GEOTHERMAL DERISKING. HOW TO LEARN AND SUCCEED FROM FAILURE STORIES

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Keywords: Geothermal Exploration. Derisking. Risk Analysis Management Mitigation. Reporting code.

ABSTRACT

Contrary to the Mining and Petroleum industries, the Geothermal Community at large shares no global vision of risk assessment and mitigation prior to resource development. Moreover, the Geothermal Industry lacks a risk evaluation methodology relating to resource classification and standardised reporting code addressing exploration, resource and reserve key issues.

Whereas risk analysis of an Oil & Gas prospect would currently integrate a number of reservoir and fluid characteristics a geothermal commitment to exploratory drilling will often reduce to the sole temperature, flow performance prediction exercise instead, regardless of any normalised reservoir assessment procedure.

Probabilities of success (POSs) will be derived accordingly, either via a (semi) deterministic factual or purely probabilistic (Monte Carlo) calculation. Note that most geothermal operators/developers favour a minimum P50 or preferably P90 "go ahead" success ratio.

Recent failures in France have shed some light on the mining risk problematic in geothermal exploration. Here it became obvious retrospectively that the oil industry mining rationale would have thoroughly modified the former exploration/production strategy.

Hence the present paper aims at statistically quantifying the history of geothermal exploration wells and field development on two reservoir case studies via a type of "prior to *post mortem*" well/campaign review.

Not restricting to the exploration/resource/reserve segment, the assessment exercise advocates the need for a standard, widely itemised, geothermal reporting code as already suggested by the Australian and Canadian national organisations.

Not only would these guidelines provide guidance to geothermal explorationists by bridging the gap between less mature geothermal and conventional fossil fuel energy know how, it would equally act as a strong stimulus among concerned investors/developers, energy/environmental planners and stakeholders.

Practical aspects for implementing new risk assessment procedures and reporting codes are also discussed.

1. INTRODUCTION

Although many countries could contemplate harnessing their geothermal potential and achieving a significant share of their domestic energy demand, either as geopower, geoheat or both; geothermal development worldwide does not progess at the expected pace.

Actually, whereas the International Energy Agency (IEA) has projected a 3.5% geothermal contribution i.e. a 200 GW_{el} installed capacity and ca 760 Mi tons yearly savings of CO_2 emissions (World Bank, 2018) in year 2050, present geopower scores hardly 14 GW_{el} worldwide with a 20 GW_{el} forecast by year 2025!

Clearly, the risk inherent to geothermal, as to any mining, exploration and related early capital in vestment in costly drilling works, have slowed down prospective development objectives.

In order to widen the scope of geothermal operators and attract potential investors and stakeholders risk mitigation policies and financial mechanisms have been implemented by International Institutions (UN, Worldbank, EBRD, Interamerican, Asian Banks) and concessional funding awarded to developing countries. Worth to mention also are the specific incentives in the form of geopower feed in tariffs (FITs), coverage of wildcat drilling failure costs, fiscal advantages (VAT deductions) set up by various national environmental schemes (France, Germany, The Netherlands).

In fact theses mitigation policies and incentives act basically as an insurance covering the mining risk and securing (FITs, fiscal incentives) downstream exploitation economics and benefits.

Simultaneously to the foregoing resource assessment methodologies and reporting codes are being promoted with a view to set up, European (EGEC, European Geothermal Energy Council, and European Commissions, EC) and world wide (IGA, International Geothermal Association), an international template, according to Petroleum and mineral industry standards (Van Vees et al, 2013) and already practiced by the Australian (Figure 1) and Canadian Geothermal Energy Associations.

Such an initiative, in addition to normalising geothermal resource/reserve evaluation and classification, is aimed at attracting investments in clearly identified geothermal plays.

The probabilistic (Monte Carlo uncertainty analysis) approach to the geothermal (reservoir/wellhead thermal energies and power generation output, both Log normal distributed) potential associated to the assessment exercise and related P90, P50, P10 probability thresholds is illustrated in Figure 2 assessment chain (Williams et al, 2008). Note incidentally that probabilistic estimates may change drastically with the time as exemplified by the following assessments of the US geothermal potential (in GW_{el}).

Installed capacity	Identified		Undiscovered	EGS
(2010)	USGS	1978		
# 3 500	23		100	
	USGS	2008		
	9		30	517 5 (mean)
	MIT	2006		
				#100

However, upstream from the mining risk mitigation/insurance and reporting code issues, remain the key prerequisite in reconciling, on specific targets, predrilling exploration, design and reservoir conceptual model with upgraded drilling success expectations.

Hence, the present paper focuses on the **geological** requirements on either a reservoir or single well doublet scales and exploratory/development strategies of two deep sedimentary Paris Basin settings, according to the petroleum assessment rationale, an example of which, borrowed to a non-drilled Angola play, will be commented.

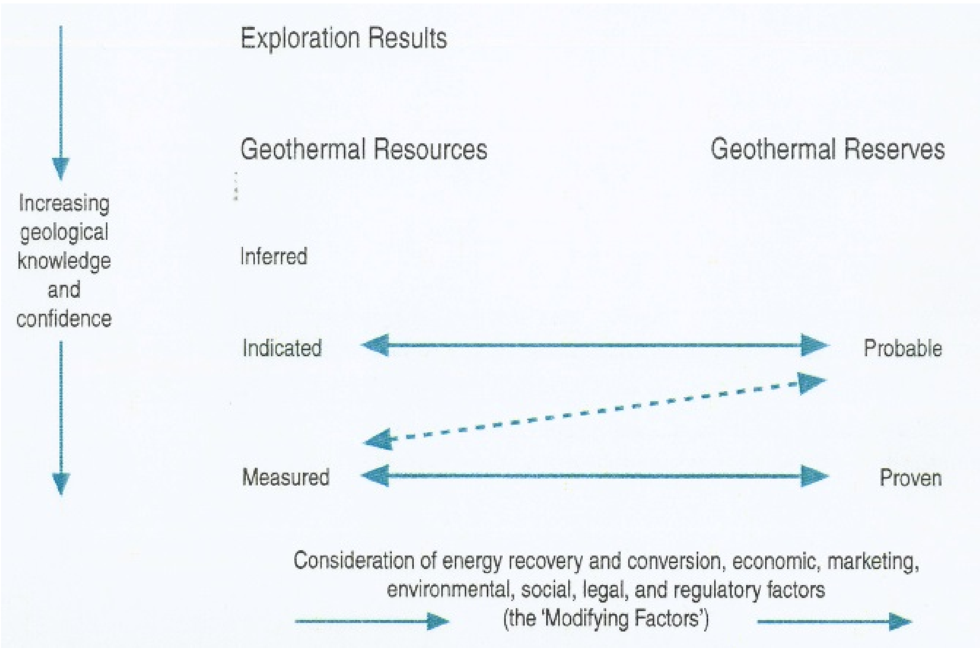

Figure 1: Insight into the Australian resource/reserve reporting code.
(source: AGCC, 2010)

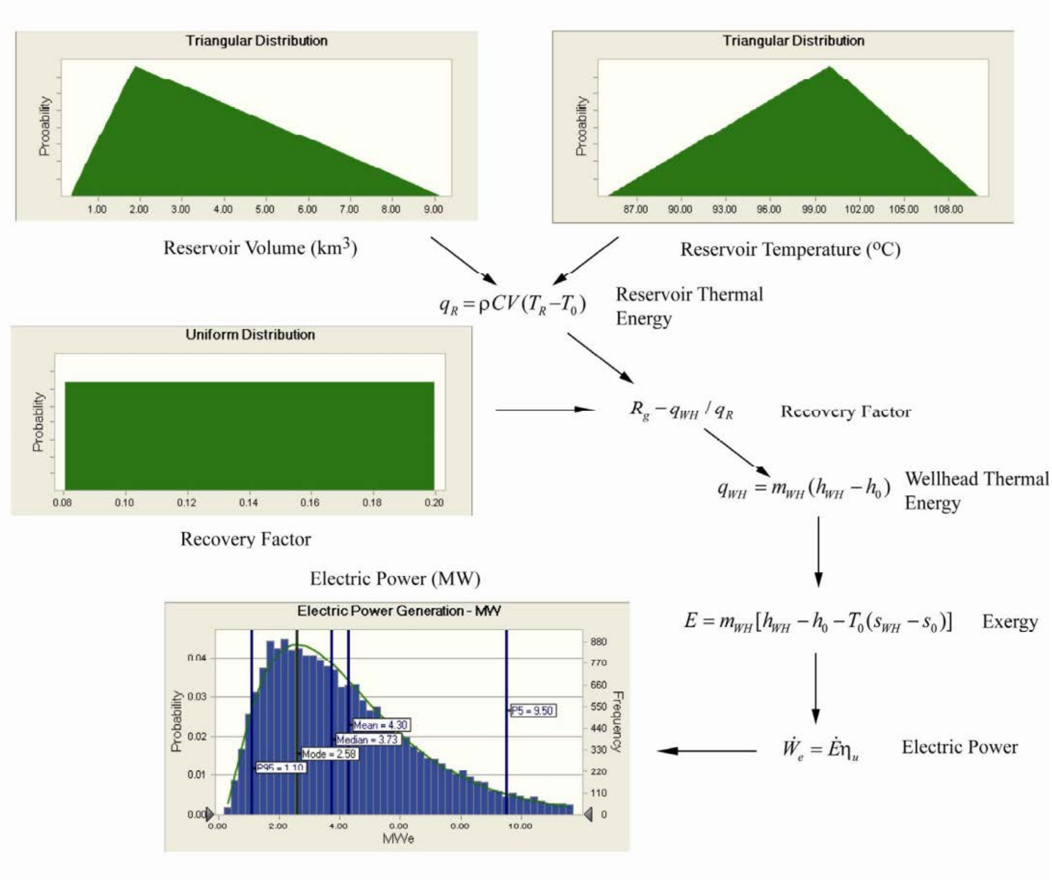

Figure 2: Geoheat and Geopower potential. Probabilistic assessment chain.
(source: C.F. Williams et al, 2008)

2. PETROLEUM VS GEOTHERMAL DE-RISKING

In spite of their distinctive attributes both sectors (should) display similar pre-drilling exploration strategies owing to the coherent, well established, petroleum doctrinal body. In so doing, respective to geothermal operators, a clear distinction should be made between exploration and development policies and regulatory frameworks.

Petroleum exploration sourced risk factors address five headings, source rocks reservoir, trap, seal and timing/migration. Geothermal exploration deals with five leading indicators, reservoir, temperature, productive (injective) capacity, geochemistry and thermal life (sustainability).

Both sectors differ markedly from the resource volume standpoint, by several orders of magnitude from Oil (gas) to heat in place (OIP vs HIP), whereas the recoverable marketed heat share, reduces drastically, contrary to oil and gas, from heat in place to distributed heat as evidenced by Figure 3 pyramidal sequence, applied to the Dutch case (Van Vees et al, 2008).

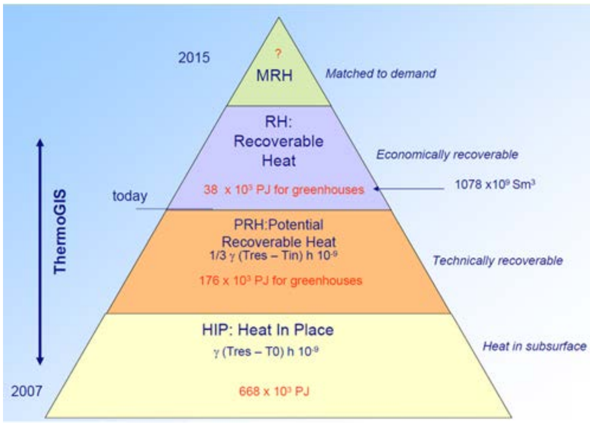

Figure 3: From heat in place to market heat. The Ditch case
(source: Van Wees e tal, 2008)

2.1. A petroleum de-risking case study.

Southern Angola (De-Risking the Frontier, Hartenergy, 2019).

The, non-drilled yet, Namibe basin (off shore Angola) belongs to a pre-salt Jurassic structure, which stands as the Eastern Atlantic margin of Western Africa and as a marginal conjugate, somewhat asymmetric though, of the dependable hydrocarbon rich, Brazilian Santos and

Campos basins *vis-à-vis*. A dual sensor broadband seismic campaign allowed to image the pre-salt/post-salt structures, which, combined with a geoscience marginal conjugate analysis of structural, lithofacies and hydrocarbon charge, led to a comprehensive featuring of a frontier unexplored/unexploited basin.

Pre-salt plays in the Angola province proved elsewhere rewarding as to commercial discoveries, raising due interest among concerned operators.

Summing up, 2D regional dual broadband seismics data processed and migrated to 15 km depths, enabled to de-risk basin architecture and pre-salt plays. The latter could be further illuminated thanks to promising premises by a 3D dual sensor survey securing imaging of the pre-salt section and delineation of reservoir facies.

The foregoing issued the following assessments regarding the reservoir system, source rock history, lithofacies distribution, traps, pre-salt structures and CO_2 contamination risks.

- *Petroleum system*

Undrilled geological and hydrocarbon features were issued from comparison with neighbouring Angola and distant Brazilian conjugate basins, amended via sequential stratigraphic analysis, ultimately complemented by inputs from Western Angola Cretaceous outcrops.

- *Source rock history*

Regional thermal and geochemical information in Angola/Namibia were input to source rock modelling, leading to promising maturation profiles.

- *Lithofacies*

Comparison to similar Angolian and Brazilian conjugate replicates and 3D seismics findings, enabled to delineate pre-salt facies, which were further compared to drilled analogs in Angolian and Brazilian fields.

- *Traps*

Aptian salt diapirs appear to act as the main seals

- *Pre-salt structures*

Those could be successfully imaged and a basin structural framework reliably derived.

- *CO_2 contamination*

Thanks to additional gravity and magnetic offshore surveys, CO_2 contamination could be derisked due to the unlikelyhood of mantle sourced CO_2.

This case study illustrated how assisted modern 2D/3D seismics and geoscientific analysis applied to an undrilled and unexploited play could be thoroughly assessed and further successfully drilled.

2.2. A geothermal mining risk assessment

Antics and Ungemach (2010) quantified the geothermal risk related to high and low enthalpy well productivities, by defining critical success/failure criteria.

- **The high enthalpy case**

The single flash conversion cycle and entropy diagramme are represented in Figure 4. From the well output parameters, namely..

Formation temperature: 250°C
Cold source (condenser) temperature: 50°C
Condenser pressure: 0,120 bar
Separator pressure (single stage flash): 10 bar
Separator temp. (single stage flash): 180°C
Mass flowrate @ 10 bar: 110 kg/s
Power output @ 10 bar turbine inlet: #10 MW_{el}

the full success and total failure figures stand at 10 MW_{el} and 5 MW_{el} respectively.

- **The low enthalpy case**

Production success/failure criteria relating to the geothermal district heating scenario listed below and imaged in Figure 6 stand as follows:

INV=12 10^6 €
OMC=5 10^5 €
n=20 years
nh=8256 hr/yr
r=5% (total failure)
r=10% (total success)
Full equity (zero debt)
Subsidies=25% INV
C=35.45 MWt
T=45.4°C

Full success
Q=299 m^3/h; no subsidy, c=35 €/MWh_{th}
T_{wh}=70°C T_i=45°C
T_{wh}=65°C T_i=40°C
Q=200 m^3/h; 25% subsidy, c=45 €/MWh_{th}
T_{wh} unchanged

Full failure
Q=246 m^3/h; no subsidy, c=35 €/MWh_{th}
T_{wh}=70°C T_i=45°C
T_{wh}=65°C T_i=40°C
Q=155 m^3/h; 25% subsidy, c=45 €/MWh_{th}
T_{wh} unchanged

In this instance the success/failure criteria, produced by coupling well productivity with exploitation economics, were adopted by the French Environmental Agency Risk Mitigation Fund.

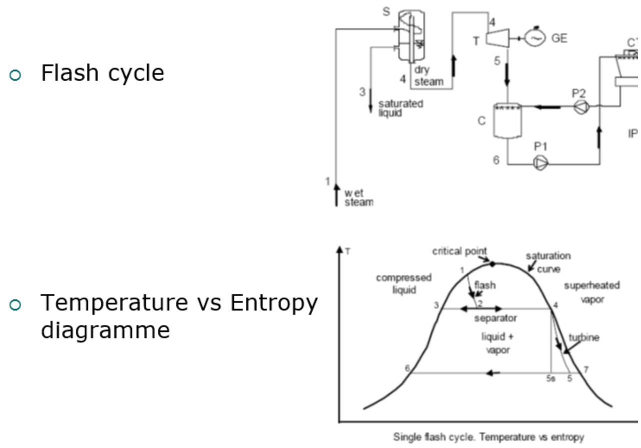

Figure 4: The high enthalpy power scheme

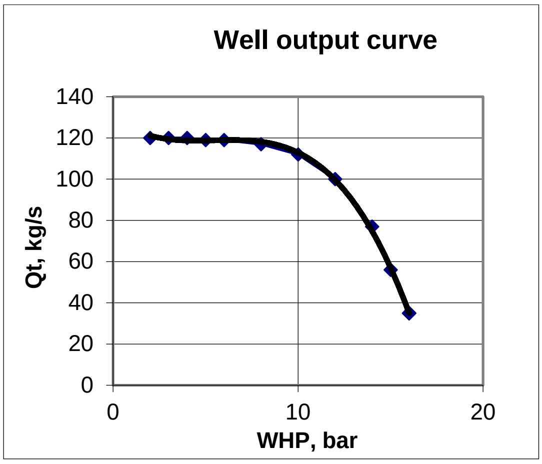

Figure 5: The high enthalpy well delivery curve

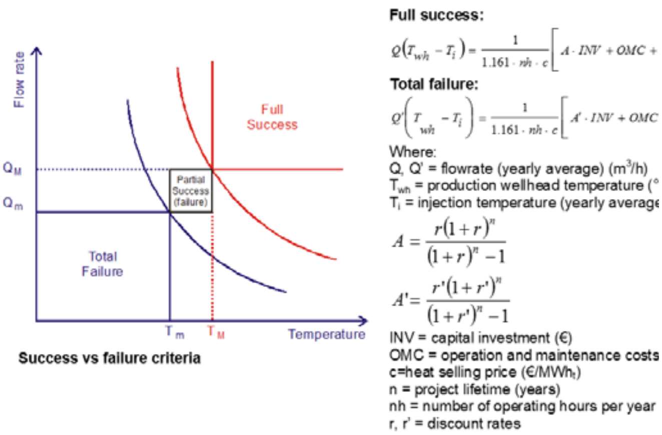

Figure 6: The low enthalpy success/failure diagramme

3. TOWARDS A RELEVANT EXPLORATION VS EXPLOITATION RISK MANAGEMENT. A PARIS BASIN PROBLEMATIC

Geothermal development of the central part of the Paris Basin was initiated in the late 1970s by Bathonian Oolithic limestones of Dogger (Mid Jurassic) age, via the doublet concept of heat farming combining a production well and an injection well pumping back the heat depleted brine into the source reservoir. The 54 to 84°C resource, at depths ranging from 1400 to 200 mTVD, extends over ca 6000 km².

Almost one half of the 48 geothermal district heating (GDH) doublets serviced to date, are located in the Val de Marne (94) district south of Paris a 250 km² area where the resource is regarded as well known and recognised of high potential.

This area undergoes a paradoxal setting. The dependable nature of the reservoir, in terms of pressures, temperatures and transmissivities is based on geostatistical (kriging) interpolation methods regardless of any complementary investigation of the sedimentological body and associated depositional, diagenetic and microfracturing attributes, whatsoever.

Nevertheless, it can be noticed (Figure 7) that the transmissivity distribution, within the 10 to 90 Dm range, remained unchanged during the two 1983-1987 and 2007-2018 key development periods, i.e. 40% of the wells stand below 20 Dm. More surprising the most favourable zone stretching eastwards is widely untapped, which reflects land occupation and market oriented concerns instead of reservoir performance as such. The same rationale is applied by the Mining Code, regulating geothermal exploration/production, where each new doublet settlement is subjected to an exploration lease application, in an area of proven reserve.

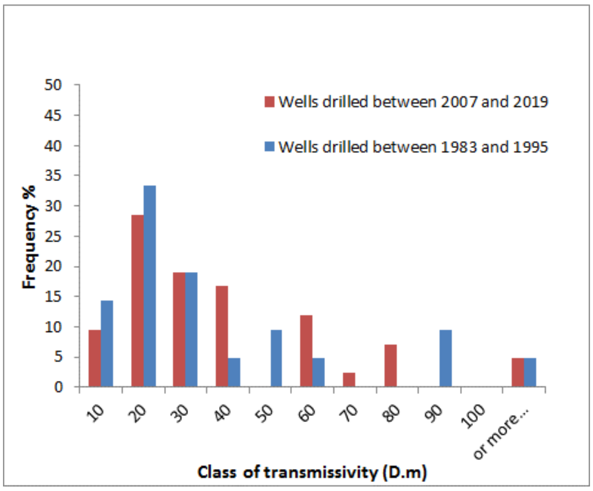

Figure 7: Transmissivity of wells drilled in the Val de Marne and the Hauts-de-Seine Districts

As a result, the new Cachan subhorizontal well achievement (Ungemach et al, 2019) ought to be regarded as a compensatory means enhancing well performance along prolonged thermal life in a reservoir area, mapped in Figure 8, dominated by low transmissivities, a high GDH doublet density and locally depleted formation temperatures.

This paradox leads us to share a vision in which the exploration problematic would be revised and the extensively mined area revisited as a single development field (equivalent to an oil field development) and not as a multiplicity of "exploration" doublets. Therefore, modern reservoir evaluation and management would prevail and 3D, eventually in combination future with 4D, seismics implemented with facies and acoustic, nuclear magnetic resonance, logging tools, whose cost would amount to that of a lost/dry well, covered by the *ad hoc* mutualised insurance mechanism.

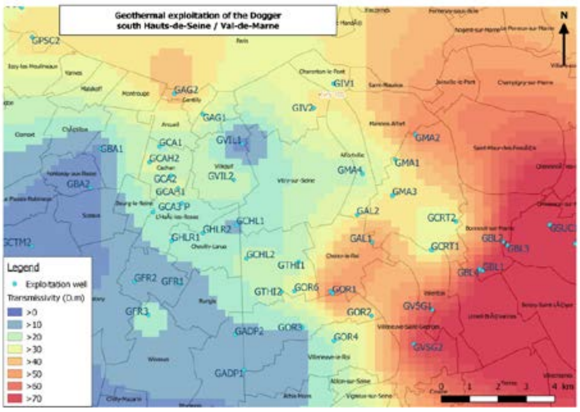

Figure 8: Location of GDH doublets South of Paris (Val de Marne and Hauts-de-Seine districts)

CONCLUSIONS

The reviewed, exploratory pre (and post) drilling back up strategies, practiced by the petroleum and geothermal sectors, lead to the following conclusions. In spite of their sectorial specificities it is strongly recommended that the upstream geothermal exploration methodologies seek guidance from the oil industry know how and stick more closely to the geological background knowledge, the essence of any reservoir occurrence and assessment, a statement supported by both a typical petroleum case history and the paradoxal mining strategy applied to the Paris Basin heat farming development.

REFERENCES

AGEA-AGEG (2010). Australian Code for Reporting of Exploration Results. Geothermal Resources and Geothermal Reserves. The Geothermal Reporting Code, Second Edition, 28 p., Canberra, Australia.

C.F. Williams, M.J. Reed, R.H Mariner (2008). A Review of Methods Applied by the U.S. Geological Survey in the Assessment of Identified Geothermal Resources, U.S. Dep. of the Interior, U.S. Geological Survey, Open-File Report 2008-1296, 27p.

HARTENERGY (2017). De-Risking the Frontier. A New Study Provides a Clearer Image of the Namibe Salt Basin, 3 April, 2017.

J.D. Van Vees, T. Boxem, P. Castagno, C.Desayes, C. Lacasse, A. Manzella (2013). A Methodology for Resource Assessment and Application to Core Countries. GEOLEC. Deliverable n°21, March 2013, Brussels, Belgium.

M. Antics, P. Ungemach (2010). Quantifying Risk in Geothermal Development. The High Enthalpy and Low Enthalpy Cases. Proc. GRC Annual Meeting, 24-27 Oct. 2010, Sacramento, CA.

P. Ungemach, M. Antics, M. Davaux (2019). Subhorizontal Well Architecture Enhances Heat Production. The Cachan Milestone European Geothermal Congress, EGC 2019, 11-14 June, 2019, The Hague, The Netherlands.

World Bank (2018). Feature Story, Geothermal Energy is on a Hot Path, May 3, 2018.