into account changes in the life cycle inventory and the temporal evolution of the impacts. In parallel, Real Options is applied in a techno-economic assessment of deep geothermal to integrate uncertainty and flexibility in economic analyses. In a final step, the environmental impact is integrated as decision criterion in the ROA-TEA.

The PSS simulator, an ROA-based TEA forecasting simulator for CO_2-storage projects, is adapted for geothermal applications. It is made modular for multiple geothermal applications, connecting with the various reservoir simulation tools that are developed. In particular, realistic project decisions and geological uncertainty evolution are integrated. First developments are also made to model subsurface interferences and surface heat transport.

Simulations are run for several scenarios. These include variations in energy price evolution, decision flexibility, support measures and operation variation.

Results and conclusions

Several interdisciplinary tools and workflows are developed for assisting decision makers in planning deep geothermal projects. Their application is demonstrated with first analyses for multiple case studies and scenarios in Belgium.

The consideration of flexibility to counter investment risk with Real Options Analysis is key when analysing economic performance of projects with large up-front investments and uncertainties such as deep geothermal projects. Similarly, dynamic life cycle analysis and its integration in ROA decision making has major benefits over the industry-standard static LCA for accurately assessing environmental impact and providing decision support. Deep geothermal energy can have an important environmental benefit over alternative heating sources (natural gas or heat pumps), with well construction and pumping operation as first targets for further impact reduction. Including risk and flexibility is also important in designing support measures, to target the correct project phase at an appropriate level.

Geological conditions, especially flow-defining parameters, largely dictate project success regarding economic and environmental impact, emphasizing the location-specific nature of the technology. Considering the current state of knowledge on the deep subsurface in Belgium, a government-led general exploration of the deep subsurface could de-risk the investment. Support measures need to be designed for attaining certain policy and business goals. Of the support measures that were analysed, investment subsidy is identified as a good balance between increasing project value, risk reduction and efficiency.

An optimised design and planning of the full geothermal, including supply, transport and use of heat, has a major influence on the business case. Matching production with demand and increasing operational time by overcoming seasonal changes in demand are key.

An integrated, interdisciplinary analysis is essential to consider all the different-natured impacts that define project decisions, development, operation and success. The developed methods can be expanded even further to achieve a fully a holistic overview by introducing for example the social context.

Keywords

Deep geothermal, mine geothermal, techno-economic assessment, life cycle assessment, analytical reservoir simulation, uncertainty, real options analysis