Performance assessment tools for Enhanced Geothermal Systems: Engine and Beyond

With fossil fuel prices skyrocketing, the economics of renewable energy sources have become significantly more attractive. Beyond that, though, some EU countries have established incentive schemes for renewable power. These are being supported by the EU with the aim of achieving renewable power production costing in the range of 8 - 15 eurocents/kWh, and ultimately as low as 5 eurocents/kWh by 2020.

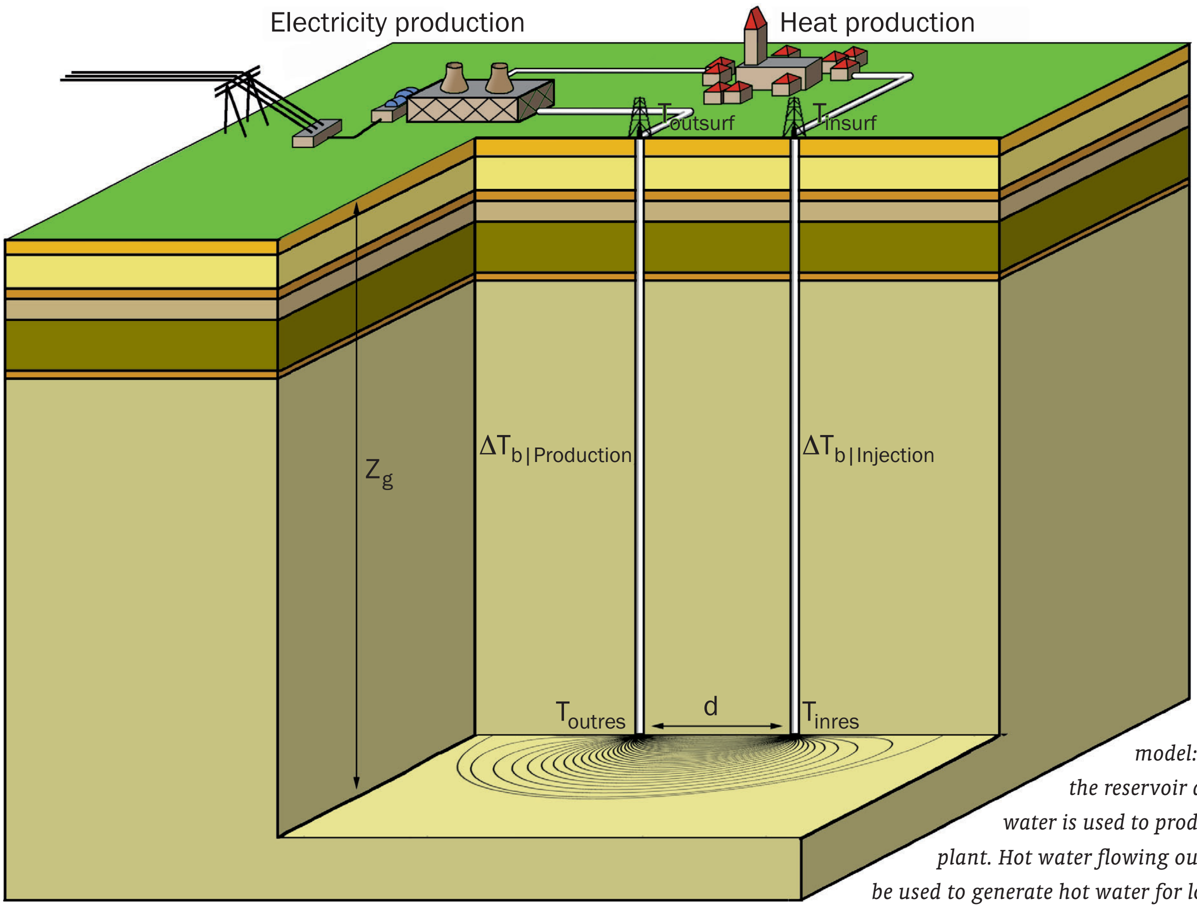

Figure 1. EGS doublet model: water is injected into the reservoir and heated; production water is used to produce electricity in a binary plant. Hot water flowing out of the binary plant may be used to generate hot water for local heat demand.

One of the renewable energy sources of interest is Enhanced Geothermal Systems (EGS). Minimising the risks associated with EGS project development, however, plays a key role in promoting its uptake, because it is a new technology with a steep technological learning curve. The exploration risks can be high, so public perception will need to be won over and legislation developed to promote the technology.

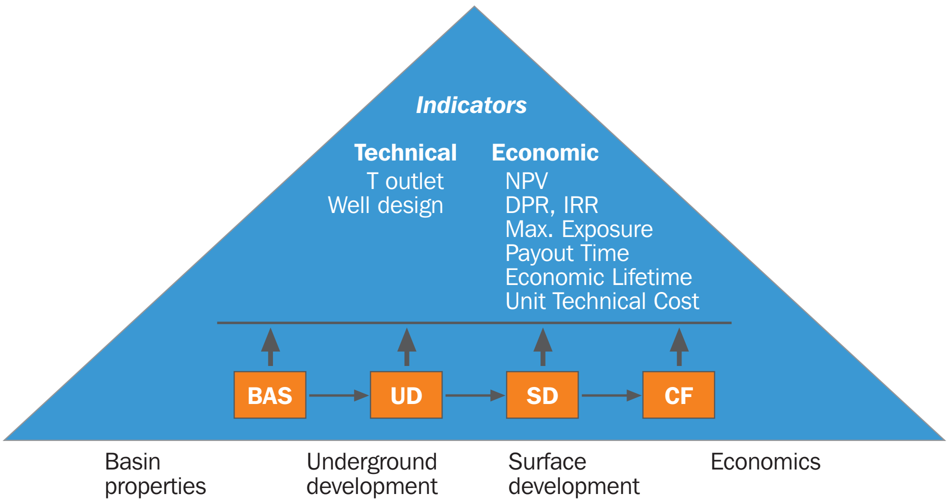

Figure 2. Techno-economic chain of models capable of calculating a range of key technical and economic performance indicators, including NPV. The chain is subdivided into four components: geological basin properties (temperature) (BAS), underground development policy (UDP), surface development policy (SDP) and commercial and cash-flow aspects (CF).

A major challenge in facilitating uptake can be overcome by promoting quantitative understanding of the economic impact of key technical and economic parameters for EGS at different phases in the workflow, from exploration to production. As part of the EU project ENGINE, we developed a simple techno-economic performance tool in Excel (engine.xls) for this. The models have also been implemented in a dedicated decision support system (EGS DSS), using best practices for asset evaluation from the oil and gas industry. This approach allows the modeller to take natural uncertainties into account and use decision trees to evaluate sensitivities and different scenarios. The tool evaluates the performance of geothermal systems by investigating sensitivity to both natural uncertainties beyond anyone's control (e.g., flow characteristics, subsurface temperatures), engineering options (well design and surface facilities options) and economic uncertainties (e.g., price of electricity, tax regimes). It can also forecast the effects of improved exploration tactics and technological performance, as well as government incentives, on the viability of prospects.

The Excel performance assessment tool (ENGINE.xls) and the Engine DSS are public deliverables of the Engine Project.

Performance assessment model

Performance assessment is an important initial step in forecasting the economic performance of a prospect to be developed. The economic performance can be cast in terms of key performance indicators such as Net Present Value (NPV) or Unit Technical Cost (UTC). Figure 1 outlines the EGS model setup: hot water is produced from a number of doublets; the hot water is then converted to electricity in a binary plant.

We used fast analytical models for the performance calculations. The Excel calculation spreadsheet provides basic insight into the way the calculations are performed and allows the user instant access to the sensitivity of his model outcomes to changes in the input parameters. The spreadsheet can be easily modified and extended for project-specific calculation models. With the EGS-DSS, probabilistic calculations can be quickly performed and users can evaluate their decision trees and perform advanced sensitivity analysis.

The fast analytical models are divided into four main groups of parameters: basin properties, underground development, surface development, and commercial and financial aspects. Two of the groups represent 'uncontrollable parameters' (basin properties and commercial and financial aspects), meaning that you have no direct influence over them. The other two (underground development and surface development) are mainly parameters related to the engineering for the project, corresponding to parameters the project developer can largely control.

Two different physical model approaches were used to describe the energy extracted from the reservoir. The first model is based on fluid-flow circulation models developed in the literature (e.g., Pruess and Bodvarsson, 1983; Heidinger et al., 2006) and physically describes the fluid flow through the reservoir using a streamline model for porous aquifers and fractures. The second is based on a recovery factor for the so-called heat in place in the reservoir suggested by ENEL (courtesy of R. Bertani).

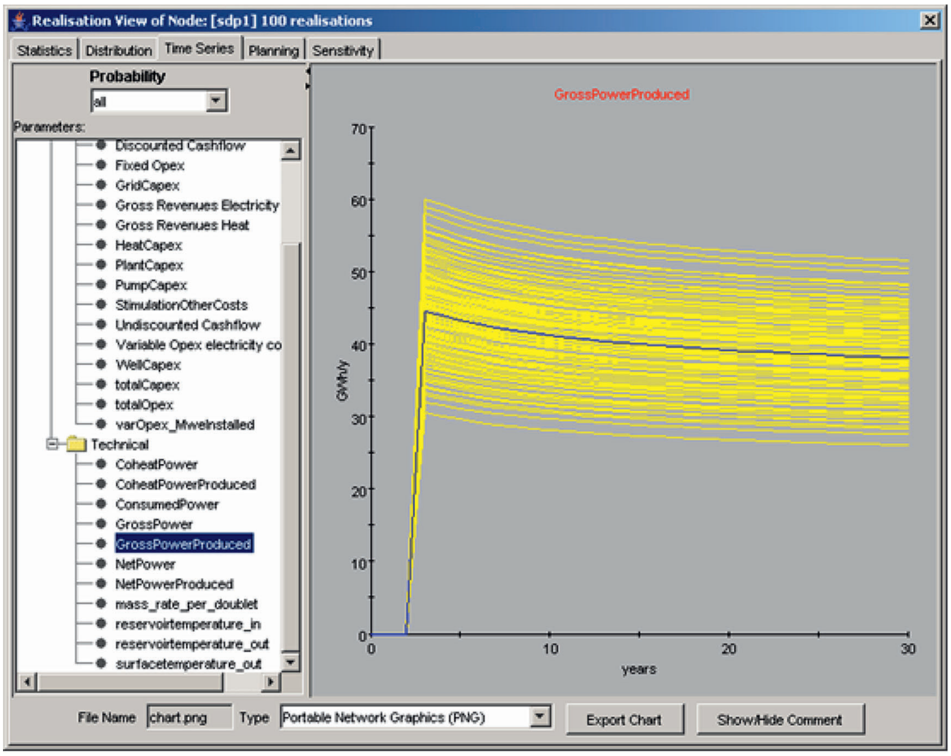

Figure 3. Projected power production given uncertainties in Reservoir Temperature and Fracture Area.

Monte Carlo runs

In addition to generating Excel spreadsheets, the EGS Decision Support System (EGS DSS) can perform probabilistic (Monte Carlo) simulations. The model parameters are subdivided into the same model components as for the Excel spreadsheet. Each of these parameters can be defined as a distribution.

Figures 3 and 4 depict an example of the effect of incorporating uncertainty into reservoir temperature and fracture area for a hot dry rock (HDR) development. The fracture area ranges from 2 - 4 km^2 and the reservoir temperature ranges from 170 - 230° C. The effect on power production and NPV is considerable.

Realisation View of Node: [sdp1] 100 realisations

Statistics | Distribution | Time Series | Planning | Sensitivity

Indicatortype: Economic — Select +Ctrl c/v to copy/paste table

Indicator	p90 value	p50 value	p10 value	mean value	Unit
Cumulative NPV	-12.65	-3.91	5.48	-3.93	mln euro
Cumulative NPV (+dead end)	-12.65	-3.91	5.48	-3.93	mln euro
Internal Rate of Return	0.4	3.6	6.8	3.5	%
Disc. Profit/Invest Ratio	-11.7	-3.5	4.8	-3.7	
Maximum Exposure	-29.21	-29.21	-29.21	-29.21	mln euro
Unit Technical Cost	0.1	0.12	0.15	0.12	EUR/kWh
Pay-out Time	21	31	31	29	year
Economic Lifetime	30	30	30	30	year
Cumulative Capex	31	31	31	31	mln euro
Maximum Exposure	-29.21	-29.21	-29.21	-29.21	mln $
Pay-out Time	21	31	31	29	year

Figure 4. Key performance indicator overview showing that the project's NPV is negative, with a considerable spread in outcomes (p90 and p10 values).

Decision trees

EGS-DSS allows planners to build decision trees in which complete probabilistic calculations can be performed for each branch. Figure 5 presents an example of a decision tree in EGS DSS. In it, the top decision is a choice between two binary plants: a less expensive one, costing €1.5 mil./MWe installed and having a relative efficiency of 0.55, and a more expensive one, costing €2 mil./MWe installed, with an efficiency of 0.60.

The two plants are represented by the 'normal' and 'high' branches in the tree, reaching up to the 'EffPlant' decision node. The square denotes the decision to be made. The reservoir is considered to have great uncertainty in terms of the whether it has one, two or three fractures. The respective probabilities for these are 80%, 10% and 10%. The different possible outcomes for the reservoir are represented by three scenarios in the tree.

The outcome of the project can be enhanced by using an exploration strategy in which we try to prevent the development of N1. Suppose we have an exploration stage that costs €250,000 and allows us to establish the presence of N1. The decision tree representing this staged approach is depicted in Figure 6.

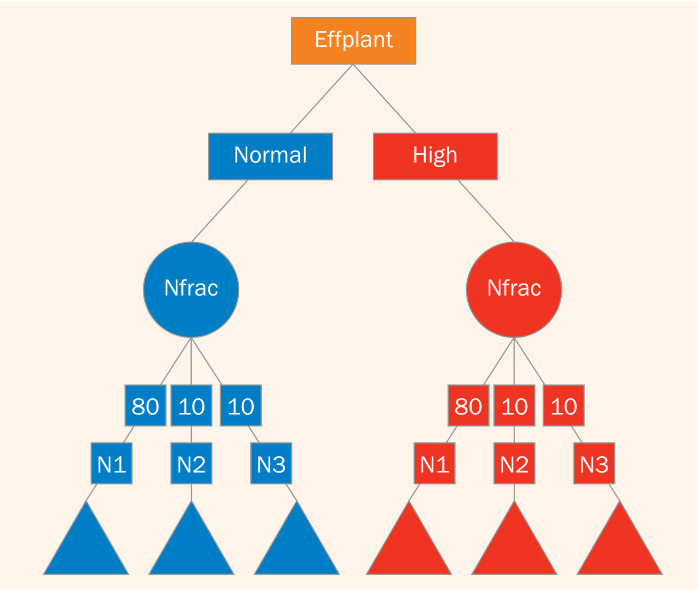

Figure 5. Decision tree for deciding between a normal- or high-efficiency plant, based on three different outcomes for the reservoir performance (N1, N2, N3). The expectation curve of the cumulative NPV for the high-efficiency plant, reflects a mix of results from the N1, N2, N3 reservoir scenarios, resulting in an average NPV, which is negative €3.71 million. The N1 scenario is marked by extremely negative NPV.

References

Pruess, K. and G.S. Bodvarsson (1983), Thermal effects of reinjection in geothermal reservoirs with major vertical fractures, paper presented at Society of Petroleum Engineers 58th Annual Technical Conference and Exhibition, San Francisco, CA, USA, October 5-8, 1983.

Heidinger, P. et al. (2006), HDR economic modelling: HDRec software, Geothermics, 35, 683-710.

Jacob, B. (1972), Dynamics of fluids in Porous Media, 764 pp., Elsevier Publishing company.

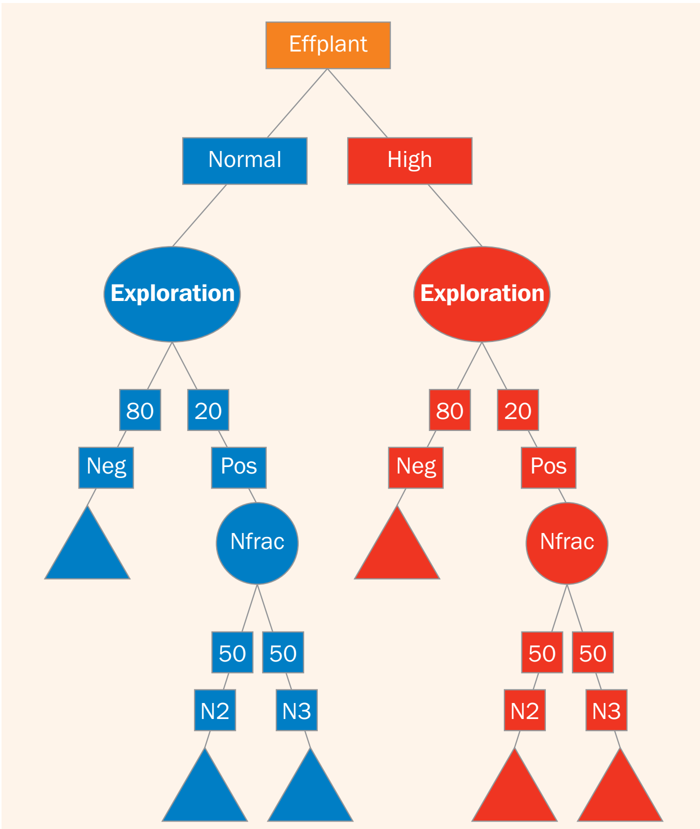

Figure 6. Staged approach incorporating an exploration phase: if the outcome of exploration is negative (N1), the project is aborted, at a cost of €250,000; if it is positive (N2, N3 scenarios), it is continued. The expectation curve of the cumulative NPV reflects a mix of results from the negative exploration phase and the N2 and N3 scenarios. The average NPV is €0.21 million.

Information

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