What target to drill? Geothermal Pre-Drill Play Evaluation (PDPE): Understanding the nexus between project risk and value

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Geothermal exploration and development in Australia is rapidly evolving and many companies will soon be at a critical juncture of deciding which targets to drill and likely well locations. Although the global petroleum sector has evolved a detailed system of prospect evaluation and risking, the same level of discipline has not yet been formalised in the geothermal sector, where play evaluation decisions are largely focused on cost, rather than value and risk.

Geothermal systems in Australia can be characterised by four aspects of geological risk (P_g) - heat flow, thermal resistance, reservoir and water. These risks can be condensed, on further modelling, to temperature risk (P_t) and flow rate risk (P_w). When combined with perceived drilling, engineering and other risks (P_e), these factors form the basis of a simple risk-based evaluation system that can be applied to geothermal plays anywhere in the world.

Combining cash flow considerations allows for the estimation of Net Present Value (NPV) for each play. The product of risk and NPV (the Expected Monetary Value, EMV) provides a more robust and considered assessment of the relative 'risked-value' of a geothermal play.

Keywords: Drilling, Levelised Cost, Risk, NPV, EMV

Introduction

Many geothermal energy explorers in Australia are rapidly approaching a phase of the exploration cycle where an informed decision needs to be made regarding the siting of either a deep 'proof-of-concept' development well, or a moderate-depth exploratory well. In most cases multiple plays will be available within a single tenement or group of tenements and explorers must make a critical decision between them, which may have wide-reaching impact.

The prevailing decision making process within the geothermal sector is to make relative empirical assessments of sites based on known geology (but usually biased by perceptions of temperature alone) and then to further constrain site-selection based on cost, usually expressed in the immediate term as drilling cost, and in the long-term as the project Levelised Cost of Electricity (LCOE). This cost-based approach has some significant flaws, which may be misleading at the best.

The use of a cost-based approach (such as LCOE) alone for site evaluation encompasses neither project risk nor revenue and can therefore lead to erroneous perceptions of relative value - and misguided decisions on drill site location.

In contrast the petroleum sector has evolved a mature and formalised system of project evaluation, which encompasses the inherent geological and commercial risks of a prospect. The assessed value of the prospect (eg. Magoon and Dow, 1994; Otis and Schneidermann, 1997) is usually quantified as the Net Present Value (NPV). The combination of risk and value is the Expected Monetary Value (EMV) of the project, and this risked-value approach more accurately defines the relative worth of projects.

This study describes a risk-based approach to assessing the value of a geothermal project in the Australian context, synonymous with the approach used by the petroleum sector. The study demonstrates how project NPV can be combined with risk via a simple decision tree, to ascertain the EMV of a geothermal project.

The dilemma

A geothermal explorer (hypothetical) has a series of potential 'plays' across GEL7000 and must make a decision to drill one play in the next 6 months. Each target has slightly different characteristics, pros and cons. Two targets (A and B) are schematically shown in Figure 1.

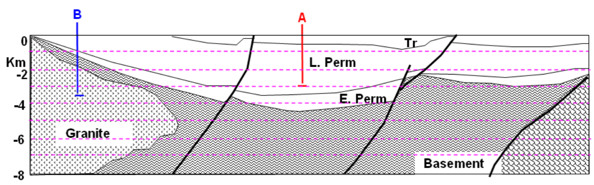

Figure 1: Schematic section showing two hypothetical geothermal plays. Play A is a HSA play targeting 160°C at 3 km depth and Play B is an EGS play targeting 185°C at 3.5 km depth.

Target A is a HSA play with a target sandstone aquifer at 3 km depth. The modelled conductive heat flow in the vicinity of A is 85 mW/m^2, giving a reservoir target temperature of 160°C. Target B is an EGS play with a target granite reservoir at 3.5 km depth. The modelled conductive heat flow in the vicinity of B is 110 mW/m^2, giving a reservoir target temperature of 185°C. Both plays are about the same distance from the national electricity grid and have similar market potential. The exploration company would like to establish a 10 MWe binary power plant, and although initially attracted to Target B due its high surface heat flow and potentially high reservoir temperature, it is now uncertain about the relative value of Target B compared to the shallower Target A.

Which target offers the best value?

Geothermal systems risk and the exploration and development cycle

Australia is unique amongst the world of geothermal exploration and development in that it is mainly driven by capital investment via public share issues. Costs and timing are, therefore, strongly influenced by the capital-raising cycle. Most Australian geothermal exploration activities can be summarized in a five-year cycle (Figure 2), although longer periods may be expected for more complex projects.

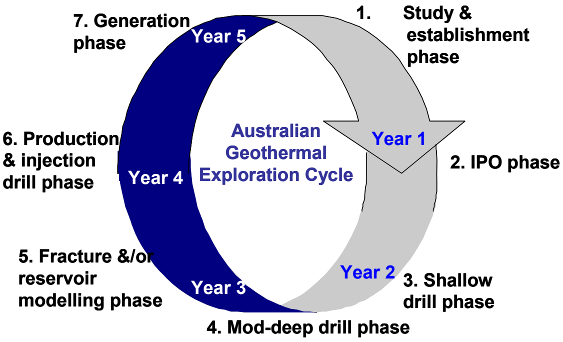

Figure 2: The Australian Geothermal Exploration Cycle showing the progress of activities typical in a five-year exploration cycle leading to the establishment of a small 'proof-of-concept' plant by the end of year 5 (idealised).

By the time most companies reach the moderate-depth drilling phase (Phase 4) in about year 3 of the cycle, they need to have some form of analysis of the value of their plays by which they can make a decision about drilling location, target type and target depth. Anecdotal evidence suggests that, to-date, much of this decision process is empirical, ad-hoc, or (at best) lacks documented systematics.

Whilst petroleum and geothermal systems have a number of differences, there is no reason why the geothermal sector cannot benefit from a risk-based approach as used in the petroleum sector. In the case of the petroleum system, total geological risk (P_g) is defined by:

$$P_g = P_{ch} \times P_s \times P_r \times P_{cl} \quad \text{(Eq 1)}$$

The four aspects of petroleum system risk are shown in Table 1., along with suggested equivalent risk categories for geothermal.

Table-1 Comparison of geological risk categories

Petroleum System	Geothermal System
Charge (P_{ch})	Heat flow (mW/m^2)
Seal (P_s)	Thermal resistance (m^{2}K/W)
Reservoir (P_r)	Reservoir
Closure (P_{cl})	Water

By assigning a probability value (P) to each of the risk categories in Equation 1, petroleum companies derive a relative, but nevertheless useful, risk ranking for their prospects.

Conductive geothermal systems in Australia can be assessed against four discrete aspects of geological risk (Cooper and Beardsmore, 2008). In the early phases of the exploration cycle, companies should undertake a comprehensive Geothermal Systems Assessment (GSA) to identify the key risks in their plays and the relative degree of these risks.

The key geological risks can be summarised as follows:

Heat flow: Probability that heat flow measurements or assumptions reliably characterise the play under investigation. Estimated from geographic coverage and 'uncertainty' of heat flow estimates.

Thermal resistance: Probability that thermal resistance and heat transfer mechanism beneath the level of well intersects are as assumed (purely conductive, convective component, advective component).

Reservoir: Probability that reservoir properties and volumetric extent are as assumed. Estimated from geographic coverage, data type and reservoir type.

Water: Probability that water supply or chemistry may adversely impact on the project.

The above risk variables are defined by measurable factors with intrinsic distributions. For example, in petroleum exploration reservoir risk (P_r) incorporates the distributions of porosity, permeability, area and net:gross thickness data. These factors are typically combined in Monte-Carlo simulations to define the overall probability distribution of reservoir risk. This process provides a disciplined and uniform approach to help mitigate exploration/drilling risks (Capen, 1992; Rose, 1992).

Some aspects of risk in the geothermal system share varying degrees of co-dependence. For example, heat flow and thermal resistance risk share a common link via rock thermal conductivity measurements. It is perhaps more useful to combine geological variables of the geothermal system into just two simple risk categories which are first derived from the four factors in Table 1. These two risk categories are:

P_t – target temperature risk, and,

P_w – flow rate risk

Pre-Drill Play Evaluation (PDPE) – a simple geothermal risk tool

The concepts outlined in the following paragraphs define a process that may be termed a geothermal *Pre-Drill Play Evaluation* (PDPE). Different geothermal plays will have different Expected Monetary Value (EMV). In simple terms, the net EMV is a proxy for 'risked value' and can be used to rank a series of geothermal plays to determine the lowest-risk, highest-value drilling location. The work path for a PDPE is schematically shown in Figure 3.

A Geothermal Systems Assessment (GSA) should be the first significant activity for an exploration company with new ground, so that the four key geological risks (P_g) can be defined and quantified (Cooper and Beardsmore, 2008). These four risks can be subsequently refined into temperature risk (P_t) and flow risk (P_w), which are quantitatively estimated through heat flow and hydro-geomechanical modelling, respectively.

In a conductive geothermal setting, the probabilistic distribution of reservoir temperatures is a function of the standard deviation of surface heat flow and the uncertainties of rock thermal conductivities. A 3D earth model with estimated surface heat flow of 90±10 mW/m^2 may have a normally distributed probability curve with a mean heat flow of 90 mW/m^2 and standard deviation (σ) 10 mW/m2. Thus the 'P90' value (ie 'true' heat flow is 90% likely to exceed this value) is 2σ less than the mean, or 70 mW/m^2, while 'P10' would be 110 mW/m^2. In some cases, the analyst may believe that heat flow risk is not normally distributed, and may define P90 and P10 according to a different distribution, perhaps based on a log-probability plot of regional heat flow data.

The risk that heat flow is not purely conductive is addressed through hydraulic reservoir modelling, by assessing the thermal stability of conductive models when populated with permeability data. A threshold, or 'critical', permeability is identified for key layers, beyond which spontaneous convection might occur. The analyst is then in a position to quantify the risk that the critical permeability may be exceeded. This is the risk that temperature may be overestimated.

Likewise, the outcomes of hydraulic reservoir modelling, using tools such as TOUGH2 and FEFLOW finite element code, determines the likely distribution of well flow rates for a given distribution of porosity, permeability, pressure, fluid viscosity, well and pump design variables.

Combined, the temperature and flow rate probability distributions allow a direct assessment of probable well power output for different geothermal plays, well patterns, design parameters, or other variables. The outcome is a probability based picture of well output. Geological risk is directly apparent from the median value and the shape and width of the probability distribution curve. The well productivity (typically time-variable) feeds directly into economic models for the expected revenue stream, which are combined with cost estimates to derive the Net Present Value (NPV) of a play.

The NPV, however, does not address non-geological risks. The most significant non-geological risk in a geothermal program is *engineering risk* (P_e). This is largely the explorer's

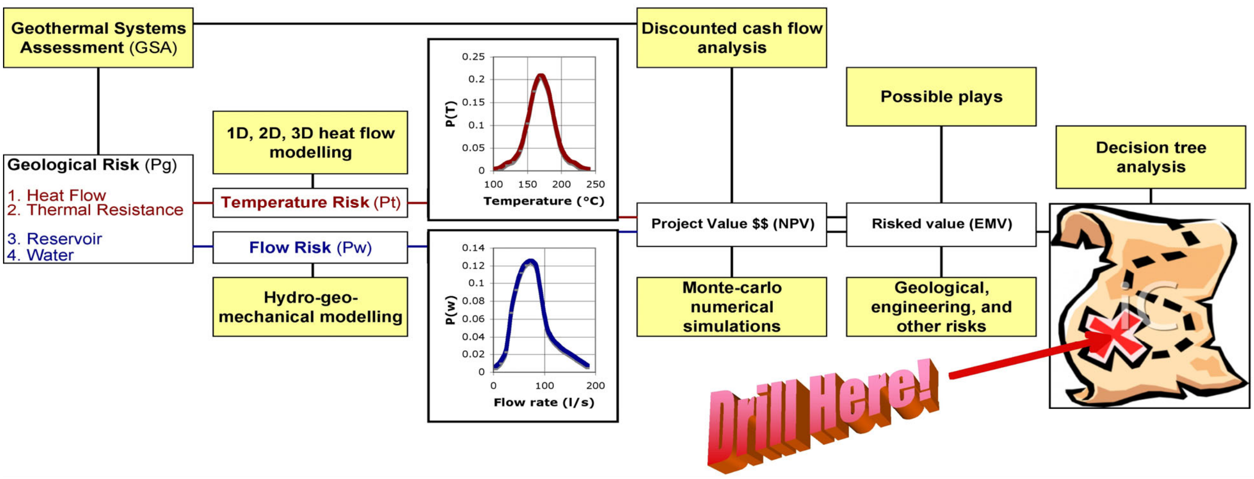

Figure 3: A simple flow chart for a geothermal Pre-Drill Play Evaluation (PDPE). Quantifiable geological risks are incorporated with the NPV. The product of all risks and NPV results in the net EMV, which can be used to decide target priority.

perception of the chance (probability) of experiencing trouble-free drilling. This may be influenced by play type (EGS or HSA), drilling depth, lithology, temperature, logging capabilities etc. The product of geological risk (P_g) profile and the engineering risk (P_e) largely defines the geothermal exploration and development risk. Other risks (eg perceived sovereign risk) can also be addressed at this stage. The product of NPV and risks is the net EMV of a play.

Incorporating project value into the decision making process

The *Levelised Cost of Electricity* (LCOE) is a standard measure of the cost of energy over a project life and is used to compare the relative costs of various forms of energy (eg. coal, solar, wind, geothermal). It is defined as the sum of all discounted project costs over a stated lifetime divided by the sum of discounted net electricity generation. It has been used in the geothermal sector as a project evaluation tool, but LCOE alone does not incorporate information about the relative risks involved in a project.

Example

In the hypothetical example discussed earlier (Figure 1), the exploration company has assessed the LCOE for plays A and B.

Play A has a shallower target reservoir and lower drilling costs than Play B. However, the lower reservoir temperature in Play A means that net well output is expected to be about 0.7 MWe less per well, compared to Play B. Consequently both projects have a similar LCOE of about $115/MWh over a 20 year project life, discounted at 10% (Table 2).

Table-2 Comparison of parameters for hypothetical plays A and B

Parameter	Play A	Play B
Play type	HSA	EGS
Reservoir temp. (P50)	160°C	185°C
Modelled flow (P50)	100 l/s	90 l/s
Expected net MWe/well	4.6	5.3
LCOE ($MWh)	$115	$115
NPV ($ million) 20 years	$20	$30
Geological Risk (P_g)	0.53	0.44
Engineering Risk (P_e)	0.80	0.50
Net EMV ($ million)	**$8.4**	**$6.6**

The LCOE, however, only tells the company the 'break even' price for the electricity produced. It does not reveal the relative value of the two plays. After modelling expected flow rates, thermal draw down and pressure draw down over 20 years using TOUGH2 and FEFLOW, the company found that the higher expected net MWe production for Play B resulted in a NPV of $30 million, compared to $20 million for Play A. Consequently, based on NPV alone, Play B appears to offer better lifetime value (Table 2).

In assessing the relative geological and engineering risks (including reservoir engineering) of each play, however, the opinion of the exploration company is that Play B (EGS) has a much lower probability of success compared to the more conventional Play A.

The net EMV for the 'success case' for each play is the product of NPV, P_g and P_e, so Play A has a more attractive net EMV than Play B. Although both plays have similar costs (LCOE) and Play B has an attractive NPV, the perceived risks for Play B are much higher, such that the 'risked-value' is poorer. Consequently, in this instance, the company decides that Play A provides better long-term value.

Discussion

A Pre-Drill Play Evaluation (PDPE) incorporates all available information about a geothermal play, its geological and engineering risks, its probable costs and revenue stream. Geological uncertainty is minimised through an early and thorough Geothermal Systems Assessment (GSA). The GSA process identifies the geological variables (heat flow, thermal resistance, reservoir and water) with the greatest uncertainty (risk), which allows targeted exploration to reduce those risks.

Other, non-geological, risks are, to a large extent, subjective and may be perceived at different levels by different people. Parameters such as 'drilling risk', 'sovereign risk' etc should be quantified through a process of discussion and careful consideration to incorporate a range of views.

There will very likely be widely different opinions about drilling risk for EGS, convection risk in permeable sediments, sovereign risk in developing nations, and other. It may be that probability distributions are derived for each of these risks, rather than simple 'median' values. EMV may then, also, be derived as a distribution with P10, P50 and P90 values. This is a valid alternative to the process outlined above.

If undertaken in a methodical and inclusive manner, a PDPE will naturally reach a consensus view for the exploration (or investment) company about the relative 'risked-value' of potentially very disparate geothermal plays.

Conclusions

The methodical application of a risk-based assessment system, similar to that used by the petroleum sector, will assist geothermal exploration and investment companies to appraise the relative value of different geothermal plays. When risks are combined with cash flow projections, the net EMV for each play can be ranked to produce an inventory of drilling or investment options. This approach is distinctly different from a cost-based approach.

The use of a 'risked-value' approach to geothermal exploration and investment decision-making provides internal company discipline for drilling decisions and some surety for investors who are familiar with existing and similar systems in the petroleum sector.

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