

WP2: unlocking marginal reservoirs

GEO4ALL General Assembly 2026 KAS, Woerden – September 17th, 2026

Eduardo Barros, Sławomir Szklarz, Negar Khoshnevis Gargar, Jens Wollenweber (TNO)

GEO4ALL WP2 consortium partners: Greenhouse GeoPower, ACL, HVC, Vattenfall, IF Technology, Gemeente Amsterdam, Gemeente Almere, WellPerform, Canopus Drilling Solutions, EBN, Geothermie NL

Objectives and aims

- Apply optimization workflow from GEOTHERMICA-RESULT to 4 case studies in the Netherlands
 - Diverse set of case studies: varying locations, development status and overall context
- Enhance understanding of effectiveness of different well design solutions in different reservoir conditions, for geothermal systems both in planning and operational phases
- Disseminate lessons learned to the Dutch geothermal sector
 - ⇒ **Help geothermal operators to select the best well configuration**
 - ⇒ **Aid geothermal sector in considering a broader range of well concepts** during concept select stage
 - ⇒ **Establish an advanced well design workflow** to enhance achievable flow rates, at limited additional costs, thereby enabling positive business cases at acceptable risk levels

Project structure

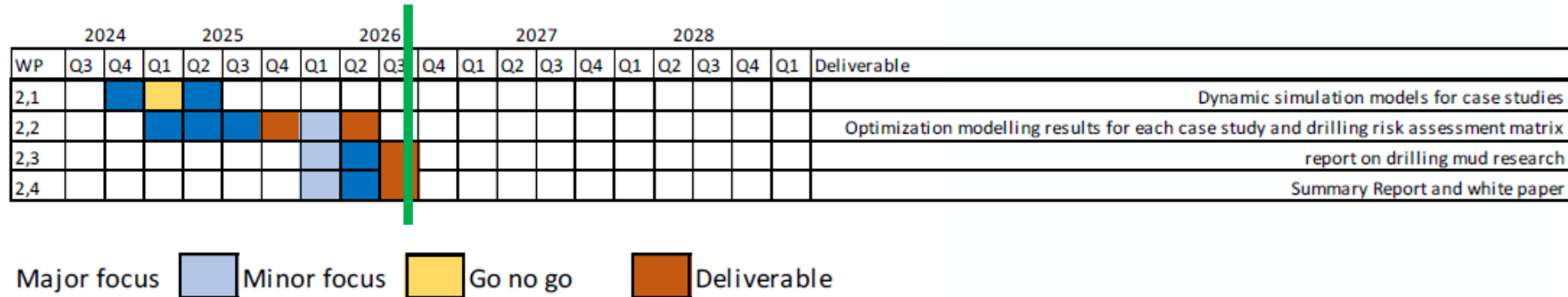
Task 2.1 – Data collection and review

Task 2.2 – Modelling well concept scenarios and business case for selected cases

- Optimization results (4 case studies)
- Drilling risk assessment matrix

Task 2.3 – Research on drilling mud options

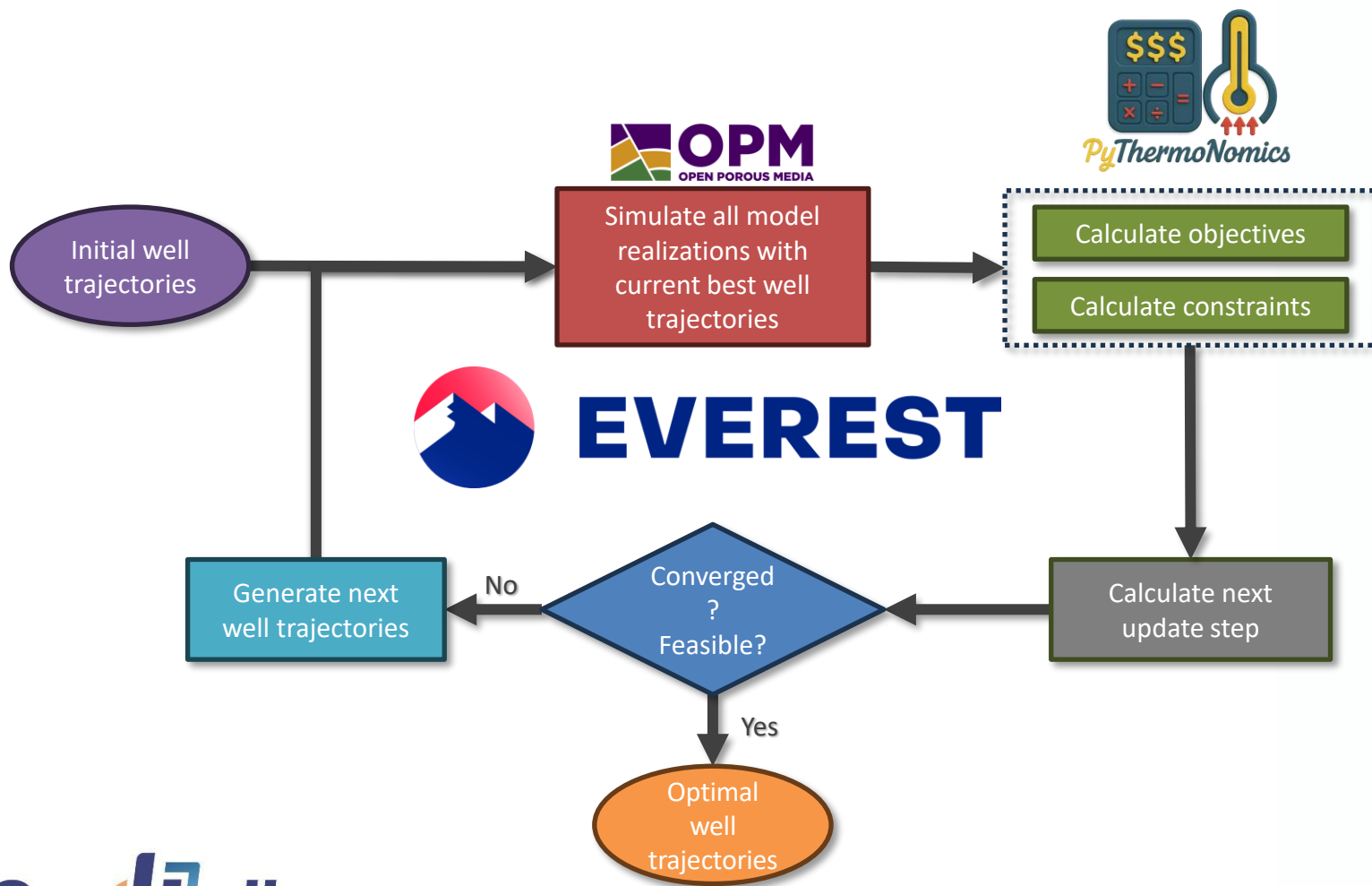
Task 2.4 – Reporting and white paper



Starting point and knowledge gaps

- **Starting point** – optimization workflow from GEOTHERMICA-RESULT project:
 - Optimize well locations and trajectories for sub-vertical, sub-horizontal and multi-lateral wells
 - Optimize in the presence of subsurface uncertainties (geological properties, reservoir quality)
 - Impose maximum allowed curvature (dogleg severity) constraints
 - Demonstrated in a single case study in the Netherlands
 - Built upon the TNO's open-source optimization technology EVEREST
- **Knowledge gaps:**
 - In practice, more drilling constraints are typically imposed
 - Detailed well design requires insight into wellbore stability and drilling risk considerations
 - Different decision-making contexts involve more than just optimization of well locations and well design
 - Publicly available tools and expertise, but not yet widely known and adopted by the sector

Fully open-source workflow



- **Refined well shape constraints:**

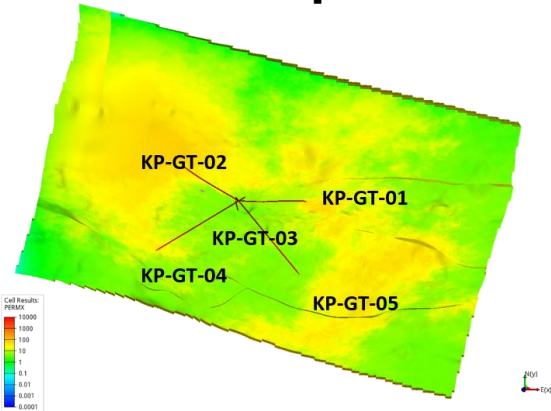
- Maximum allowed dogleg severity
- Maximum allowed well length
- Maximum allowed inclination
- Maximum allowed build rate
- Maximum allowed turn rate
- Maximum allowed step-out / TVD ratio
- Directional Difficulty Index (DDI)
- Minimum kick-off depth (producers $\neq$ injectors)

- **Other constraints:**

- Fault stability: shear capacity utilization (SCU)
- Maximum allowed distance to fault

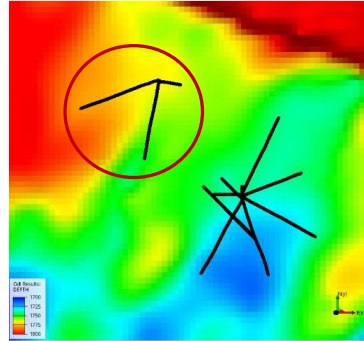
Case studies

Koekoekspolder



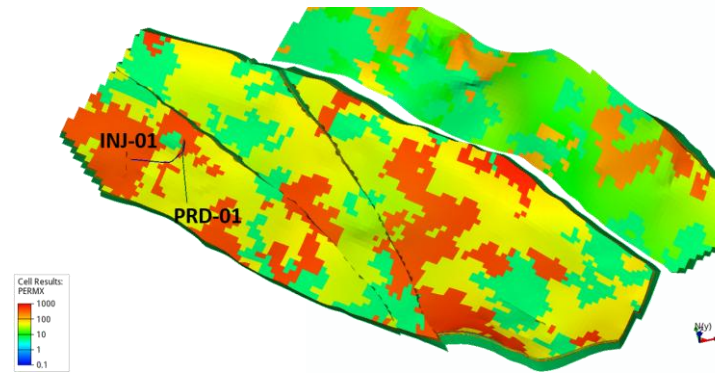
- Existing triplet (12-year production)
- New doublet planned
- What is the best placement for KKP-GT-04 and KKP-GT-05?

Luttelgeest



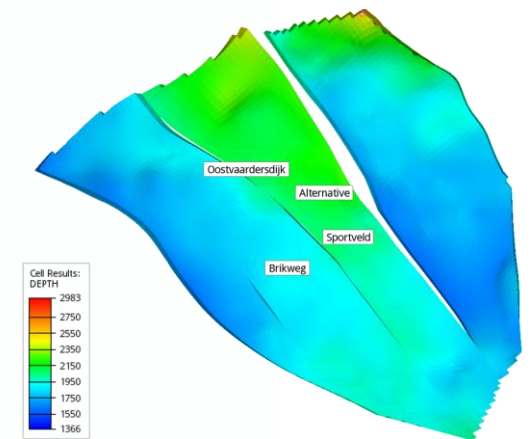
- Existing triplet in operation
- Problematic injection well LTG-GT-06
- What are the most cost-effective intervention to boost production?

Amsterdam



- Green field development
- First doublet planned for a selected surface drilling location
- Limited available data: fair degree of uncertainty (reservoir structure, facies assumptions, compartmentalization)
- What is the best well placement?

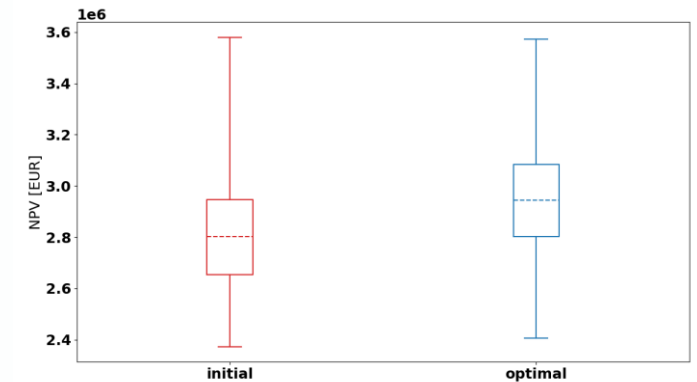
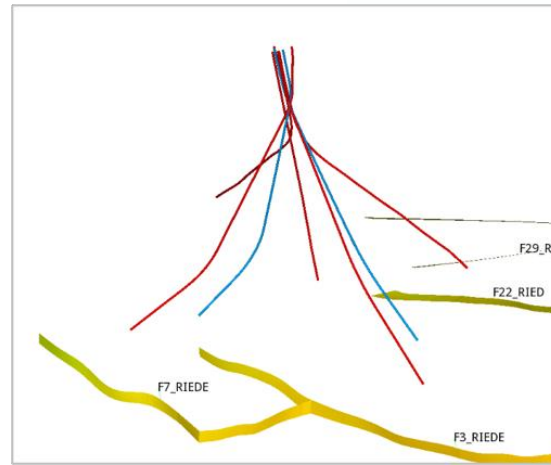
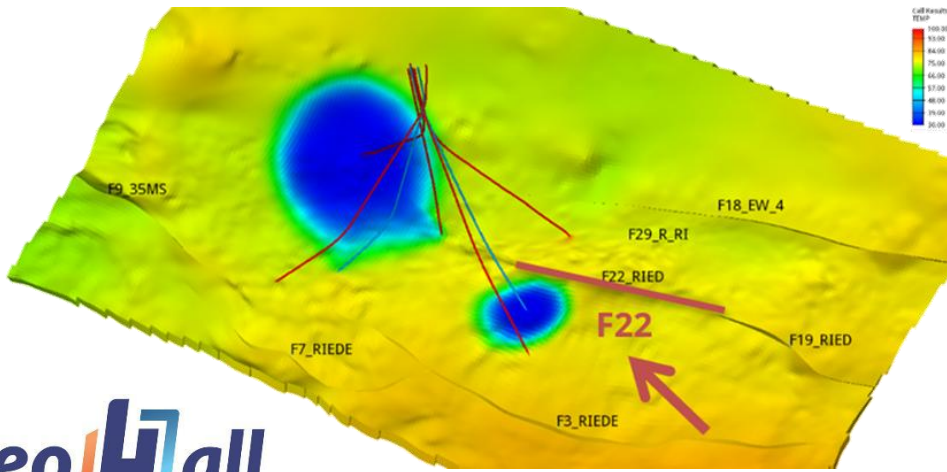
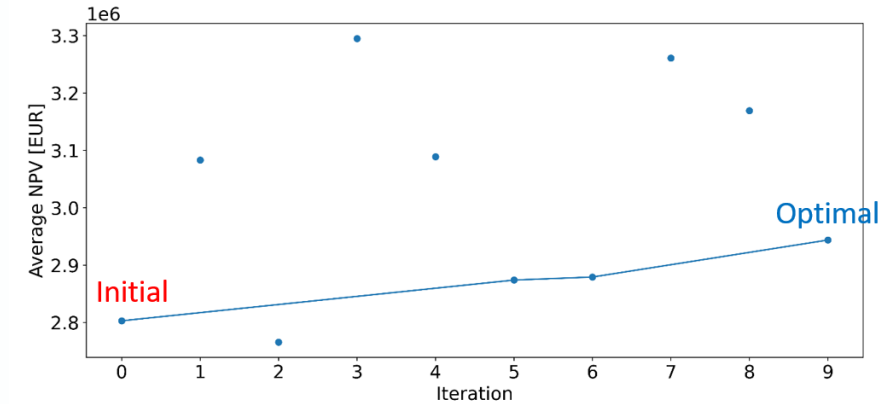
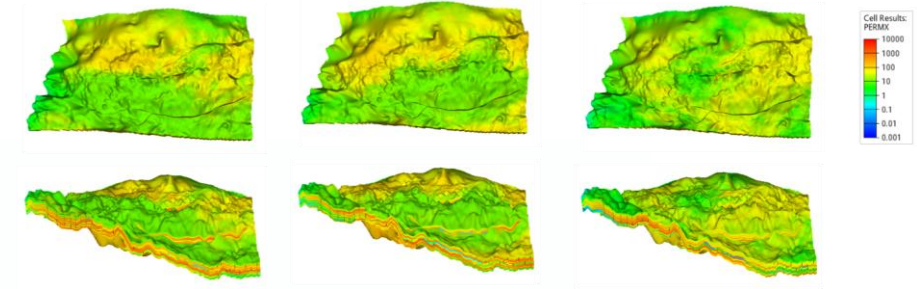
Almere



- Truly green field development
- Early stage: all decisions are open
- Limited available data: mostly conceptual model scenarios available
- What is the best well placement, surface drilling location, number of wells, play opener doublet?

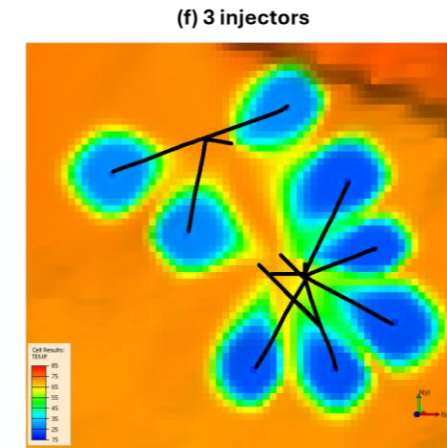
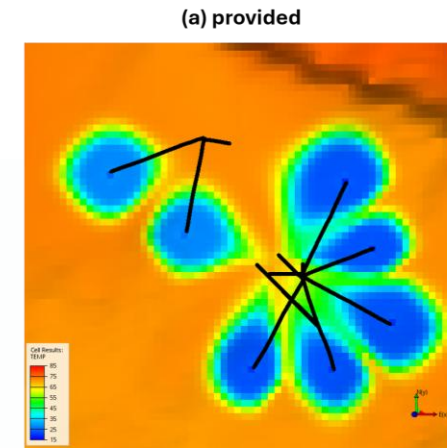
Results: Koekoekspolder

- Ensemble of 100 model realizations considered
- Optimization results:
 - NPV (average over ensemble) increases ~5%
 - All drilling constraints and fault stability constraints are satisfied
- Both wells (KKP-GT-04 and KKP-GT-05) become shorter, and therefore cheaper and less complex (in terms of DDI indicator)
- KKP-GT-05 (injector) moves closer to one of the faults but without destabilizing it
- Increased injectivity for KKP-GT-05 in optimal solution → better pressure support and higher rates in one of the existing producers (KKP-GT-03)

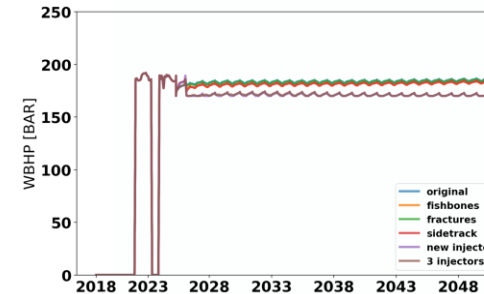
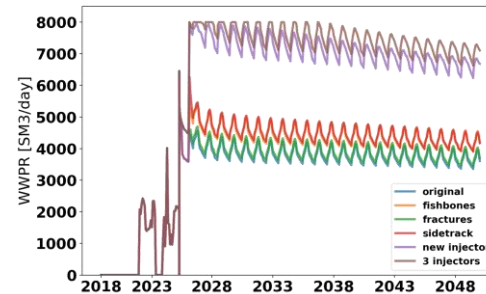
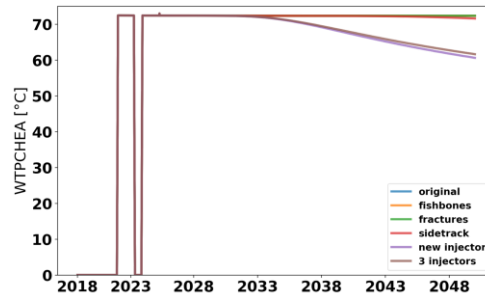


Results: Luttelgeest

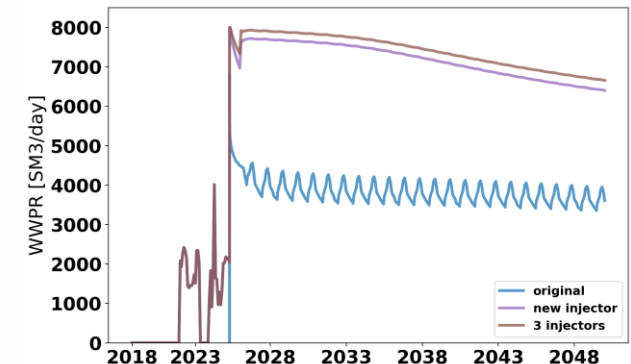
- 6 scenarios considered:
 - Original scenario, interventions in LTG-GT-06 (fishbones, fractures, side-track) and new injector (LTG-GT-12 replacing LTG-GT-6 and using 3 injectors)
- Fishbones and side-track expected to help (+17.5% in production rates), but main benefit is in adding a new injector (+85% in production rates)
- Cost-effectiveness analysis requires cost information (not available for all scenarios)
- Re-evaluated scenarios with revised well pressures: same conclusions
 - Increased drawdown in LTG-GT-04 (+10 bar), increased injection pressures (+5 and +10 bar for GT-05 and GT-06)



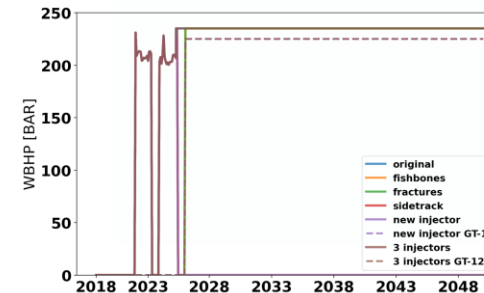
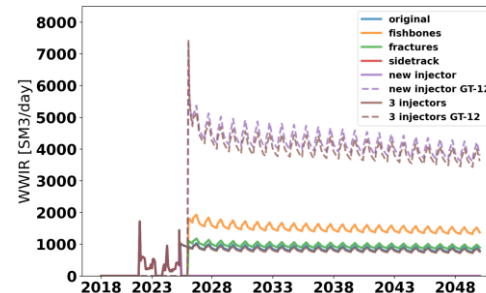
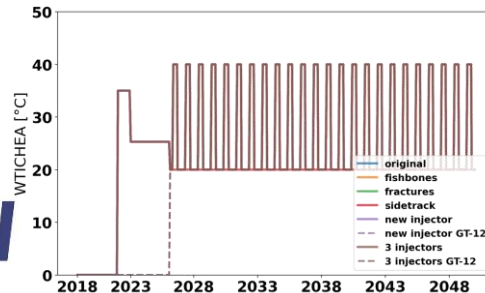
LTG-GT-04
(producer)



Production flow rates at LTG-GT-04
(scenario with revised pressures)



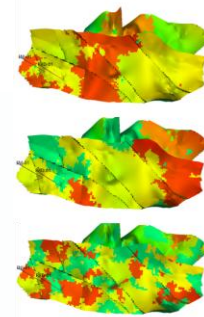
LTG-GT-06
(injector)



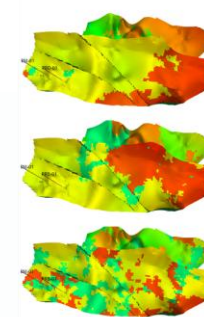
Results: Amsterdam

- Ensemble of 90 model realizations considered
- Optimization results:
 - Noticeable increase in NPV (+4 million EUR) on average over ensemble
 - All drilling constraints and fault stability constraints are satisfied
- INJ-01 moves away from fault FAULTI_6 with sufficient distance from FAULT5
- Both wells become shorter, and therefore cheaper.
PRD-01 becomes more complex (higher DDI) due to stronger directional change
- Increased rates achieved in optimal solution with no impact on thermal breakthrough

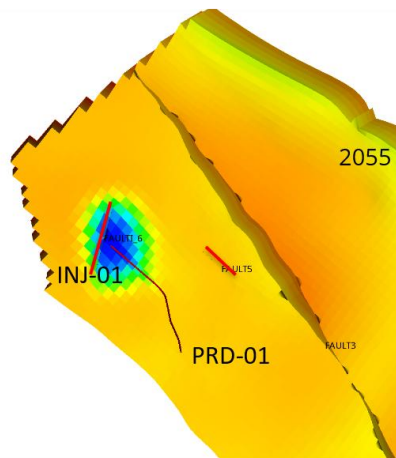
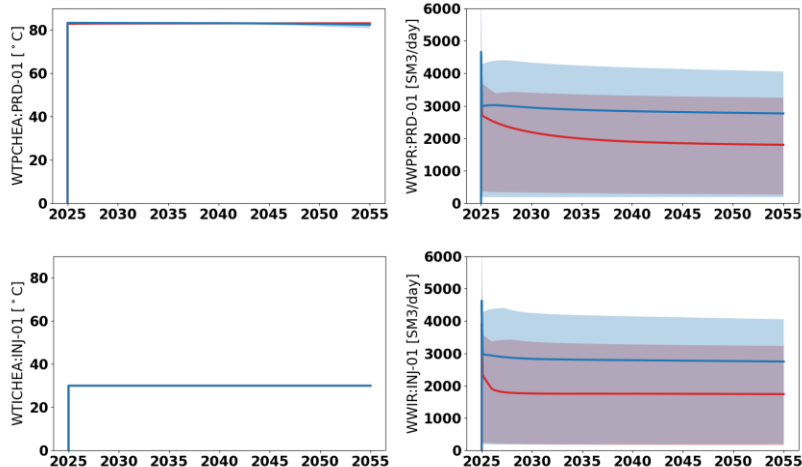
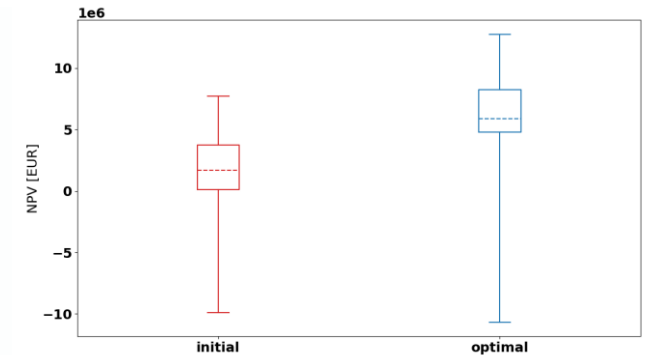
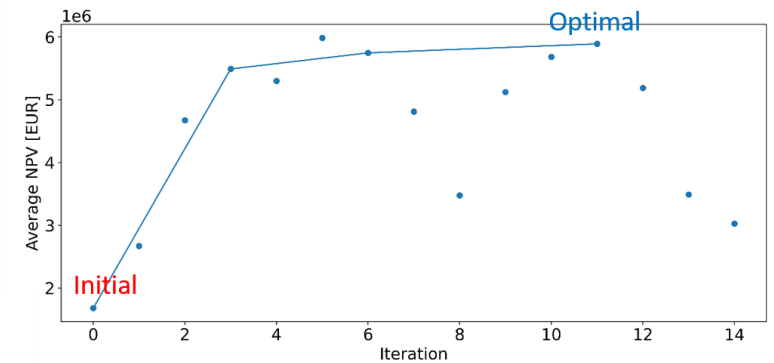
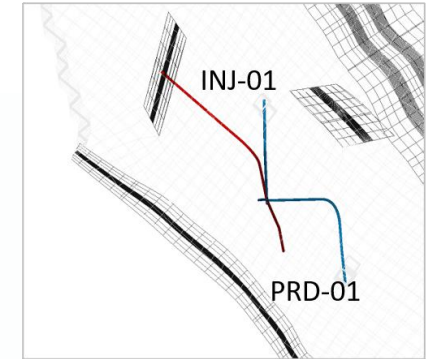
Scenario 1



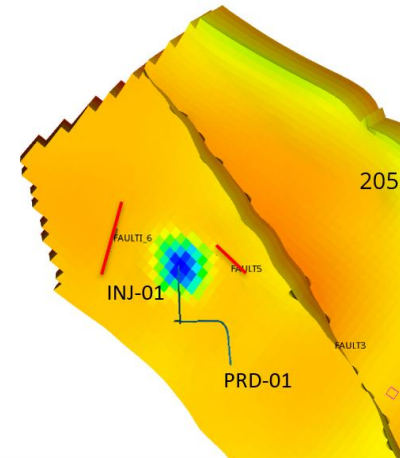
Scenario 2



Top view



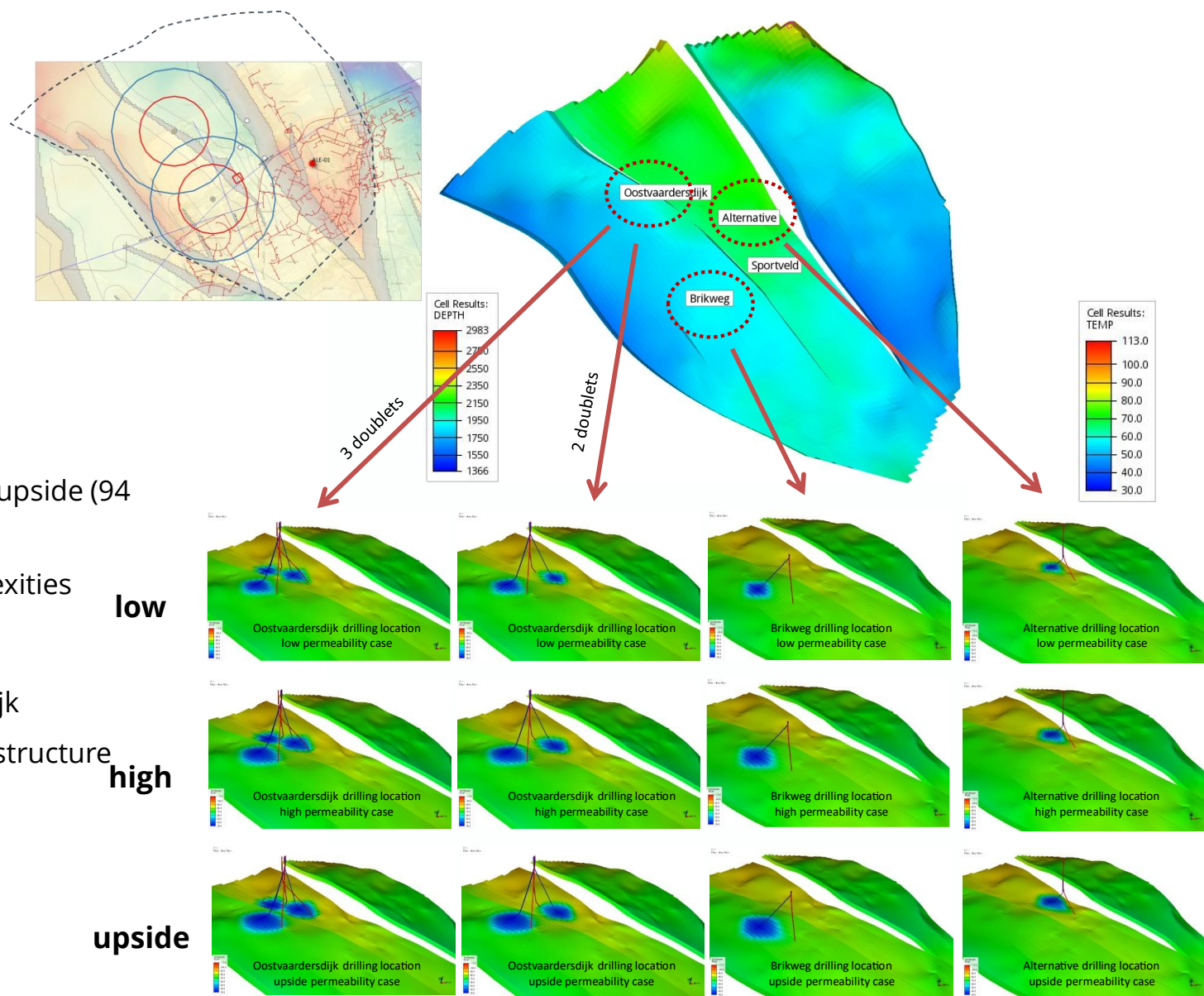
Initial



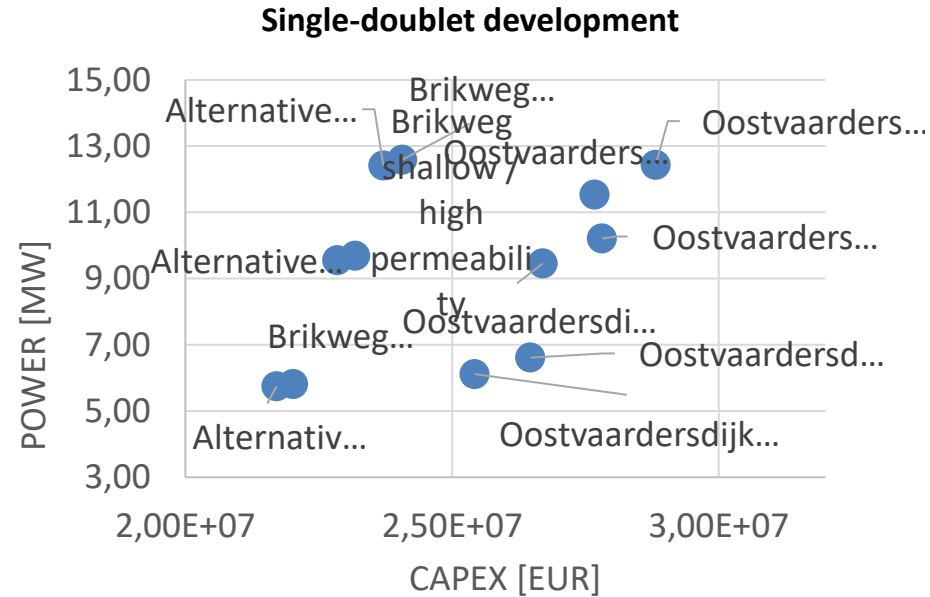
Optimal

Results: Almere

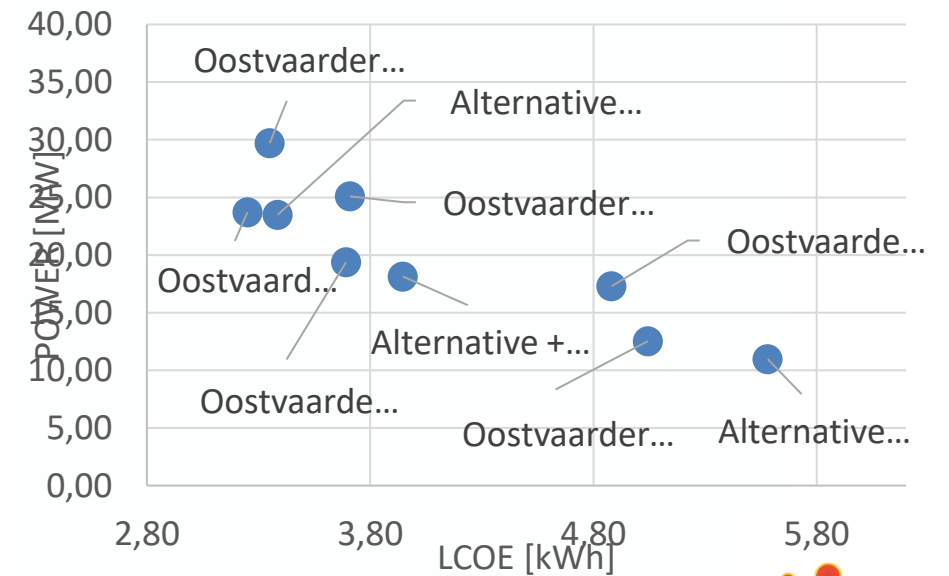
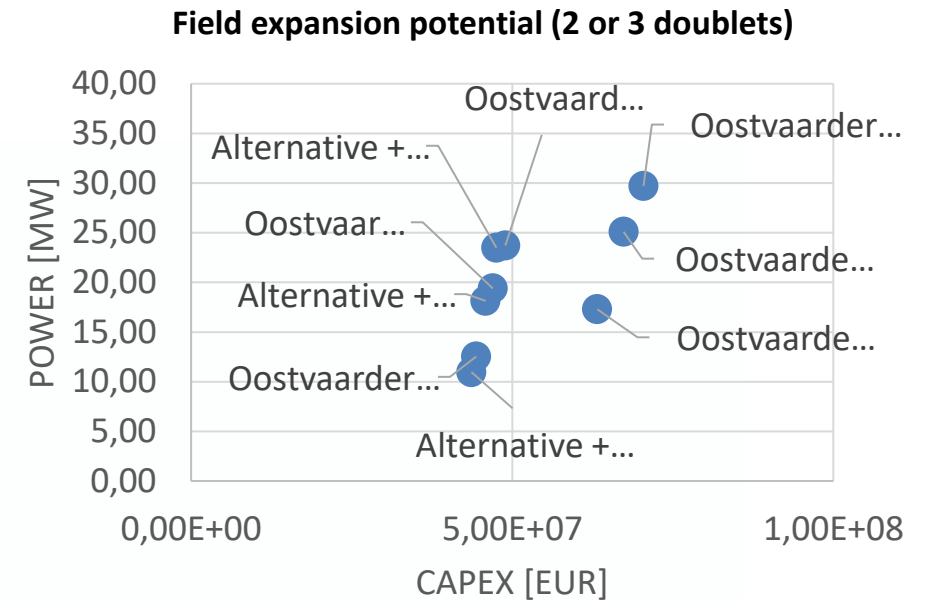
- 2 fault block compartments:
 - Deep and shallow
 - Higher temperatures in deep compartment
- Little information available (distant analog wells):
 - High uncertainty on flow properties (permeability)
 - 3 scenarios considered: low (43 mD), high (75 mD), upside (94 mD)
 - Mostly conceptual models, without detailed complexities
- 4 surface drilling locations considered:
 - Brikweg, Sportveld, Alternative and Oostvaardersdijk
 - Different costs associated with heat transport infrastructure
- **Which surface drilling location?**
How many doublets?



Results: Almere



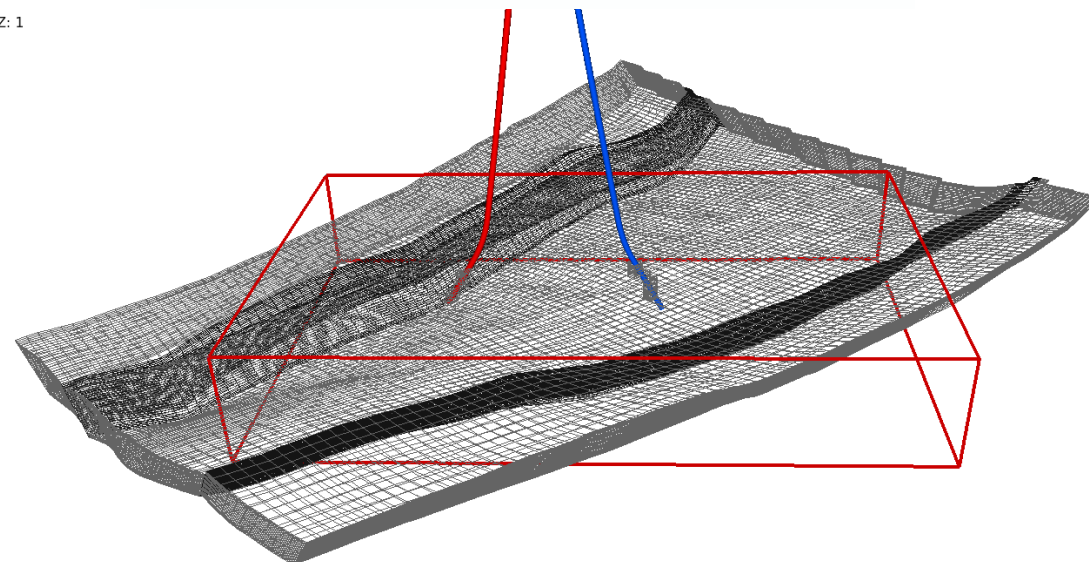
- Drilling first doublet from Oostvaardersdijk location is more expensive, but...
- It allows for expansion of the geothermal project
 - Possible to drill both compartments from single location (lower CAPEX)
 - Enables access to deeper part of deep fault block (higher temperatures)
 - Enables access to portion of deep fault block which could feed 2 doublets



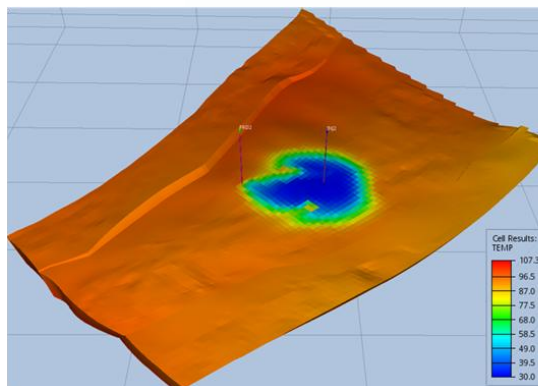
Dissemination: tutorial and workshop

- Tutorial case:
 - Realistic fictional reservoir simulation model was created
 - Illustrative example on how to use EVEREST for geothermal well trajectory optimization
 - Applies same workflow used to perform GEO4ALL-WP2 case studies
 - To be released: publicly available on TNO's Github soon
- Upcoming hands-on workshop:
 - Several participants from GEO4ALL community
 - Also a few external participants
 - Full-day workshop at Energy Cave (Rijswijk) on September 28th
 - To be covered:
 - Fundamentals of optimization methods
 - Introduction to EVEREST tool
 - Practical exercise (based on tutorial example)
 - Registration is already closed ☹️

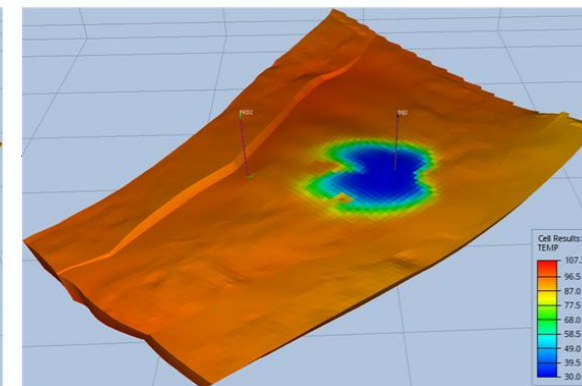
Z: 1



Temperature distribution



Initial



Optimal

Drilling risk matrix



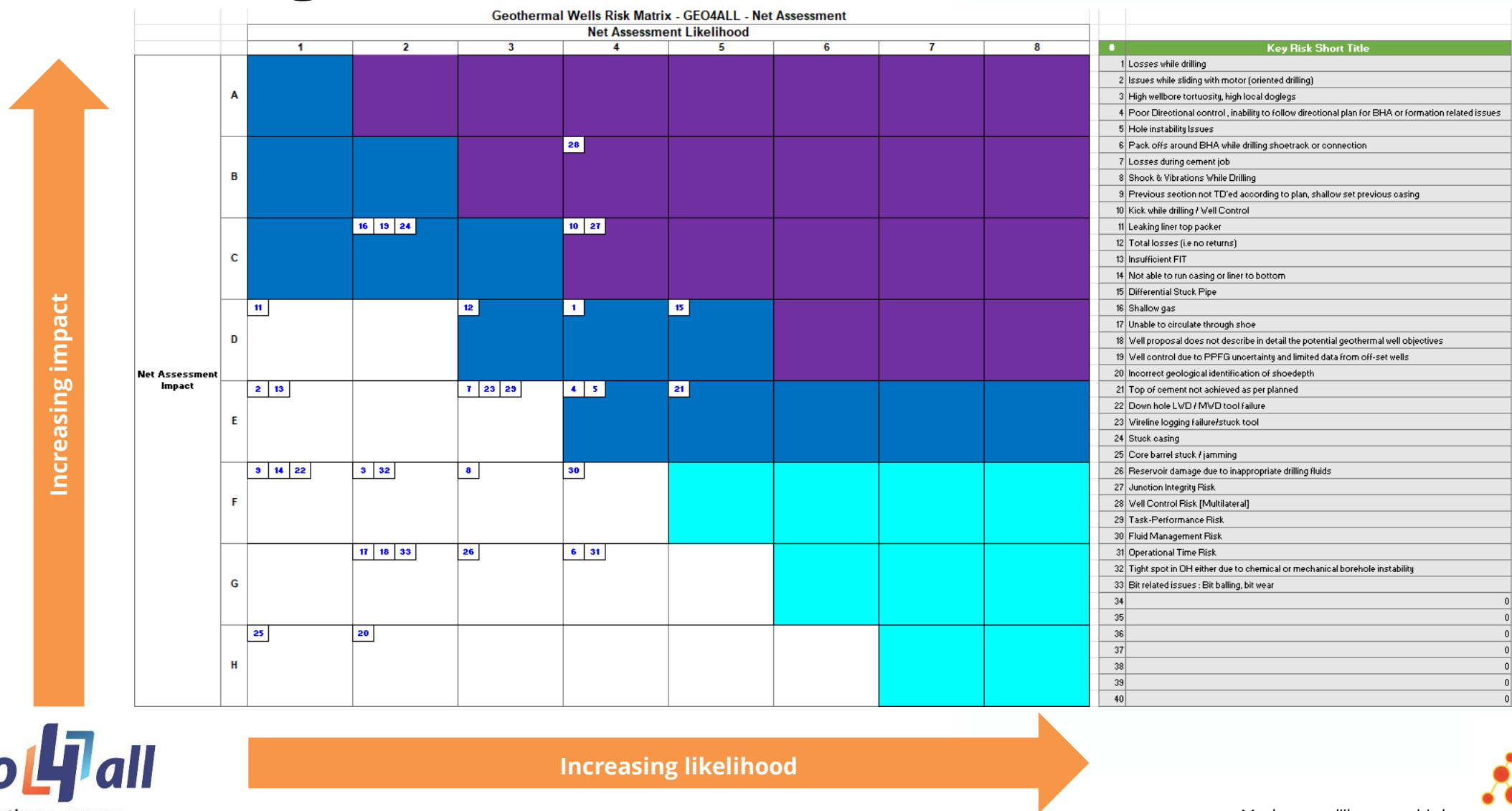
- WellPerform has prepared a **generic Geothermal Wells Drilling Risk Matrix**
 - Objective: provide geothermal operators with practical example of how drilling risks can be identified, assessed, ranked, prevented and mitigated using a transparent methodology
 - Excel sheet with qualitative risk assessment approach based on likelihood and impact ranking scales
 - Accompanying report describing the methodology and intended use of the risk matrix
- End-users may adapt structure, ranking criteria, terminology, risk categories and mitigation approach to align with their own internal risk management system, corporate risk matrix, regulatory requirements and project decision-gate process
- Note: any risk ranking exercise includes a degree of subjectivity. The rankings reflect the judgment of the assessment team based on the information available at the time of preparation. A generic risk matrix should therefore be treated as an indicative starting point, not as a definitive ranking for any specific project
- Real wells: risk ranking should be reviewed and updated by the well-specific project team using the latest subsurface interpretation, offset well evidence, planned well design, execution strategy and available mitigation measures

Drilling risk matrix

Geothermal Well Drilling Risk Register

Well: Geothermal				Risk Register Own Akram Miriyev																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
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Drilling risk matrix



Summary

- Main findings:
 - Optimization methodology is shown to be applicable and valuable to support field development decisions in various contexts
 - Integrating reservoir performance, economics and drilling constraints is key
 - Open-source optimization and simulation tools enable transparent and flexible evaluation of field development options
- Main hurdles for adoption of optimization workflows are not technological / methodological:
 - Knowledge, data and expertise seems to be very fragmented / scattered in the Dutch geothermal sector
 - Integrated optimization studies are multi-disciplinary: challenging for small teams and when not all required expertise is available in-house
 - Data curation and building subsurface models need improved best-practices
 - Uncertainties are acknowledged but not captured within models built to assess feasibility (particularly in early-phase stage)
- Next steps:
 - Deliver final report (currently under internal review at TNO)
 - Prepare a white paper / application-oriented scientific paper documenting main outcomes – first draft in Q4-2026
- Recommendations for future work:
 - Explore more detailed approaches for wellbore stability and drilling risk indicators (e.g., mud weight window index, torque and drag models)
 - More advanced subsurface characterization workflows to enable early-phase optimization opportunities

Thank you! Questions?

WP2 team:

- TNO: Eduardo Barros (lead scientist), Sławomir Szklarz (optimization expert), Negar Khoshnevis Gargar (reservoir engineer), Jens Wollenweber (PM)
- Geothermie NL: Floris Post (Hannes Groot)
- WellPerform: Akram Miriyev, Niels Frinks
- HVC: Charlotte de Wijkerslooth, Cees Willems
- Gem. Amsterdam: Esmée Waardenburg
- Gem. Almere: Sabrina Strijbos
- Vattenfall: Ivo Vos
- Aardwarmte Combinatie Luttelgeest (ACL): Gerard Fuite
- IF Technology: Nick Buik
- Greenhousegeopower (Aardwarmtecluster): Radboud Vorage
- EBN: Felix Bexkens, Nora Heijnen
- Canopus Drilling Solutions: Pieter van Nieuwkoop (Jeanet Schouten)



T2.3 Preliminary Mud Research

A controlled way to move to OBM alternatives



Felix Bexkens, General Meeting GEO4ALL, 17 September 2026

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Background

*“The different well concepts have implications for operational parameters. An important aspect is the **drilling fluid** and the ability to **remove cuttings**. The focus will lie on **performance** (both overburden and reservoir section), improvement in the **circularity** of the drilling fluid and **cost** reduction options for both fluids and cuttings. This is supplemented with a **GAP analysis** of what type of innovation is needed to successfully develop this further.”*

- T2.3 was approved without funding and scope was quite broad
- Not a result, suggestion for future research and/or workflow for operators
- Waste handling cost (OBM and oil contaminated cuttings) is rising
- HPWBM has matured over the last decade, but how to introduce in a controlled manner
- Sidetracks and drilling issues are probably more expensive than waste handling

Three ways to change from OBM to HPWBM

1. Don't do it

Stay with current practice, perfect it. Lowest effort, keeps known cost, risk and waste.

Improve performance instead.

2. Just do it

Switch and see what happens. Fast, but higher level of risk.

Expect the unexpected.

3. Do it in a controlled manner

Diagnose, characterize, test, then decide based on the evidence, still a risk, but more controlled.

Evidence before commitment.

The proposed methodology at a glance

The logo for ebn, consisting of the lowercase letters 'ebn' in white on a blue square background.

1 Problem Diagnosis

Measures: Drilling performance in the broadest possible sense; based on in-house drilling data, cross-checked against industry datasets

Why: *Fully understand current drilling performance, before touching your mud system*

2 (Overburden) Formation Characterization

Measures: XRD for clay mineral suite, CEC for reactivity, SEM for microstructure/microfractures; on overburden core where available

Why: *Overburden (reactivity) is often undocumented, what rocks does a mudsystem interact with*

3 Technology & Market Review

Measures: Scored comparison on performance, circularity (biodegradability, waste class) and cost (fluid, disposal, logistics)

Why: *Narrows a broad market to only the candidates worth the expense of lab testing*

4 Laboratory Validation (vs OBM reference)

Measures: Linear swell, hot-roll recovery, accretion, HPHT filtration, lubricity, rheological stability, contamination tolerance; core or cuttings

Why: *Performance is a threshold, not tradeable: must match or beat OBM before circularity or cost count*

5 Gap Analysis & Documentation → Implementation

Measures: OBM benchmark carried through on performance, circularity and cost; every gap marked closeable or blocker

Why: *Consolidates Parts 1–4 into an evidence base that supports an actual decision to switch mud system*

Thoughts?

- Do you already use HPWBM? What is your experience?
- Would you consider switching?
- Industry wide or individually?
- Could Dutch laboratories do this kind of testing?
- Would you be willing to acquire core for this purpose?