Parameter Interdependency In Energy And Economic Output Of A Geothermal Development Strategy

Alexandros Daniilidis[1], Hamidreza M. Nick[2] and David Bruhn[1,3]

[1] Technical University Delft, Stevinweg 1, 2629 CN, Delft, The Netherlands

[2] Technical University of Denmark, Elektrovej, 2800 Kgs. Lyngby, Denmark

[3] German Research Center for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

A.Daniilidis@tudelft.nl

Keywords: Strategy, Development, Hydraulic-Thermal, Direct-use.

ABSTRACT

In this work an ensemble of synthetic Hydraulic-Thermal (HT) reservoir simulations is carried out. Different development strategies are analysed in terms of well placement and operational parameters. At the same time, geologic heterogeneity is addressed in the form of fault transmissivity and throw, as well as layered reservoir flow properties. The geothermal system lifetime and economic performance are examined as output.

1. INTRODUCTION

The increasing demand for renewable energy supply requires a more substantial contribution from geothermal sources. In the finite subsurface space of the Netherlands, this implies a better utilization of existing licence areas and producing geothermal fields.

Additional complexity is encountered due to the marginal profits of direct heat geothermal energy in conductive dominated geological settings (Daniilidis, Alpsoy and Herber, 2017). The presence of spatial heterogeneity in a geothermal reservoir may reduce the effective volume of reservoir and the lifetime of the project (Vogt *et al.*, 2013; Crooijmans *et al.*, 2016; Nick *et al.*, 2016). Moreover, as the density of geothermal systems is increasing interference might arise as a problem (Willems *et al.*, 2017).

Transitioning to geothermal fields with improved energy extraction and a better economic output requires the understanding of the complex interactions between the two. As a prior step to the optimization of an existing field, further development strategies need to be envisioned.

This work explores the interdependency between geologic heterogeneity and development strategies. These inputs are analysed with respect to the resulting energy generation and economic.

2. METHODS

A coupled Hydraulic-Thermal (HT) model was developed in the COMSOL Multiphysics® software.

2.1 Reservoir model

The Energy Balance describes the heat flow in the model as follows:

$$\rho C \frac{\partial T}{\partial t} + \rho_f C_f \mathbf{q} \nabla T - \nabla(\lambda \nabla T) = 0 \quad [1]$$

in which T (K) is the temperature, ρ the mass density (kg/m^3), C (J/(kg·K)) the specific heat capacity, λ (W/(m·K)) the thermal conductivity q (m/s) the Darcy velocity and suffixes $_f$ and $_s$ refer to the fluid and the solid matrix respectively. The thermal conductivity and volumetric heat capacity of the system is computed based on the respective fluid and rock values separately according to:

$$\lambda = (1-\varphi)\lambda_s + \varphi\lambda_f \quad [2]$$

and

$$\rho C = (1-\varphi)\, \rho_s C_s + \varphi \rho_f C_f \quad [3]$$

in which φ is rock porosity. The pressure field is computed based on the continuity equation according to:

$$\varphi \frac{\partial \rho_f}{\partial t} + \nabla.(\rho_f\, \mathbf{q}) = 0 \quad [4]$$

where the flux q (m/s) is defined by Darcy's law:

$$q = -\frac{k}{\mu}(\nabla P - \rho_f g \nabla z) \quad [5]$$

in which k is the intrinsic porous medium permeability (m^2), μ the dynamic viscosity of the fluid (Pa·s), g the acceleration of gravity (m/s^2) and P the hydraulic pressure (Pa).

The fluid density and viscosity are a function of temperature according to:

$$\rho_T = 838.466135 + 1.40050603 \cdot \mathrm{T} - 0.0030112376 \cdot \mathrm{T}^2 + 3.71822313 \cdot 10^{-7} \cdot \mathrm{T}^3 \quad [6]$$

$$\mu_T = 1.3799566804 - 0.021224019151 \cdot \mathrm{T} + 1.3604562827 \cdot 10^{-4} \cdot \mathrm{T}^2 - 4.6454090319 \cdot 10^{-7} \cdot \mathrm{T}^3 + 8.9042735735 \cdot 10^{-10} \cdot \mathrm{T}^4 - 9.0790692686 \cdot 10^{-13} \cdot \mathrm{T}^5 + 3.8457331488 \cdot 10^{-16} \cdot \mathrm{T}^6 \quad [7]$$

The system lifetime is calculated when the condition

$$\mathrm{T}_{\mathrm{prod}_\mathrm{t}} \leq 0.95 \cdot \mathrm{T}_{\mathrm{prod}_{\mathrm{t}=0}} \quad [8]$$

is met. The produced power is computed according to:

$$P_{well} = Q\rho_f\, C_f\, \Delta T \quad [9]$$

in which Q is the flow rate (m^3/s) and ΔT is the temperature difference between producer and injector wells (K). The pump power only considers the pressure drop in the reservoir:

$$P_{pump} = \frac{\Delta P \cdot Q}{\eta} \quad [11]$$

where ΔP is the pressure difference between the wells and η is the pump efficiency. The overall system power is then calculated as:

$$P_{system} = P_{well} - P_{pump} \quad [10]$$

The cost of the wells is computed according to (van Wees *et al.*, 2012):

$$C_{well} = s(0.2Z^2 + 700Z + 25000) \quad [12]$$

where s is a cost scalling factor taken here to be 1.7 and Z is the measured depth. The NPV is then calculated as:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \quad [13]$$

Where CF is the cashflow, r thediscount rate and t the time.

2.2 Model geometry

The model considers a reservoir domain with a thickness of 150 m, comprised of three individual flow layers of 50 m thickness each, with homogenous flow properties. The top of the west part of the reservoir is situated at 2000 m depth. Over- and under-burden layers have a minimum thickness of 250 m. The whole domain (reservoir and over/under burden) is offset at the middle by a fault. The fault is a planar, vertical surface that extends 50 m above and below the reservoir layers (Figure 1). The throw of the fault takes different values (Table 2).

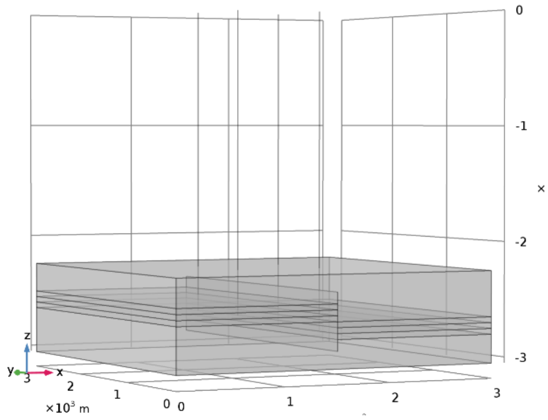

Figure 1: Overview of the synthetic model geometry.

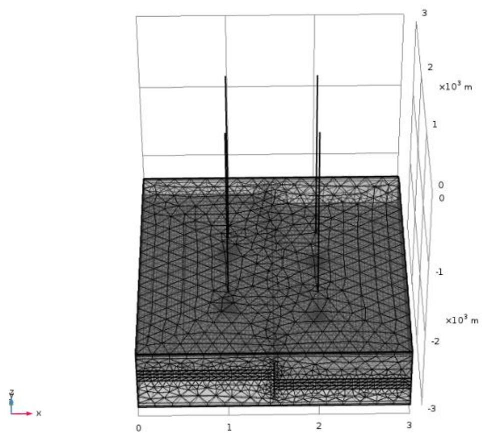

Figure 2: The meshed geometry. Total element count is ~100k depending on the parameter combination.

Table 1: Layer flow properties.

Layer	Permeability (m^2)	Porosity (%)
min	4.94×10^{-15}	17.2
mid	9.87×10^{-14}	18.5
max	4.93×10^{-13}	19.1
over-& under-burden	9.87×10^{-18}	1.0

Two doublets are positioned in the system, one in the west and one in the east block of the model (Figure 2). The well spacing of the wells in a single doublet is 600 m and equals the spacing between the doublets, as this has been shown to be the most beneficial configuration for lifetime and NPV (Willems *et al.*, 2017). The doublets are oriented along the N-S direction. The west doublet has the producer on the north and injector on the south, while the east doublet has either the same (tram) or the opposite configuration (checkerboard) (Table 2).

2.2 Simulations

The model is run for all the parameter combinations presented in Table 2. Each simulations spans over 50 years. It is assumed that both doublets are controlled by a single operator. Therefore, the breakthrough condition of eq [8] is applied to the mean production temperature of both doublets.

Table 2: Simulation input parameters and their respective values. All combination parameters are simulated, resulting in 32 unique simulations.

Parameter	Values	Units
Fault throw	50, 75	m
Fault permeability	9.87×10^{-18}, 4.93×10^{-13}	m^2
Reservoir layers (top to bottom)	min/mid/max, min/max/mid	-
Well configuration	Tram, Checkerboard	-
Flow rate	100, 250	m^3/h

3. RESULTS

The considered scenarios could result in a system lifetime that is below 20 years for some scenarios with a flow rate of 250 m^3/h. This might mean that a well spacing of 600 m as used in the simulations is short for such high flow rates and might not be a feasible solution for field development (Figure 3). The implication to this is that the NPV of the system is also reduced compared to the lower flow rate of 100 m^3/h. The lower flow rate allows the system to remain longer in production, thus generating a higher profit.

With regards to the well configuration, checkerboard is always preferable to a tram configuration of the doublets. In all scenarios the checkerboard configuration leads to a longer system lifetime and improved NPV (Figure 3).

Additionally, the reservoir layer flow properties also have an effect. When the maximum flowing layer is the deeper one, the system exhibits a longer lifetime and also a higher NPV. Lastly, a higher fault throw seems to be beneficial for both the system lifetime and NPV (Figure 3). Similar NPV can be achieved with different system lifetimes. It is therefore important to consider this trade-off at the policy level.

Figure 4 depicts the cumulative generated energy by the system. The steepness highlights that lower flow rates need longer lifetime and therefore produced energy to generate increased NPV. Figure 5 summarizes the sensitivity of each parameter and its respective values to the system lifetime.

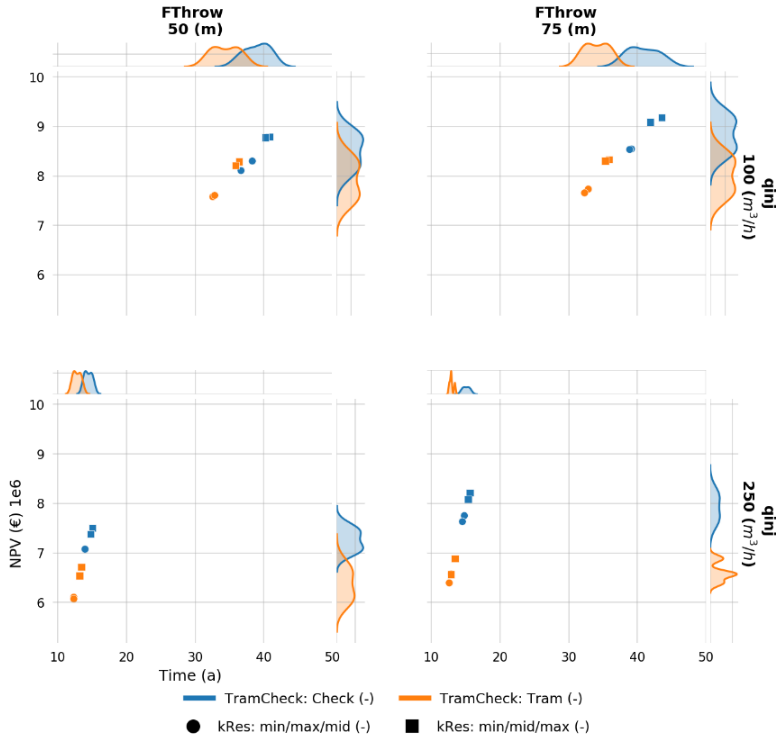

Figure 3: System lifetime and mean NPV for the combined system of two doublets, colour coded according to well configuration and marked according to reservoir layer properties.

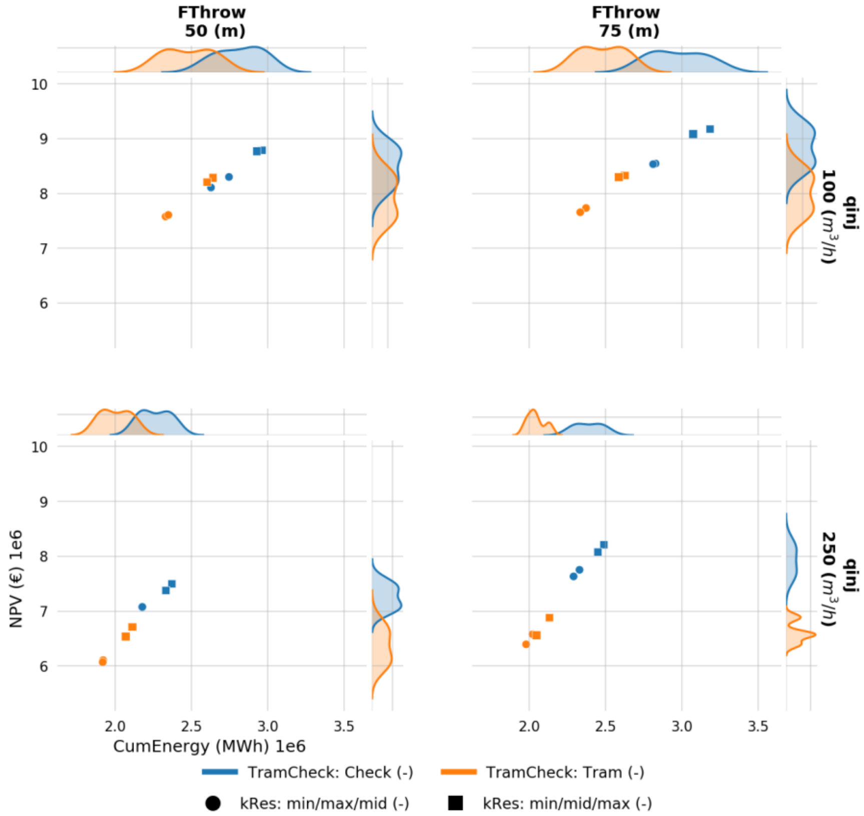

Figure 4: System cumulative produced energy and mean NPV for the combined system of two doublets, colour coded according to well configuration and marked according to reservoir layer properties.

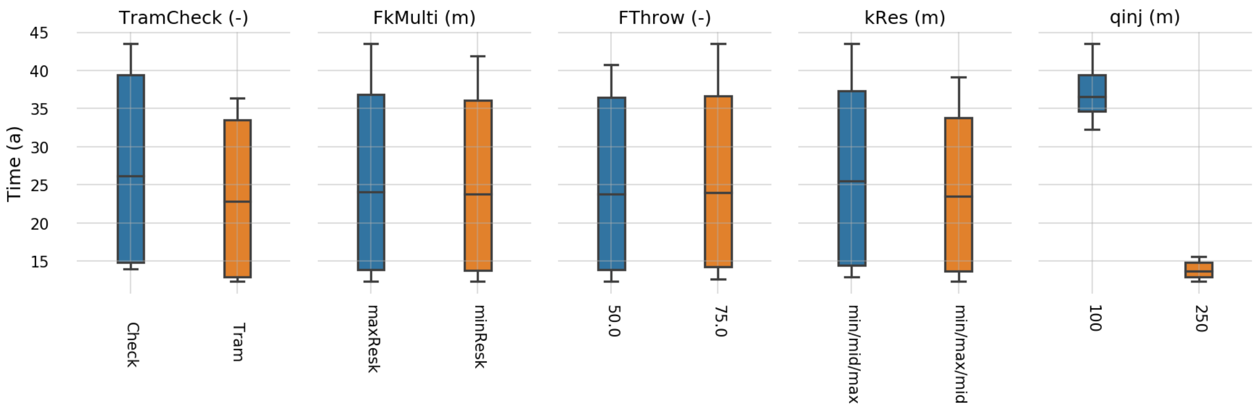

Figure 5:Overview of the system lifetime based on each parameter value considered.

3. CONCLUSIONS

It can be concluded that flow rate remains the most dominant parameter influencing system lifetime for the studied scenarios. Nonetheless, a higher flow rate might not necessarily lead to better NPV values. The well spacing of 600 m considered in this analysis might be small for long-term developments as system lifetime might drop below 15 years in some cases.

With regards to development strategies, a checkerboard configurations proves beneficial under all parameter combinations presented in this work. The inclusion of additional uncertainties and development scenarios could deepen the understanding of the interdependencies presented and further expand the relevance of the proposed methodology.

REFERENCES

Crooijmans, R. A. et al. (2016) 'The influence of facies heterogeneity on the doublet performance in low-enthalpy geothermal sedimentary reservoirs', Geothermics. CNR-Istituto di Geoscienze e

Georisorse, 64, pp. 209–219. doi: 10.1016/j.geothermics.2016.06.004.

Daniilidis, A., Alpsoy, B. and Herber, R. (2017) ‘Impact of technical and economic uncertainties on the economic performance of a deep geothermal heat system’, Renewable Energy. Elsevier Ltd, 114, pp. 805–816. doi: 10.1016/j.renene.2017.07.090.

Nick, H. M. et al. (2016) ‘On the connectivity anisotropy in fluvial Hot Sedimentary Aquifers and its influence on geothermal doublet performance’, Geothermics. doi: 10.1016/j.geothermics.2016.10.002.

Vogt, C. et al. (2013) ‘Modeling contribution to risk assessment of thermal production power for geothermal reservoirs’, Renewable Energy, 53(0), pp. 230–241. doi: http://dx.doi.org/10.1016/j.renene.2012.11.026.

van Wees, J. D. et al. (2012) ‘Geothermal aquifer performance assessment for direct heat production—Methodology and application to Rotliegend aquifers’, Netherlands Journal of Geosciences-Geologie en Mijnbouw, 91(4), p. 651.

Willems, C. J. L. et al. (2017) ‘An evaluation of interferences in heat production from low enthalpy geothermal doublets systems’, Energy. Elsevier Ltd, 135, pp. 500–512. doi: 10.1016/j.energy.2017.06.129.

ACKNOWLEDGEMENTS

This work has been funded by the Dutch Ministry of Economic Affairs and Climate Policy and ECW Netwerk BV under the research program Kennisagenda. The authors would like to acknowledge the constructive feedback of Harmen Mijnlief (TNO), Raymond Godderij (EBN) and Frank Schoof (Platform Geothermie) that helped shaping this work.