Technical and Economic Uncertainties Assessment to Derive a High Enthalpy Geothermal Project Optimal Development Scheme*

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Abstract

Like in the oil and gas business or gas storage industry, getting reliable production and temperature forecasts is a key aspect of any geothermal project. The field assessment phase prior to investment sanction is characterized by relatively large uncertainties at the time important decisions have to be made. It is, for instance, crucial to select an appropriate development strategy (e.g. number of producers, well architecture or re-injection pattern) to obtain optimal cumulative energy production whilst ensuring good profitability of the project. Reservoir evaluation as well as economic uncertainties and quantification of their impact on the project reserves and economics are needed before the field development concept selection. The proposed application case is about high enthalpy geothermal projects for electricity generation through ORC cycle, like the ones which might be found in Germany, Italy, Turkey or the United States for instance.

A fully integrated numerical modeling of the (well+pump+ORC) system was developed, including technical as well as economic inputs, ending up with a business model delivering typical economic figures for management decision making. Capitalizing on existing workflows from the oil and gas business to assess those subsurface and economic uncertainties, an optimal development scheme is then derived through an optimization process, while taking correctly into account both types of uncertainties. In more details, extensive use of: (1) advanced Design of Experiments techniques for optimal uncertainty space sampling (of both technical and economic parameters), (2) reliable proxy-models computations of technical and/or economic modeling outputs, (3) global sensitivity analysis to rank the most impacting parameters, and (4) optimization techniques under uncertainty to find the optimal values of controllable parameters (e.g. well architecture), ending up with an optimal development scheme. This allows, through a single study, to assess both the technical and economic uncertain parameters for uncertainty quantification and risk analysis for optimal decision making.
Technical and Economic Uncertainties Assessment to Derive a High Enthalpy Project Optimal Development Scheme

AAPG workshop - Geneva – 10 April 2019
Thomas SCHAAF*, C. Bontemps, D. Patriarche, P. Egermann, STORENGY, ENGIE group
Outline

- Common framework: geological reservoir characterization
- Common goal: reliable performance forecasts
- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies: Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme
- Wrap up and perspectives
Common framework – Reservoir Characterization

- Reservoir characterization: Obtain representative model(s!) of a geological object in an uncertain framework
- Our concern: subsurface uncertainties (up to economics possibly)

Data from:
- Geophysics,
- Geology,
- Reservoir.

Modelling:
- Structural,
- Facies,
- Petrophysical,
- Dynamic Simulation.
Common goal – Reliable production forecasts

- Proper uncertainties quantification assessment and risk analysis
- Reliable production forecasts:

Cumulative oil production

Mean pressure

E&P application case
Geothermal doublet case
Geothermal HT case
Gas storage case
Outline

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• Wrap up and perspectives
Full well/pump/ORC System Modelling

Developed through an Excel multi tab spreadsheet (+ macros):

- Technical inputs (number of wells, reservoir P&T, etc.),
- Financial inputs (DRILLEX, CAPEX/OPEX, etc.)

To end up with

- Key technical results (Gross, Net Power, pump consumption, etc.)
- Key financial results (Cash Flow, NPV, WACC, etc.)
Full well/pump/ORC System Modelling

- Technical inputs:

<table>
<thead>
<tr>
<th>Storengy Case</th>
<th>Development scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>1</td>
</tr>
<tr>
<td>Targeted producing well rate (kg):</td>
<td>150</td>
</tr>
<tr>
<td>Number of producing wells:</td>
<td>3</td>
</tr>
<tr>
<td>Number of injection wells:</td>
<td>3</td>
</tr>
<tr>
<td>Production uptime:</td>
<td>0</td>
</tr>
<tr>
<td>ORC - low, medium, and high duty cycle:</td>
<td>0</td>
</tr>
</tbody>
</table>

Pressure constraints:
- Minimum producer/MPH inlet pressure (bar): 17.5
- Maxor MPH outlet pressure (bar): 5

ORC Plant definition:
- Electrical power generation output (kW): 1
- Temperature at outlet ORC plant (°C): 60
- Plant consumption (%): 10%
- Plant efficiency (%): 10%

Reservoir definition:
- Net thickness (m): 500
- Permeability (md): 60
- Water salinity (g/l): 40
- Produced fluid temperature (Bottom hole temp. °C): 175
- Reservoir pressure (bar): 215

Well data:
- 30 m:
  - Depth: 300
  - Total skin factor: 0
  - Permeability (bhp/psi x ft): 1.00
  - Well pump efficiency (%): 70%

Production string (from top to bottom):

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Diameter (inch)</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>781</td>
<td>8.06</td>
<td>610</td>
</tr>
<tr>
<td>52</td>
<td>12.56</td>
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<tr>
<td>532</td>
<td>8.50</td>
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</tr>
<tr>
<td>454</td>
<td>7.50</td>
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Injection string (from top to bottom):

<table>
<thead>
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<th>Diameter (inch)</th>
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<td>8.50</td>
</tr>
<tr>
<td>454</td>
<td>7.50</td>
<td>7.50</td>
</tr>
</tbody>
</table>

Well data & architecture

- Well flowrate, decline rate,
- Number producers/injectors
- Surface pressure constraints
- ORC definition

Reservoir data
## Full well/pump/ORC System Modelling

### Financial inputs:

<table>
<thead>
<tr>
<th>Storengy Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning:</strong></td>
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<tr>
<td>Duration of Exploration phase (yr)</td>
</tr>
<tr>
<td>Duration of Appraisal phase (yr)</td>
</tr>
<tr>
<td>Duration of Development phase (yr)</td>
</tr>
</tbody>
</table>

### F&A phase (Subsurface):
- Number of appraisal wells: 1
- Exploration well cost (excluding core drill): 0
- Appraisal well cost (M$): 2.845
- Average inflation in production well cost (M$): 3.0
- G&M study, data acquisition, core drill (M$): 1.00
- Permitting & EIA (M$): 0.50
- Surface Engineering before development (USD): 0.50
- Project management during exploration & appraisal phase (M$): 1.00
- Contingencies for well (%): 10%

### Development phase (ORC Plant & surface):
- Electricity connection (M$): 2.0
- Plant ORC CAPEX (M$/Mw installed): 2.8

### Financial data:
- FIT on sales $/MwH (electricity): 200
- Revenue from internal consumption (YN): 0
- FIT on consumption $/WwH (electricity): 0
- Discount rate (%): 7.3
- FIT on sales $/MwH (thermal): 7.0

**Timing - Project phases**
- Well costs, etc.
- Plant CAPEX, etc.
- Feed In tariff, discount rate, etc.
- Key Technical outputs e.g. pump power (kW), Plant Net power (MWe)
Full well/pump/ORC System Modelling

- Key Economic outputs e.g. cash flow (M$), NPV (M$)

### Storengy Case

Electricity Generation Excluding District Heating part

Electricity power generation option (1/0) = 1

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<thead>
<tr>
<th>No</th>
<th>Year</th>
<th>Q</th>
<th>Date</th>
<th>Period</th>
<th>Total expenditures (M$)</th>
<th>OPEX (M$)</th>
<th>Net Mwe</th>
<th>Revenue from sale (M$)</th>
<th>Revenue from consumption (M$)</th>
<th>Cashflow (M$)</th>
<th>Cumulative CF (M$)</th>
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<td>45.39</td>
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</table>

- VAN (M$) = 8.18
- TRI (%) = 11.09%
- CAPEX @ Risk (M$)
Outline

- Common framework: geological reservoir characterization
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- Wrap up and perspectives
Experimental Design & Proxy models

- Capitalizing on existing soft/workflows from the Oil & Gas Industry
- ATOUT* software (soft deliverable from 4 IFPEN JIPs “COUGAR”)  
  * = Advanced Tools for Optimization and Uncertainty Treatment

  Experimental Designs + Proxy Model Approach

  + Global Sensitivity analysis
  + Mixed-Integer Proxy
  + Bayesian framework
  + Probabilistic decision tree
Outline

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Parameter set definition

- **Parameters:**
  1. Geology and reservoir Engineering,
  2. Controllable
  3. Economic

Real / Integer ; Uncertain / controllable ; active I/O
Experimental Designs

- Using Classical and Latin Hyper Cube Experimental Designs

171 runs
Spreadsheet configuration

- Configure inputs as well as outputs:

![Spreadsheet configuration diagram](image)
Both technical and economic outputs/results from the 171 runs:

- **Plant Net Power**
- **Cumulative Cash Flow**
Proxy models computation

- Mixed-Integer Proxy model computation:

Key Quality Control steps
Sensitivity Analysis – Technical outputs

- Standard Tornado & Spider plots – Analysis of the Plant Net Power
- Global Sensitivity Analysis (Sobol coefficients computation)
Sensitivity Analysis – Economic outputs

- Standard Tornado & Spider plots – Analysis of the NPV
- Global Sensitivity Analysis (Sobol coefficients computation)
Outline

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Optimization of the development scheme

- Optimizing (under uncertainty) the controllable parameters – Maximizing the NPV

- 3+3 wells development scheme
- Large diameter wellbores
Wrap-up & Perspectives

● Able to derive an optimal development plan for a HT ORC project

● Sensitivity studies and risk analysis were conducted considering:
  ● Technical uncertain and controllable parameters,
  ● As well as economic ones,
  ● Thus leading to a integrated technical & economic analysis

● Looking at both technical and economic key outputs

● Way forward:
  ● Using multi-objectives optimization : Pareto front
  ● On-going discussion with Business Dev. to fine tune the financial part