

Digital Twin of Geothermal Assets

An Open-Source Approach for the Geothermal Sector

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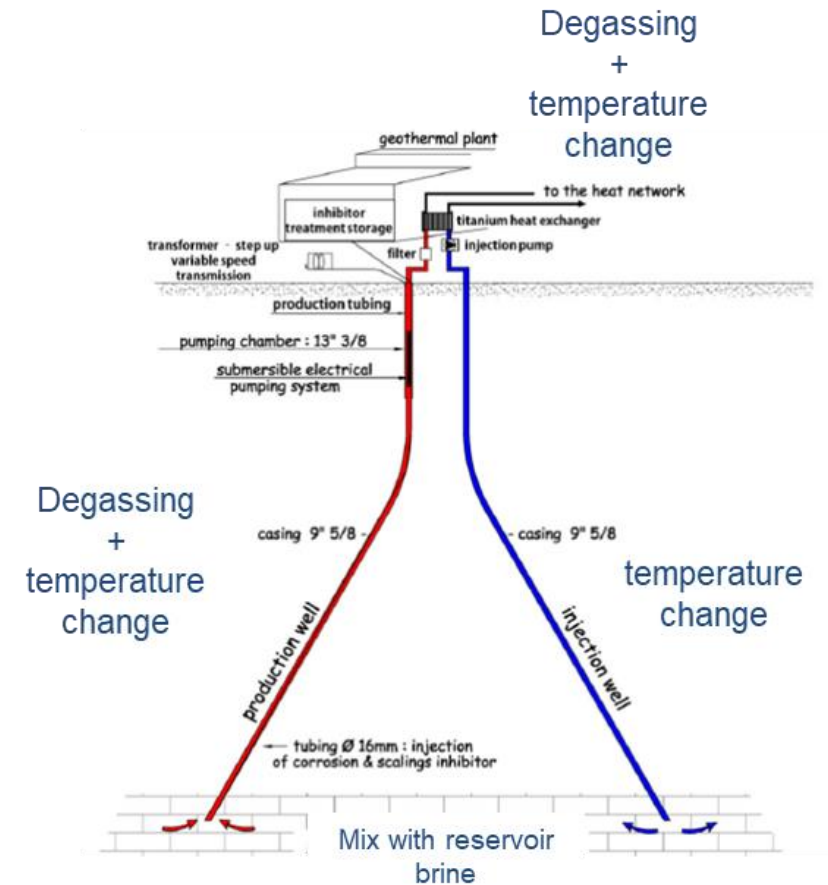
DRAFT

Photo generated by AI

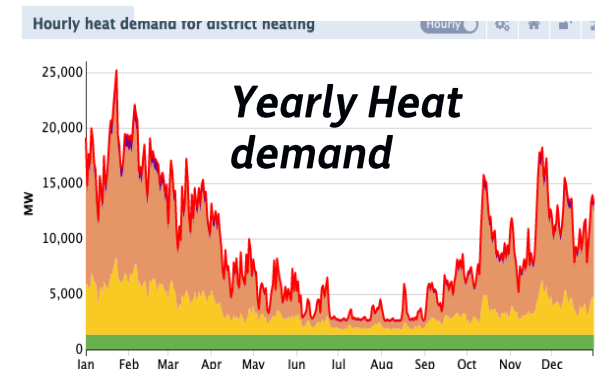
A futuristic control room with multiple monitors and a large screen displaying data. The room is dimly lit, with the primary light source being the screens and panels. The monitors show various data visualizations, including maps and charts. The overall aesthetic is high-tech and modern.

Motivation

- Growth in geothermal assets in NL and worldwide
- Increasingly complex production and operation
 - Responding to heat demand with a minimum environmental footprint
 - Complex operational challenges
 - Planned and unplanned maintenance
 - Learning curve for operators needs to be accelerated
- Need for a centralized, fast, optimum and robust operational decisions employing data in the life cycle of a plant



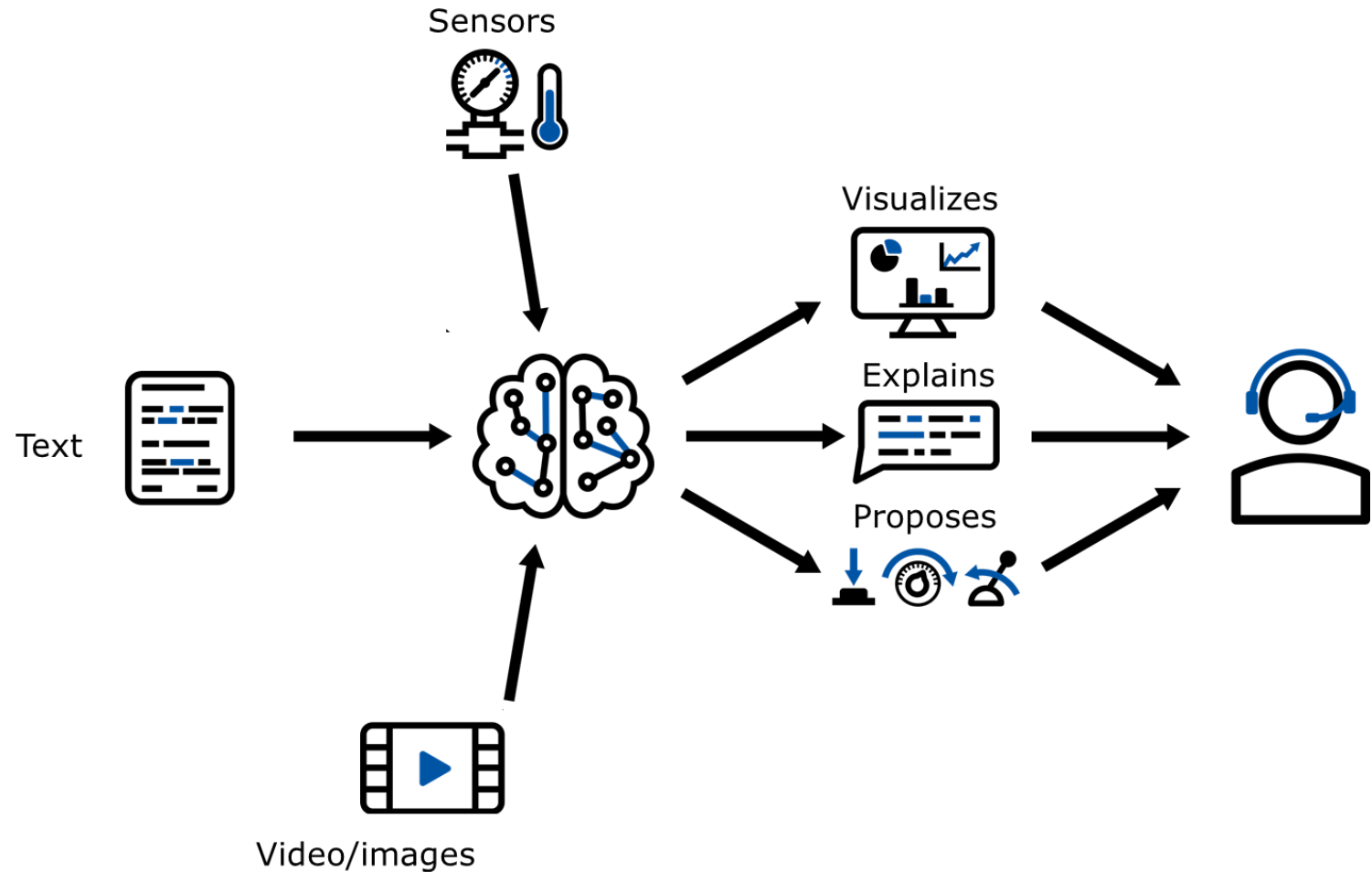
From Kervevan et al., 2014



TNO for life

Vision: Optimum Operational Decisions

- Towards an intelligent decision support framework
- Increase production efficiency
- Reduce risks and emissions
- Accelerate the learning curve in the sector
- Enabling the knowledge transfer from experienced operators to young operators



Development and Demonstration Projects



- A national growth fund project in the Netherlands to demonstrate GEMINI in geothermal systems and ATES
 - 3 sites, Live demonstrations
 - Monitoring the implementation for > 6 months
 - Full value chain onboard
 - An Open-Access tool to be available in 2025
 - Open-source libraries to be released in 2026



Rijksdienst voor Ondernemend Nederland

Digital Twin of Geothermal Assets

- A virtual representation that serves as the real-time digital counterpart of a physical object or process (NASA)
- Dynamic processes, dynamic system changing overtime, variable demand, uncertainties in subsurface and surface processes
- Why? Minimize maintenance cost, maximize production, Reduce environmental footprint, ...

Physical object



Static and real-time data

Mechanisms

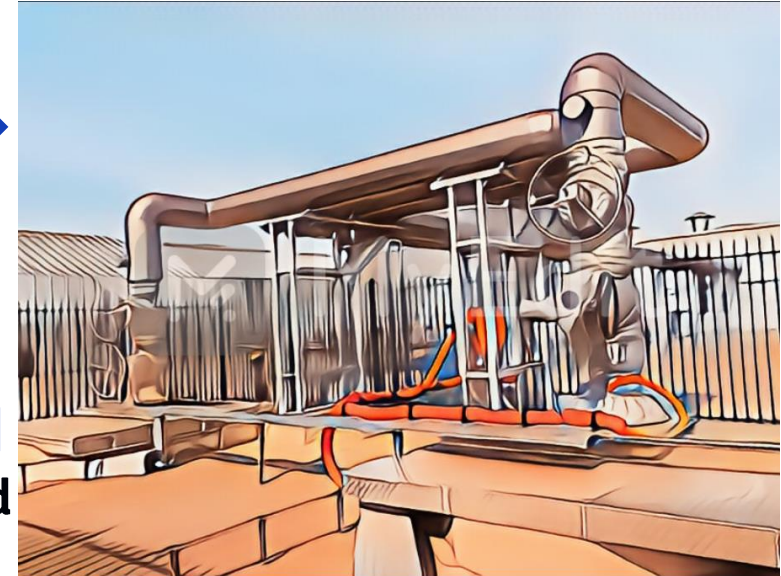


Data exchange



Information, actions and
feedbacks

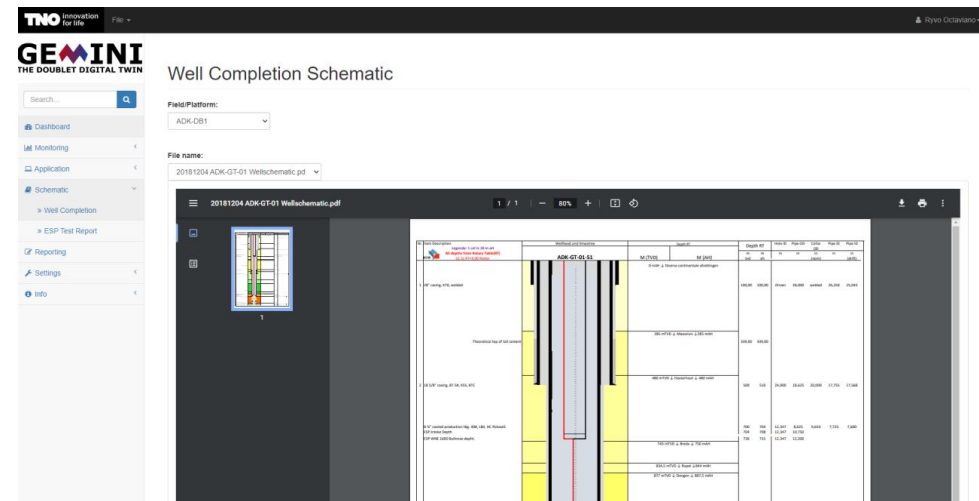
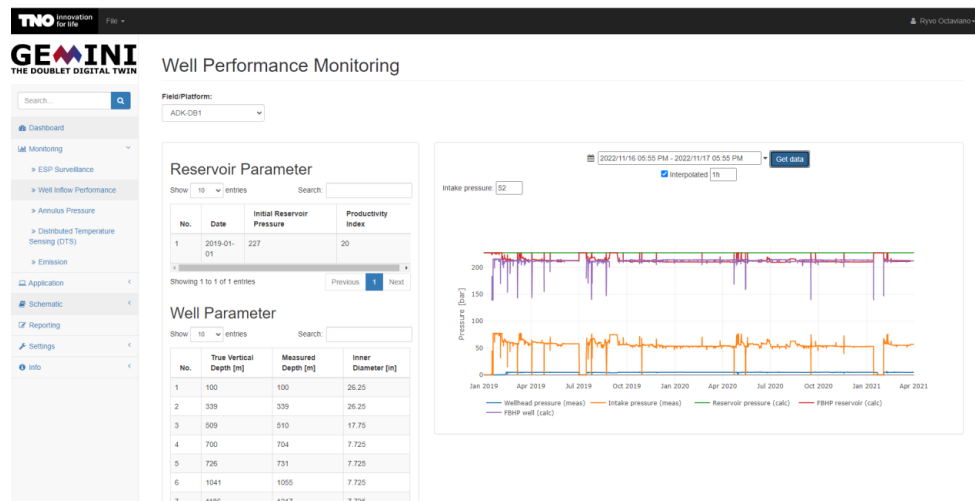
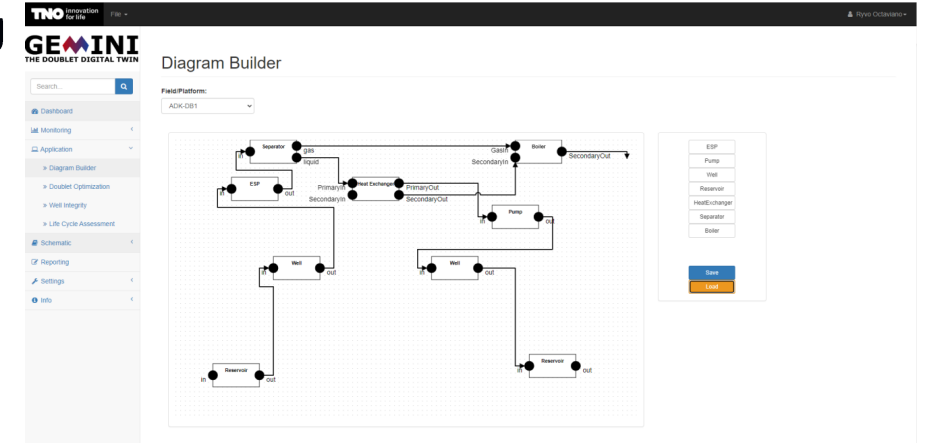
Digital object



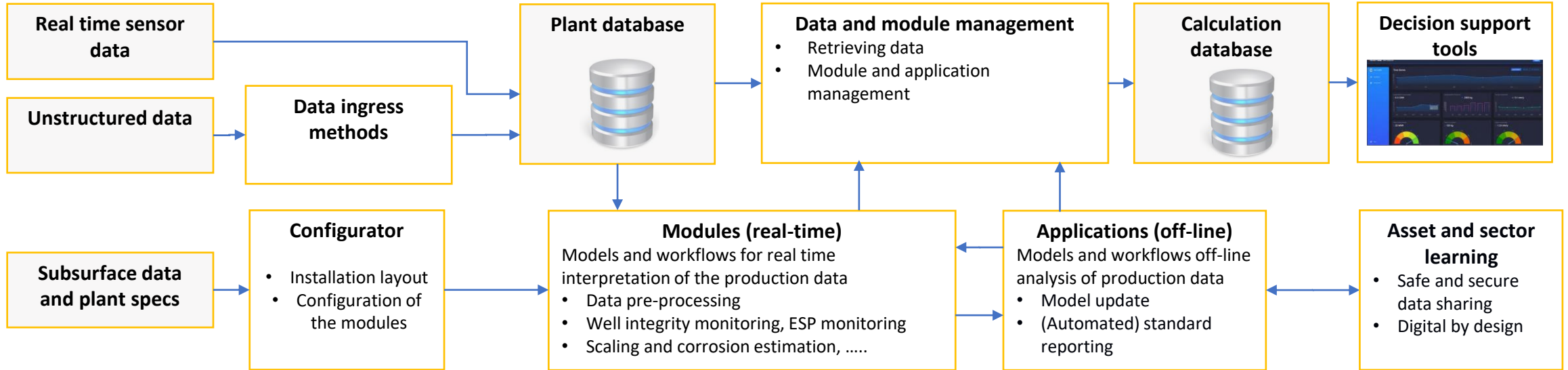
GEMINI



- A flexible web-based framework for real-time **monitoring, forecasting and optimization**
- Act as an assistant to the operators of geothermal and ATEs systems
- Centralized location to access all the (updated) data
 - Performance, integrity and environmental footprint monitoring
 - Critical processes (scaling, erosion, corrosion)
 - Production and operation advisory system



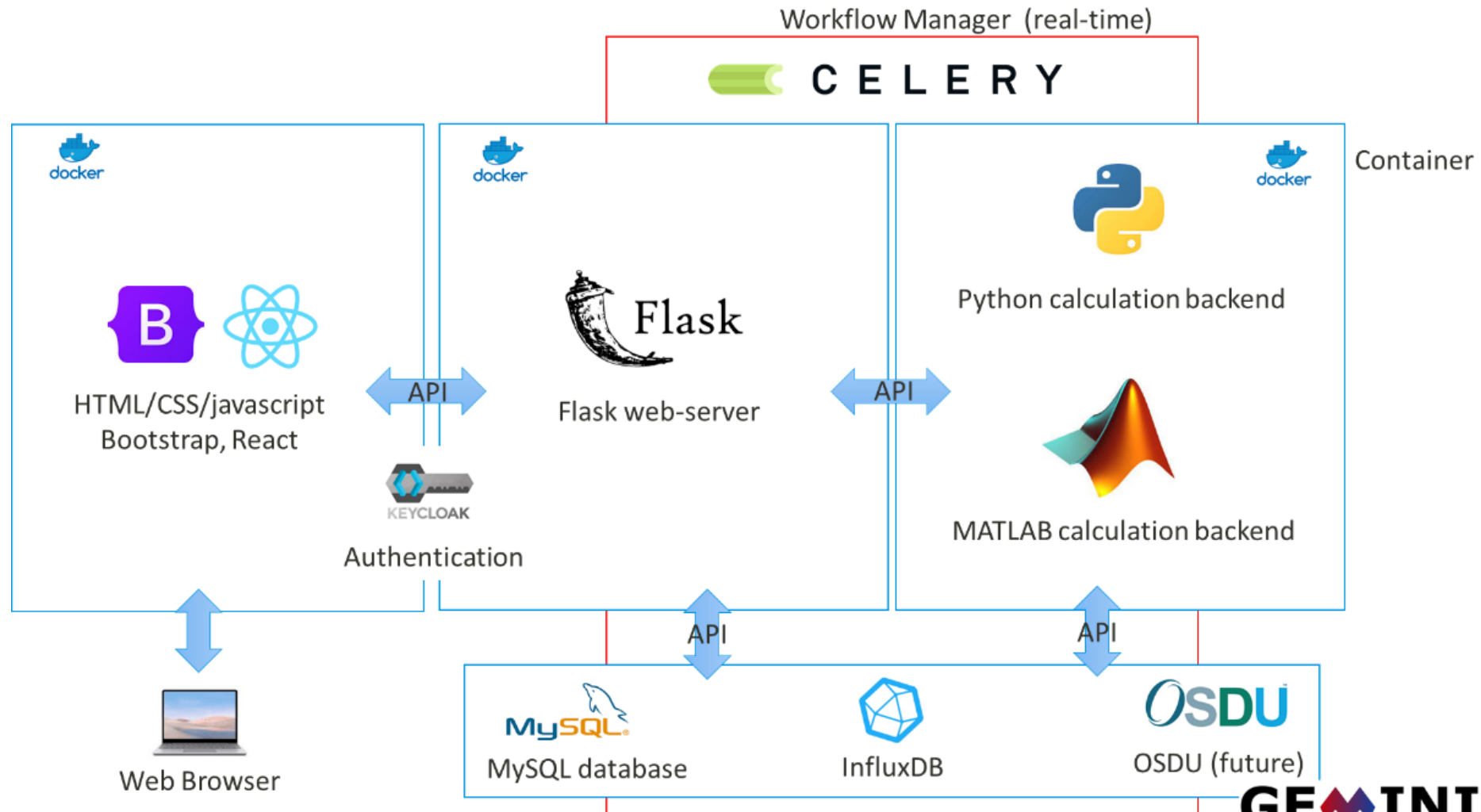
Digital Twin Key Components



Key component	Functions
Data management system	Data retrieval, preprocessing, module management
Configurator	Plant lay out, configuration of the modules
Modules	Models and workflows for real time interpretation of the production data
Applications	Models and workflows off-line analysis of production data
Real time decision support tools	Modules for real time decision support, event detection, automated alarms , control, real time production advice.
GUI	User interface
Asset and sector learning	
Data ingress system	API production database, methods for ingress of intermittent and static data

GEMINI Architecture

Towards an Open-Source Implementation



GEMINI

An Impression of GEMINI

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GEMINI
THE DOUBLET DIGITAL TWIN

Search...

- Dashboard
- Monitoring
- Application
- Diagram Builder
- Doublet Optimization
- Well Integrity
- Life Cycle Assessment
- Schematic
- Reporting
- Settings
- Info

Diagram Builder

Field/Platform: ADK-DB1

Components: ESP, Pump, Well, Reservoir, Heat Exchanger, Separator, Boiler

Buttons: Save, Load

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THE DOUBLET DIGITAL TWIN

Search...

- Dashboard
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- Schematic
- Reporting
- Settings
- Info

Well Performance Monitoring

Field/Platform: ADK-DB1

Reservoir Parameter

Show 10 entries

No.	Date	Initial Reservoir Pressure	Productivity Index
1	2019-01-01	227	20

Well Parameter

Show 10 entries

No.	True Vertical Depth [m]	Measured Depth [m]	Inner Diameter [m]
1	100	100	26.25
2	339	339	26.25
3	509	510	17.75
4	700	704	7.725
5	726	731	7.725
6	1041	1055	7.725
7	1185	1217	7.725

Intake pressure: 52

2022/11/16 05:55 PM - 2022/11/17 05:55 PM

Get data

Interpolated 1h

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- Reporting
- Settings
- Info

Annulus Pressure Monitoring

Field/Platform: ADK-DB1

Monitoring | Alarm limit

2022/11/16 05:55 PM - 2022/11/17 05:55 PM

Get data

Interpolated 1h

EMW (ppg):

Surface Casing Shoe TVD (m): 1000

RKB Tubing hanger (m): 1000

Save Parameter

Calculated A-annulus MAA SP (bar):

Calculated B-annulus MAA SP (bar):

Labels: tubing hanger, tubing head, casing head, C annulus, B annulus, A annulus, surface casing, intermediate casing, production casing, production tubing, formation, gas chamber, mud, gas bubble, cement, A annulus monitor, B annulus monitor, C annulus monitor

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Search...

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- Reporting
- Settings
- Info

Well Completion Schematic

Field/Platform: ADK-DB1

File name: 20181204 ADK-GT-01 Wellschematic.pdf

20181204 ADK-GT-01 Wellschematic.pdf

1 / 1 | 80% | + | -

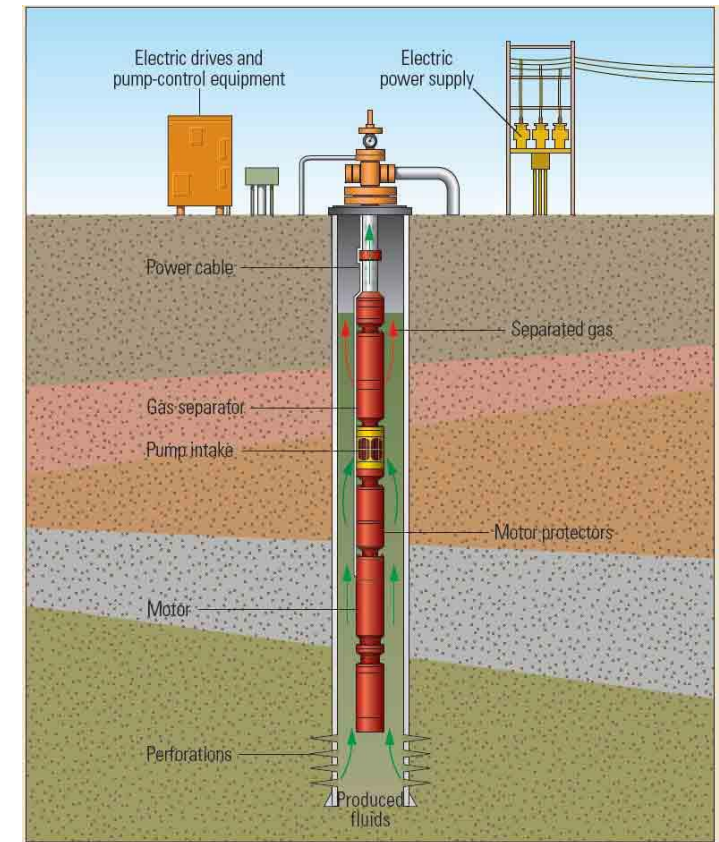
Depth (RT)	MAASP	Flow Rate	Flow Rate	Flow Rate	Flow Rate
100.00	100.00	10.00	10.00	10.00	10.00
300.00	300.00	30.00	30.00	30.00	30.00
500.00	500.00	50.00	50.00	50.00	50.00
700.00	700.00	70.00	70.00	70.00	70.00
900.00	900.00	90.00	90.00	90.00	90.00
1100.00	1100.00	110.00	110.00	110.00	110.00
1300.00	1300.00	130.00	130.00	130.00	130.00
1500.00	1500.00	150.00	150.00	150.00	150.00
1700.00	1700.00	170.00	170.00	170.00	170.00
1900.00	1900.00	190.00	190.00	190.00	190.00
2100.00	2100.00	210.00	210.00	210.00	210.00
2300.00	2300.00	230.00	230.00	230.00	230.00
2500.00	2500.00	250.00	250.00	250.00	250.00
2700.00	2700.00	270.00	270.00	270.00	270.00
2900.00	2900.00	290.00	290.00	290.00	290.00
3100.00	3100.00	310.00	310.00	310.00	310.00
3300.00	3300.00	330.00	330.00	330.00	330.00
3500.00	3500.00	350.00	350.00	350.00	350.00
3700.00	3700.00	370.00	370.00	370.00	370.00
3900.00	3900.00	390.00	390.00	390.00	390.00
4100.00	4100.00	410.00	410.00	410.00	410.00
4300.00	4300.00	430.00	430.00	430.00	430.00
4500.00	4500.00	450.00	450.00	450.00	450.00
4700.00	4700.00	470.00	470.00	470.00	470.00
4900.00	4900.00	490.00	490.00	490.00	490.00
5100.00	5100.00	510.00	510.00	510.00	510.00
5300.00	5300.00	530.00	530.00	530.00	530.00
5500.00	5500.00	550.00	550.00	550.00	550.00
5700.00	5700.00	570.00	570.00	570.00	570.00
5900.00	5900.00	590.00	590.00	590.00	590.00
6100.00	6100.00	610.00	610.00	610.00	610.00
6300.00	6300.00	630.00	630.00	630.00	630.00
6500.00	6500.00	650.00	650.00	650.00	650.00
6700.00	6700.00	670.00	670.00	670.00	670.00
6900.00	6900.00	690.00	690.00	690.00	690.00
7100.00	7100.00	710.00	710.00	710.00	710.00
7300.00	7300.00	730.00	730.00	730.00	730.00
7500.00	7500.00	750.00	750.00	750.00	750.00
7700.00	7700.00	770.00	770.00	770.00	770.00
7900.00	7900.00	790.00	790.00	790.00	790.00
8100.00	8100.00	810.00	810.00	810.00	810.00
8300.00	8300.00	830.00	830.00	830.00	830.00
8500.00	8500.00	850.00	850.00	850.00	850.00
8700.00	8700.00	870.00	870.00	870.00	870.00
8900.00	8900.00	890.00	890.00	890.00	890.00
9100.00	9100.00	910.00	910.00	910.00	910.00
9300.00	9300.00	930.00	930.00	930.00	930.00
9500.00	9500.00	950.00	950.00	950.00	950.00
9700.00	9700.00	970.00	970.00	970.00	970.00
9900.00	9900.00	990.00	990.00	990.00	990.00
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10300.00	10300.00	1030.00	1030.00	1030.00	1030.00
10500.00	10500.00	1050.00	1050.00	1050.00	1050.00
10700.00	10700.00	1070.00	1070.00	1070.00	1070.00
10900.00	10900.00	1090.00	1090.00	1090.00	1090.00
11100.00	11100.00	1110.00	1110.00	1110.00	1110.00
11300.00	11300.00	1130.00	1130.00	1130.00	1130.00
11500.00	11500.00	1150.00	1150.00	1150.00	1150.00
11700.00	11700.00	1170.00	1170.00	1170.00	1170.00
11900.00	11900.00	1190.00	1190.00	1190.00	1190.00
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12300.00	12300.00	1230.00	1230.00	1230.00	1230.00
12500.00	12500.00	1250.00	1250.00	1250.00	1250.00
12700.00	12700.00	1270.00	1270.00	1270.00	1270.00
12900.00	12900.00	1290.00	1290.00	1290.00	1290.00
13100.00	13100.00	1310.00	1310.00	1310.00	1310.00
13300.00	13300.00	1330.00	1330.00	1330.00	1330.00
13500.00	13500.00	1350.00	1350.00	1350.00	1350.00
13700.00	13700.00	1370.00	1370.00	1370.00	1370.00
13900.00	13900.00	1390.00	1390.00	1390.00	1390.00
14100.00	14100.00	1410.00	1410.00	1410.00	1410.00
14300.00	14300.00	1430.00	1430.00	1430.00	1430.00
14500.00	14500.00	1450.00	1450.00	1450.00	1450.00
14700.00	14700.00	1470.00	1470.00	1470.00	1470.00
14900.00	14900.00	1490.00	1490.00	1490.00	1490.00
15100.00	15100.00	1510.00	1510.00	1510.00	1510.00
15300.00	15300.00	1530.00	1530.00	1530.00	1530.00
15500.00	15500.00	1550.00	1550.00	1550.00	1550.00
15700.00	15700.00	1570.00	1570.00	1570.00	1570.00
15900.00	15900.00	1590.00	1590.00	1590.00	1590.00
16100.00	16100.00	1610.00	1610.00	1610.00	1610.00
16300.00	16300.00	1630.00	1630.00	1630.00	1630.00
16500.00	16500.00	1650.00	1650.00	1650.00	1650.00
16700.00	16700.00	1670.00	1670.00	1670.00	1670.00
16900.00	16900.00	1690.00	1690.00	1690.00	1690.00
17100.00	17100.00	1710.00	1710.00	1710.00	1710.00
17300.00	17300.00	1730.00	1730.00	1730.00	1730.00
17500.00	17500.00	1750.00	1750.00	1750.00	1750.00
17700.00	17700.00	1770.00	1770.00	1770.00	1770.00
17900.00	17900.00	1790.00	1790.00	1790.00	1790.00
18100.00	18100.00	1810.00	1810.00	1810.00	1810.00
18300.00	18300.00	1830.00	1830.00	1830.00	1830.00
18500.00	18500.00	1850.00	1850.00	1850.00	1850.00
18700.00	18700.00	1870.00	1870.00	1870.00	1870.00
18900.00	18900.00	1890.00	1890.00	1890.00	1890.00
19100.00	19100.00	1910.00	1910.00	1910.00	1910.00
19300.00	19300.00	1930.00	1930.00	1930.00	1930.00
19500.00	19500.00	1950.00	1950.00	1950.00	1950.00
19700.00	19700.00	1970.00	1970.00	1970.00	1970.00
19900.00	19900.00	1990.00	1990.00	1990.00	1990.00
20100.00	20100.00	2010.00	2010.00	2010.00	2010.00
20300.00	20300.00	2030.00	2030.00	2030.00	2030.00
20500.00	20500.00	2050.00	2050.00	2050.00	2050.00
20700.00	20700.00	2070.00	2070.00	2070.00	2070.00
20900.00	20900.00	2090.00	2090.00	2090.00	2090.00
21100.00	21100.00	2110.00	2110.00	2110.00	2110.00
21300.00	21300.00	2130.00	2130.00	2130.00	2130.00
21500.00	21500.00	2150.00	2150.00	2150.00	2150.00
21700.00	21700.00	2170.00	2170.00	2170.00	2170.00
21900.00	21900.00	2190.00	2190.00	2190.00	2190.00
22100.00	22100.00	2210.00	2210.00	2210.00	2210.00
22300.00	22300.00	2230.00	2230.00	2230.00	2230.00
22500.00	22500.00	2250.00	2250.00	2250.00	2250.00
22700.00	22700.00	2270.00	2270.00	2270.00	2270.00
22900.00	22900.00	2290.00	2290.00	2290.00	2290.00
23100.00	23100.00	2310.00	2310.00	2310.00	2310.00
23300.00	23300.00	2330.00	2330.00	2330.00	2330.00
23500.00	23500.00	2350.00	2350.00	2350.00	2350.00
23700.00	23700.00	2370.00	2370.00	2370.00	2370.00
23900.00	23900.00	2390.00	2390.00	2390.00	2390.00
24100.00	24100.00	2410.00	2410.00	2410.00	2410.00
24300.00	24300.00	2430.00	2430.00	2430.00	2430.00
24500.00	24500.00	2450.00	2450.00	2450.00	2450.00
24700.00	24700.00	2470.00	2470.00	2470.00	2470.00
24900.00	24900.00	2490.00	2490.00		

Example: Predictive maintenance

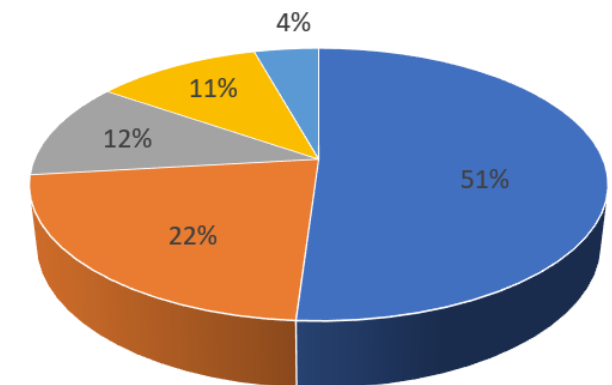
The current geothermal ESPs have several shortcomings;

- Relatively **short lifetime** (~ 1-2 years)
- Available ESP designs are optimized for oil wells (sub-optimum for geothermal conditions) leading to **frequent failures**
- ESP operational envelope should accommodate with production variations (P, rates, clogging,...)
- Lack of **proactive monitoring** of system performance during the operation
- High **costs** associated with **ESP inspection** and **replacement**

Suboptimum operation of the ESP caused by lack of proper monitoring and operator errors

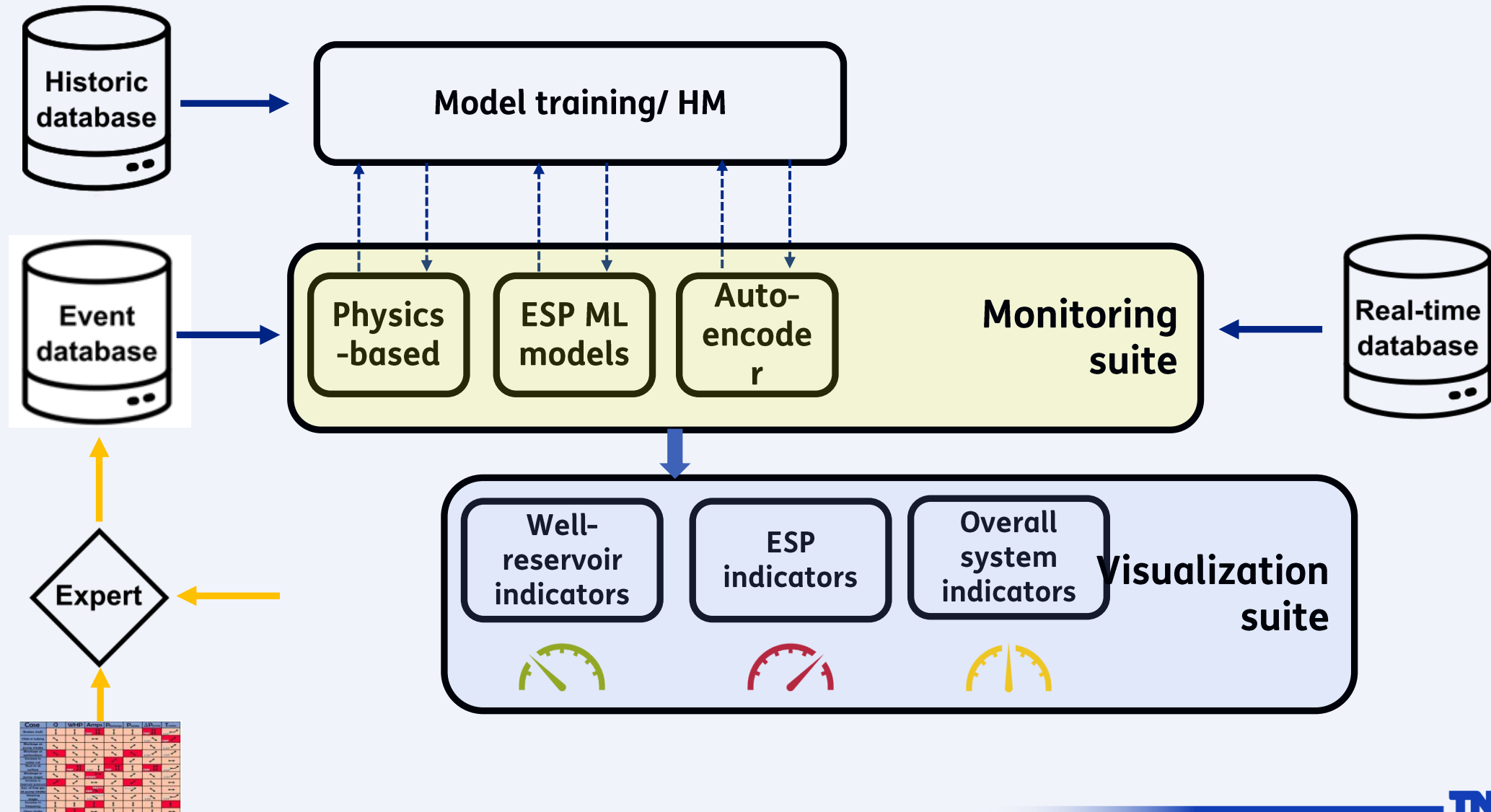


Annual OPEX of each component, operator 1

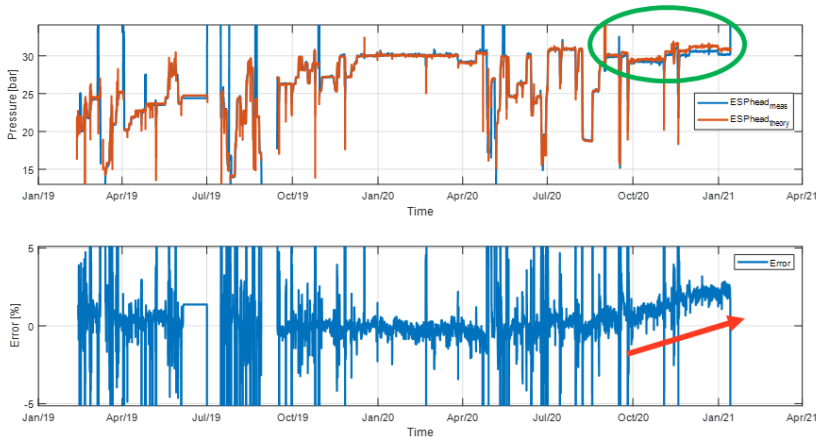
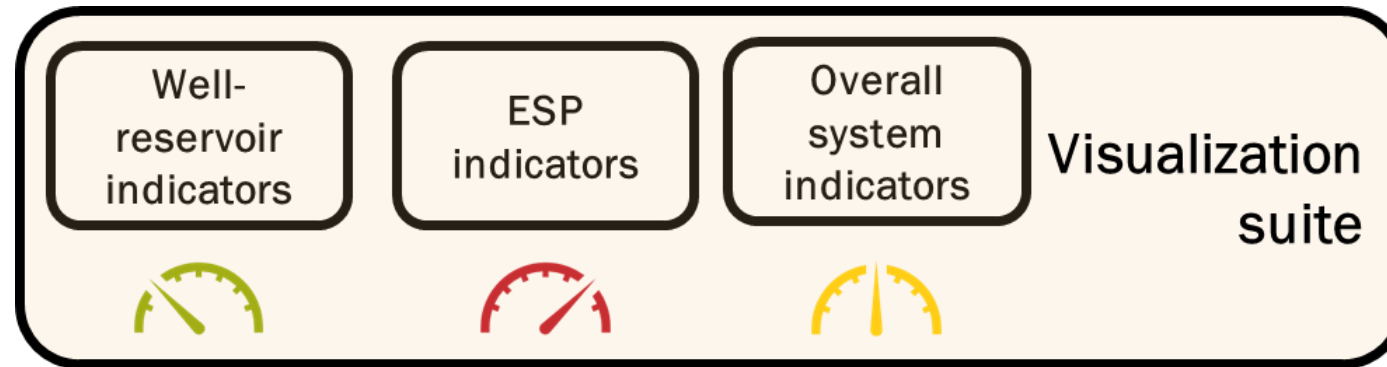


■ ESP: ■ Production well: ■ Surface facilities: ■ Injector well: ■ Filters:

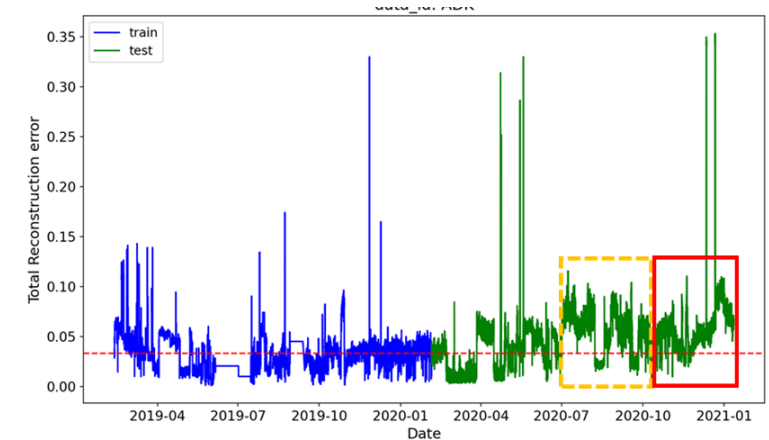
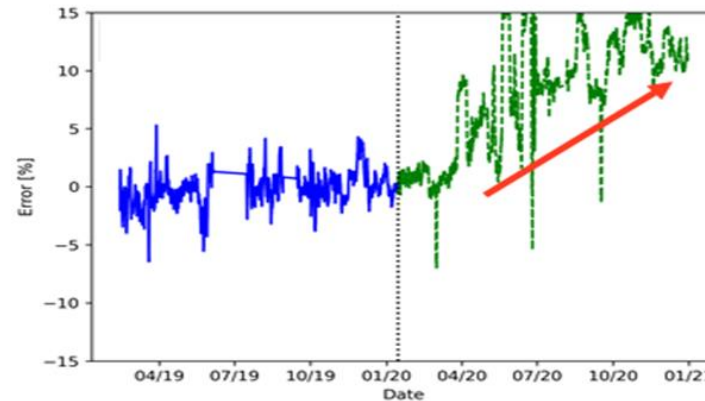
Workflow for Predictive Maintenance



Example: Predictive maintenance



ESP vibration




Early signs of degradation visible 6 months prior to the failure.

Operation Scenarios Evaluation

- Optimize geothermal operating condition parameters
- Maximizing based objective functions:
 - Total produced power
 - Minimum power consumption
 - Minimum CO2 emission

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Doublet Optimization Application

Field/Platform: Select Field

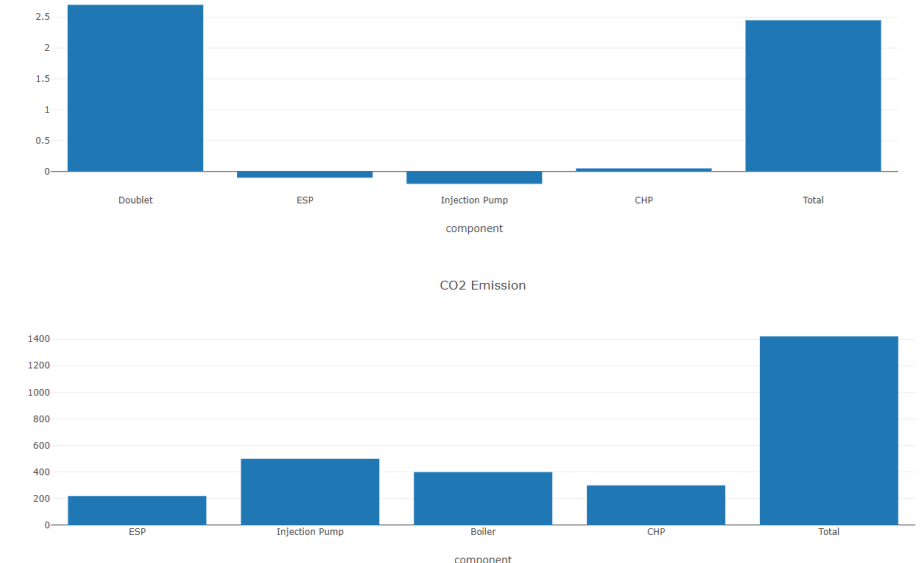
Optimization Variable	Lower Bound	Initial Value	Upper Bound
<input checked="" type="checkbox"/> Wellhead pressure [bar]	<input type="text" value="1"/>	<input type="text" value="5"/>	<input type="text" value="10"/>
<input checked="" type="checkbox"/> ESP Frequency [Hz]	<input type="text" value="30"/>	<input type="text" value="52"/>	<input type="text" value="60"/>
<input checked="" type="checkbox"/> Temp secondary side [C]	<input type="text" value="20"/>	<input type="text" value="41"/>	<input type="text" value="62"/>
<input checked="" type="checkbox"/> Flow secondary side [m3/h]	<input type="text" value="50"/>	<input type="text" value="200"/>	<input type="text" value="400"/>
<input checked="" type="checkbox"/> Gas flow percentage [-]	<input type="text" value="0"/>	<input type="text" value="0.05"/>	<input type="text" value="1"/>
<input checked="" type="checkbox"/> Water flow percentage secondary side [-]	<input type="text" value="0"/>	<input type="text" value="0.9"/>	<input type="text" value="1"/>

Constraints	Lower Bound	Upper Bound
<input checked="" type="checkbox"/> Temperature Output [C]	<input type="text" value="60"/>	<input type="text" value="100"/>
<input checked="" type="checkbox"/> Total Power [kW]	<input type="text" value="1000"/>	<input type="text" value="8000"/>
<input checked="" type="checkbox"/> Electricity Surplus [kW]	<input type="text" value="300"/>	<input type="text" value="1000"/>


Objective Function:

Maximize total net energy

Optimize

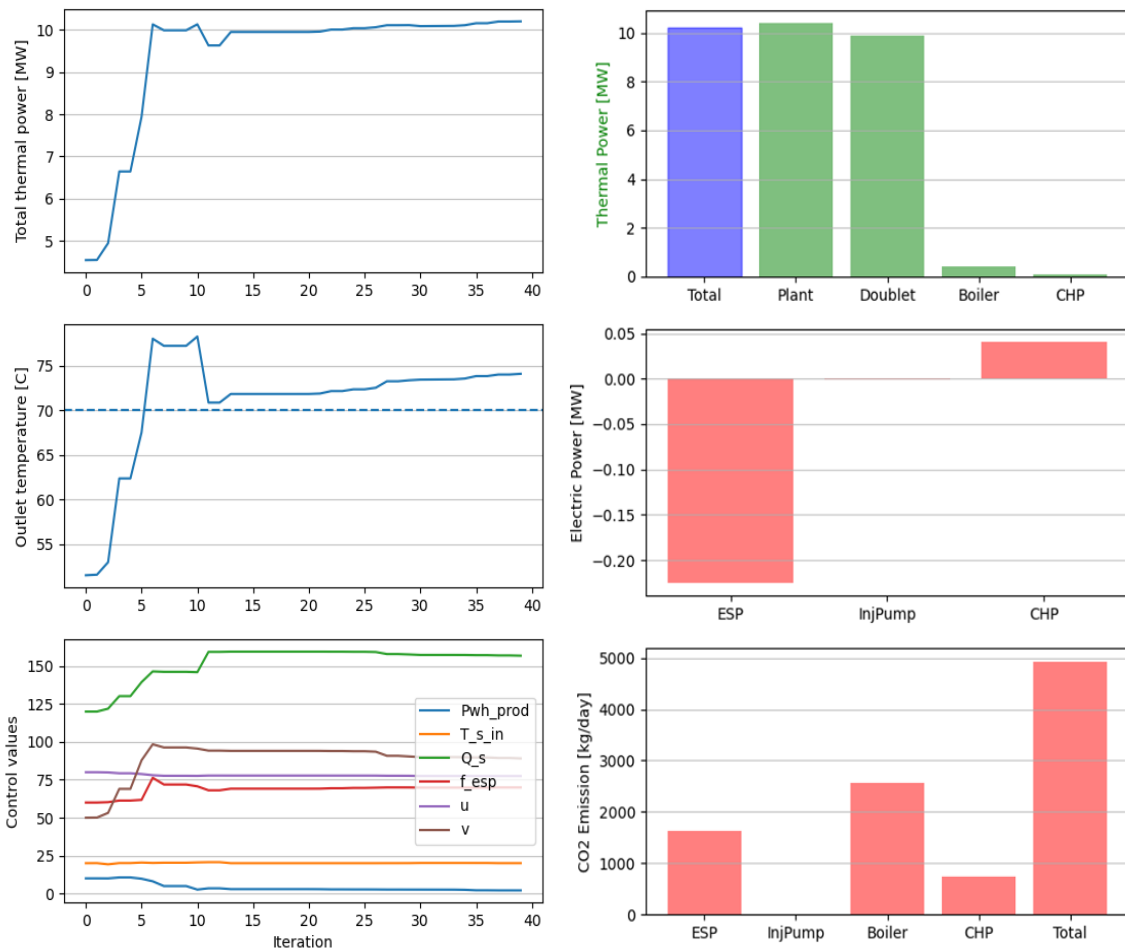


CO2 Emission

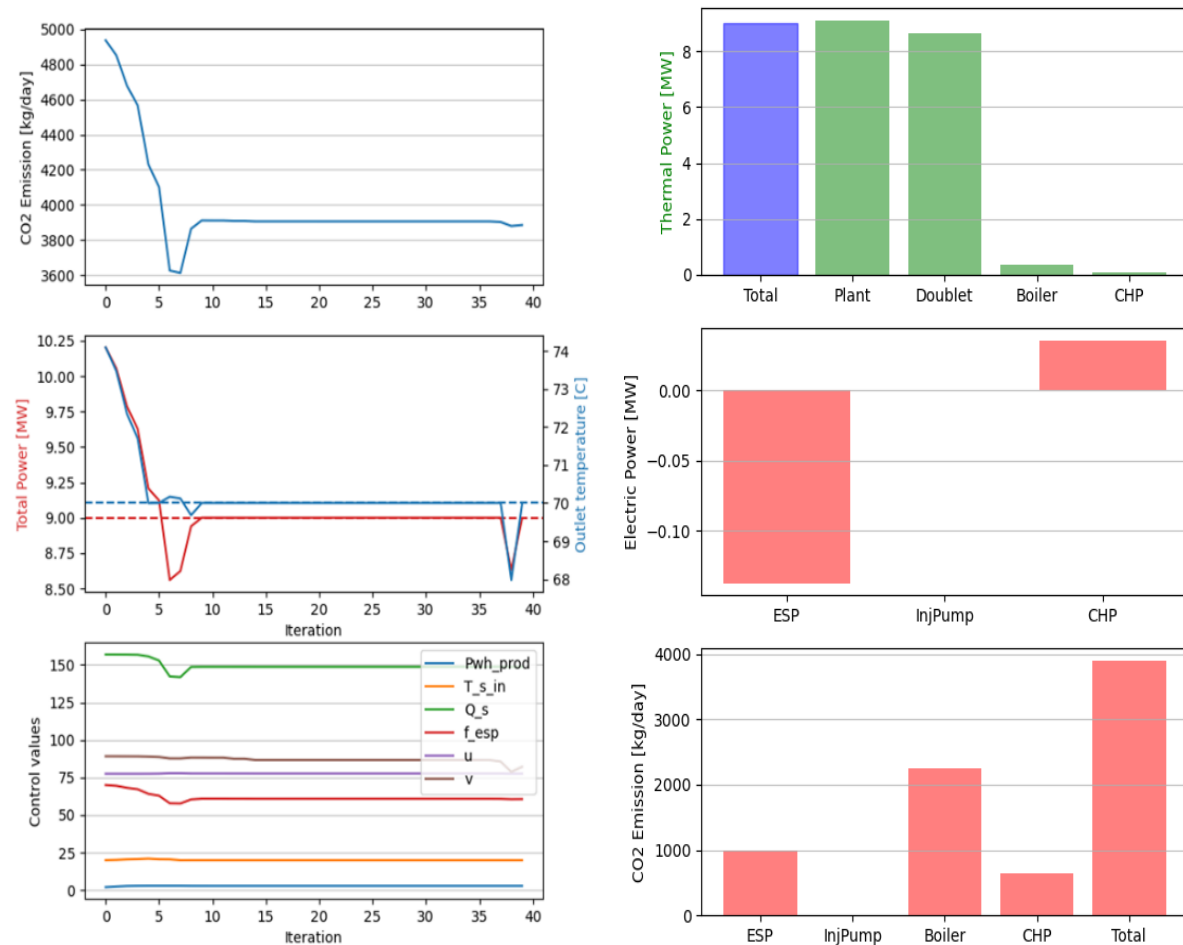


Operation Scenarios Evaluation

Maximizing thermal energy production



Minimizing emission

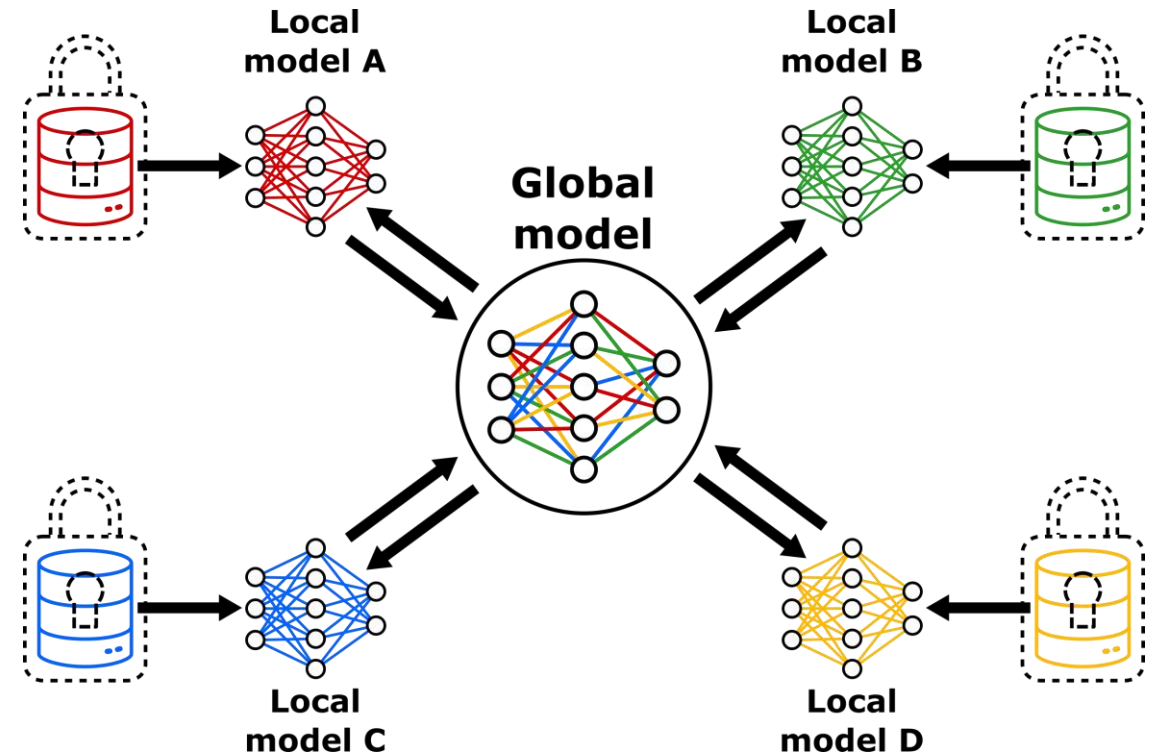


The emission reduction ~ 12% (from 5.7 kg CO₂/GJ to 5.0 kg CO₂/GJ)

Increase in Levelized Cost of Heat (LCoH) ~ 11.8%

Towards Sector Learning

- Added value for sector learning through standardizing the digital twin of geothermal assets
- No need to share data, but share the learnings
- Decentralized methods to be deployed on top of digital twin technologies to develop global models of processes, components and equipment
 - Uses local information to build global knowledge, without the need to disclose data
 - Enables learning a single model across multiple distributed devices using local data samples



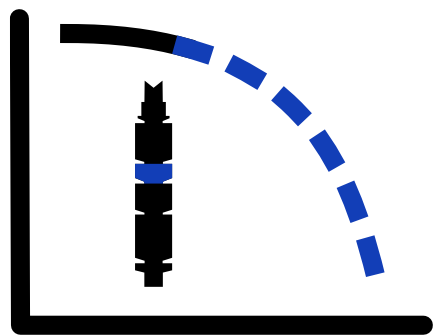
Summary and Next Steps

- Digital twin can improve the operation of geothermal assets aiming at saving cost, increasing production and reduce downtime
- A workflow is proposed to be demonstrated and being made open-source for the geothermal assets (direct use, heating)
- We plan to extend/develop GEMINI's functionalities in the following areas:

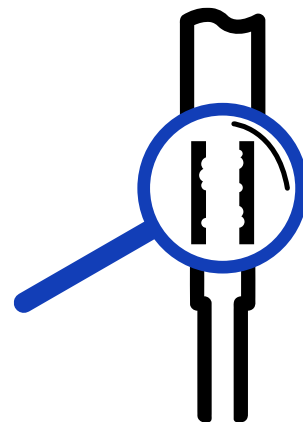
Text data analysis



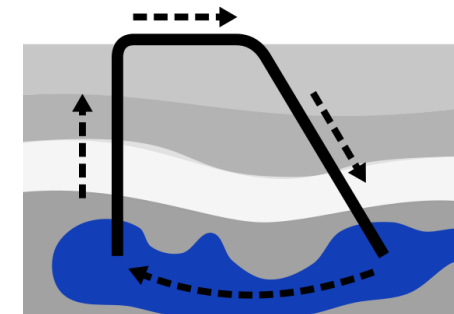
Predictive maintenance



Well integrity management



Subsurface integration





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