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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Consiglio Nazionale delle Ricerche
Institute of Geosciences and Earth Resources igg

GEOTHERMOS: a new Matlab code for geothermal potential assessment

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InGEO

Innovation in **GEO**thermal resources and reserves potential assessment for the decarbonization of power/thermal sectors

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Geothermal potential assessment (NEW CODE by IGG-CNR)

INPUT

Volumetric method:
- 3D Volume discretization
- Geothermal model
  - ➢ 3D petrophysical model
  - ➢ 3D thermal and pressure models
- Logical evaluation of active cells

OUTPUT

Power potential maps
- Power generation [MW/km^2]
- Levelized Cost of Energy
- Net Present Value

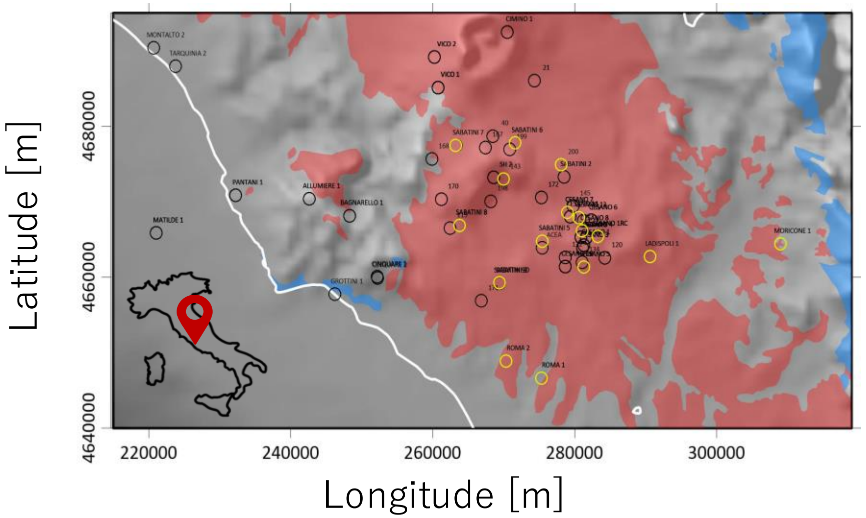
Borehole-reservoir coupling
- Inflow
- Skin factor
- FloWell: fluid pressure drop and heat loss across the wellbore, phase change

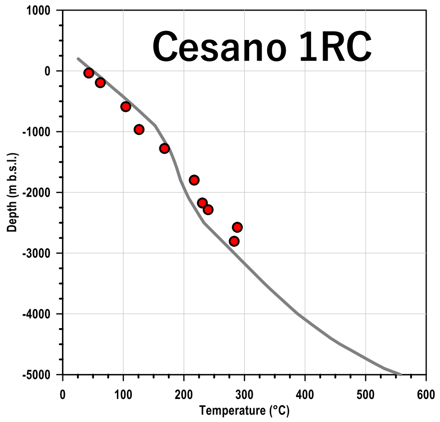
Power Plants
- Different technologies (dry steam, flash, binary power plants)
- Thermodynamic cycles
- Using external function to evaluate fluid properties (P,T)
- Size optimization of plant's components

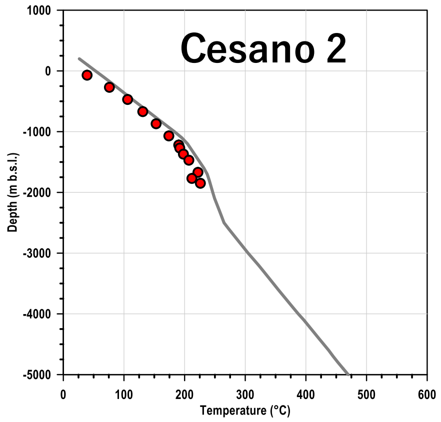
Constants & functions
- Ambient conditions
- Geothermal fluid composition (NCG)
- Borehole number, depth, diameter, drilling and exploration costs
- Power plant working pressure and component's efficiencies

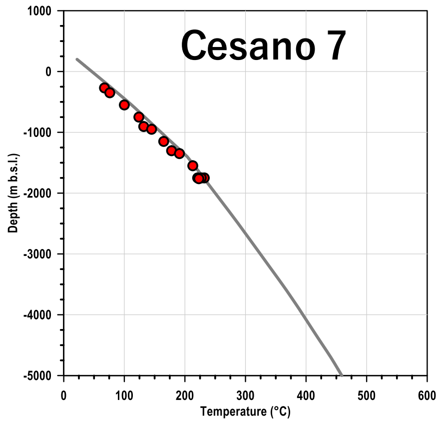
InGEO

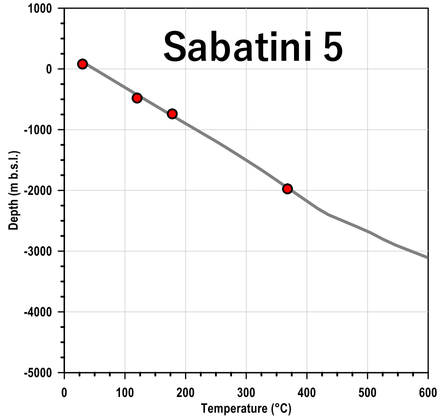
INPUT: thermal model of Cesano-Sabatini geothermal field

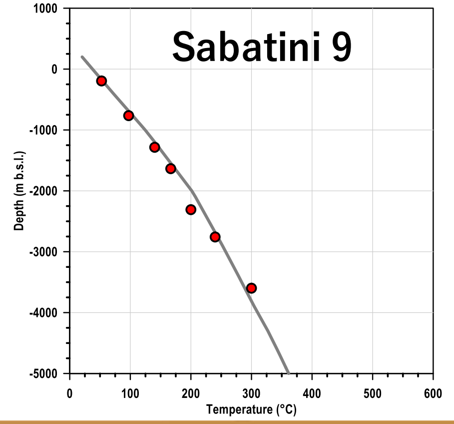












High geothermal gradient

About 80 – 150 degC/km

Recent magmatic activity (0.8 – 0.07 Ma)

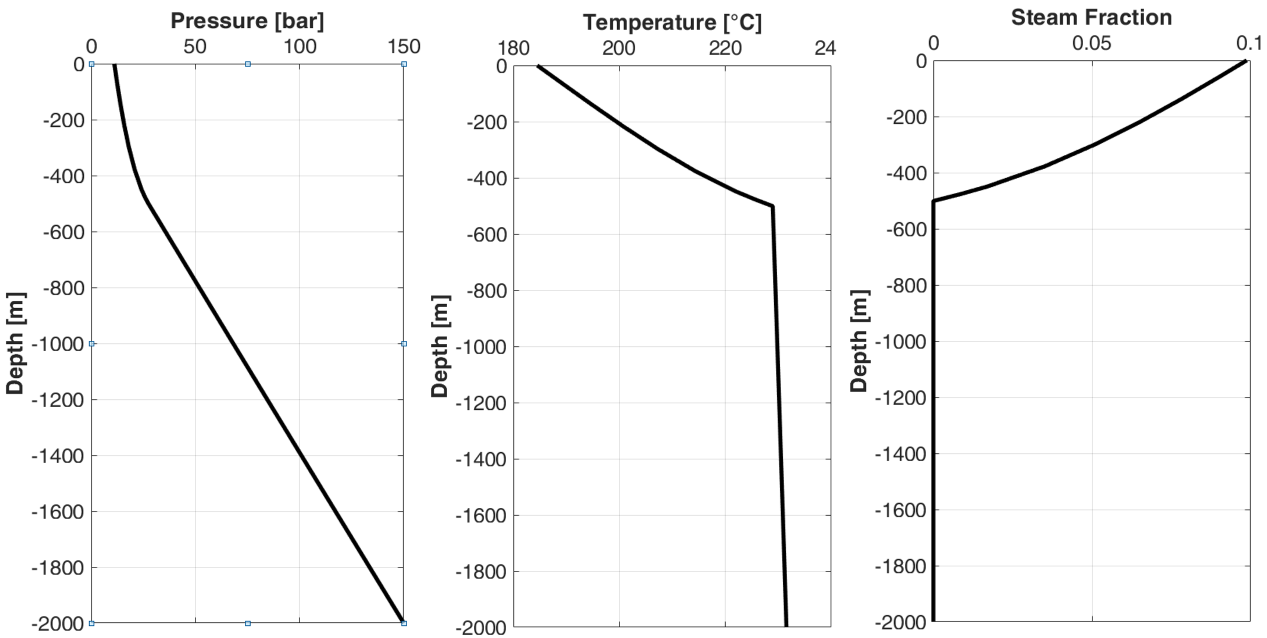
Borehole-reservoir coupling

Bottom hole:
Evaluate inflow rate Q (radial flow, homogeneous reservoir)

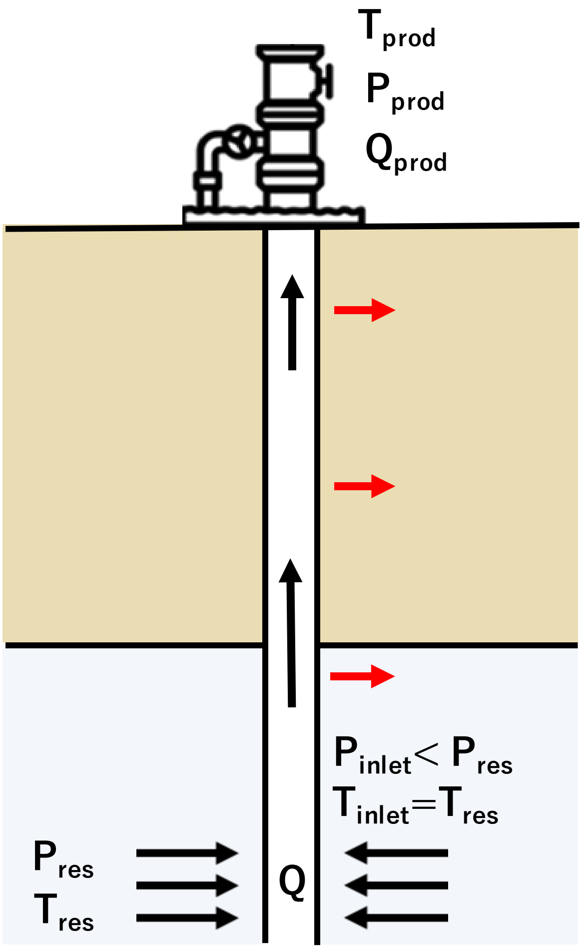
- Rock permeability
- Thickness of productive horizon
- ΔP (pressure drop from static P_o to dynamic P_1 conditions)
- Fluid dynamic viscosity (P,T dependence)
- Compressibility (= zero)
- Borehole and influence radii
- Skin factor

Well-head conditions: $f(h_{inlet}, P_{inlet}, X_{steam})$
Evaluate outflow variables:

- Pressure (Swamee friction factor)
- Temperature (conductive radial heat loss)
- Steam fraction



FloWell (Guomundsdottir et al., 2013) solves energy and momentum equations using numerical integration. The MATLAB ode23 built-in function is used.



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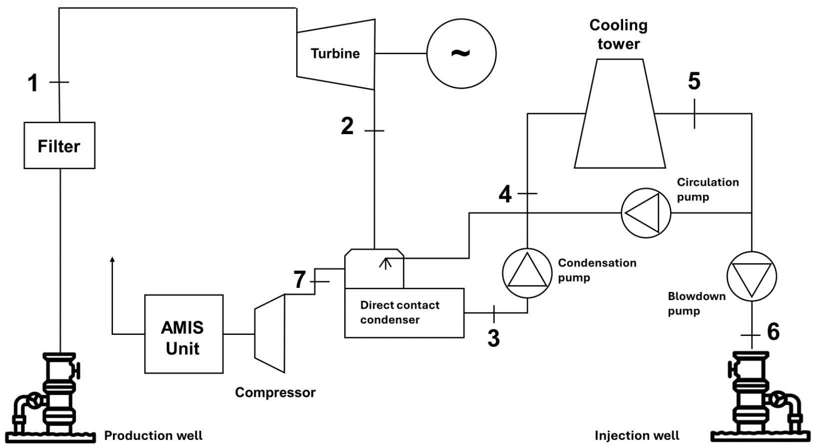
Power Plants

DRY STEAM POWER PLANT

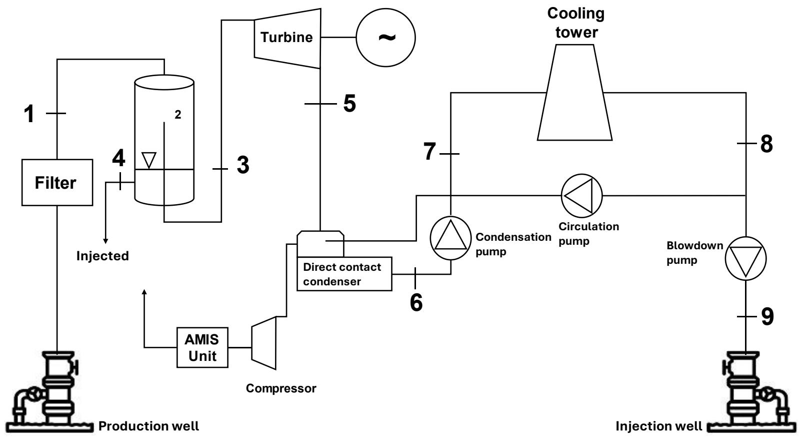


T_{prod}

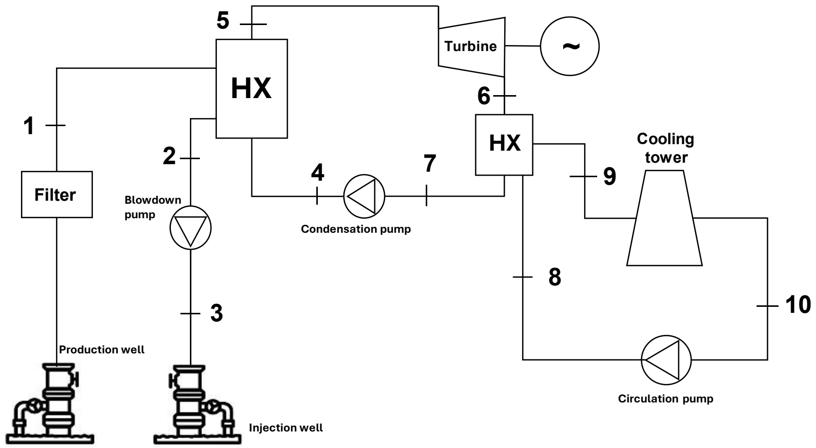
P_{prod}

Q_{prod}

SINGLE FLASH POWER PLANT



BINARY POWER PLANT



SPECIFIC WORK

$$w_{turb} = h_1 - h_2 \left[\frac{kJ}{kg}\right]$$

POWER TURBINE

$$\dot{W}_{turb} = \frac{w_{turb} \cdot \dot{m}_1}{1000} \; [MW]$$

POWER GENERATOR

$$\dot{W}_{gen} = \dot{W}_{turb}\eta_{gen} \; [MW]$$

InGEO

Validation

The validation of these models is required to check the reliability of the code, which simulates the thermodynamic cycle of the plants. The validation was done by comparing the power capacity (installed and running) of the real power plants, reported in the work done by Zarrouk et al. (2014), against the power output evaluated by the code.

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Contents lists available at ScienceDirect

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Review

Efficiency of geothermal power plants: A worldwide review

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Table 4
Single flash plant pressure showing separator and turbine exhaust pressure.

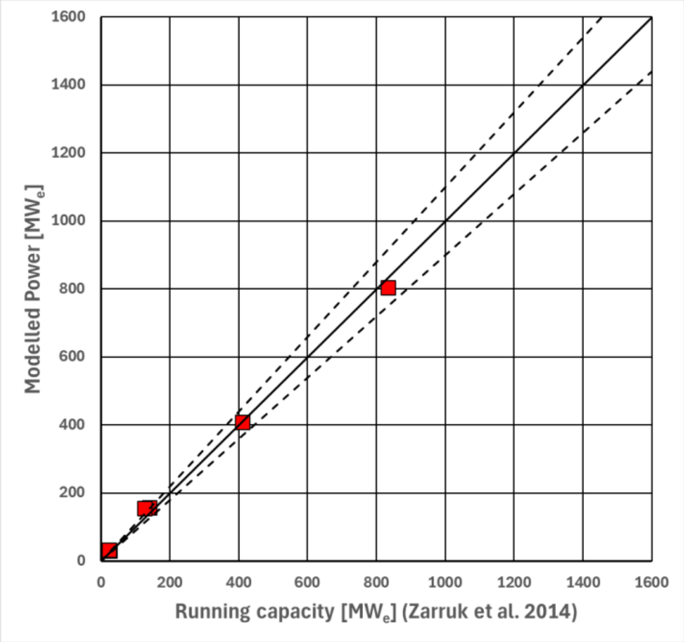
Country	Field (plant name)	No. unit	Type	Start date	Installed capacity (MWe)	Running capacity (MWe)	$\dot{m}$ (t/h)	$\dot{m}_s$ (t/h)	$\dot{m}_f$ (t/h)	h (kJ/kg)	Reference
Russia	Pauzhetka	3	1F	1967	11	11	864	–	–	780	[6,68]
Turkey	Kizildere	1	1F	1984	20.4	10	1000	114[a]	886[a]	875	[6,10,11]
Japan	Oita (Takigami)	1	1F	1996	25	25	1270	–	–	925	[6,69]
Japan	Akita (Onuma)	1	1F	1974	9.5	9.5	540	107	433	966	[6,17,69]
Japan	Iwate (Kakkonda)	2	1F	1978	80	75	2917	416	2501	992	[69–71]
Japan	Miyagi (Onikobe)	1	1F	1975	12.5	12.5	625	–	–	1020	[17,69,72,73]
USA	Utah-Roosevelt Hot Springs (Blundell1)	1	1F	1984	26	23	1020	180	840	1062	[32,63]
Costa Rica	Miravalles (1,2,3, Well heat unit)	4	1F	1993	144	132.5	5634	1188[a]	4446[a]	1107	[23,74,75]
France	Bouillante 2	1	1F	2004	11	11	450	90	360	1110	[46,76,77]
El Salvador	Ahuahapan (U1,2)	2	1F	1975	60	53.3	1848	373	1475	1115	[78,79]
⋮						⋮					⋮
Japan	Tokyo (Hachijyojima)	1	1F	1999	3.3	3.3	44	40[a]	4[a]	2582	[14,69]
USA	California – The Geyser	24	D	1971	1529	833	6950	6950	–	2650	[32,79,109–111]
New Zealand	Wairakei (Pohipi)	1	D	1996	25	25	200	200	–	2750	[6,112,113]
Italy	Larderello	21	D	1985	542.5	411.7	3060	3060	–	2770	[6,114]
Indonesia	Darajat	2	1F	1994	145	145	907	907	–	2783	[6,7,105]
Indonesia	Java (Kamojang)	3	D	1982	140	140	1086	1086	–	2792	[6,23,105]
Italy	Travale/Radicondoli	6	D	1986	160	126.6	1080	1080	–	2793	[114,115]
Japan	Iwate (Matsukawa)	1	D	1966	23.5	23.5	201	201	–	2797	[6,17,69]

Numbers refer to numbered references in the list in the online supplement.
[a] Mass of steam and brine are calculated based on separator pressures.

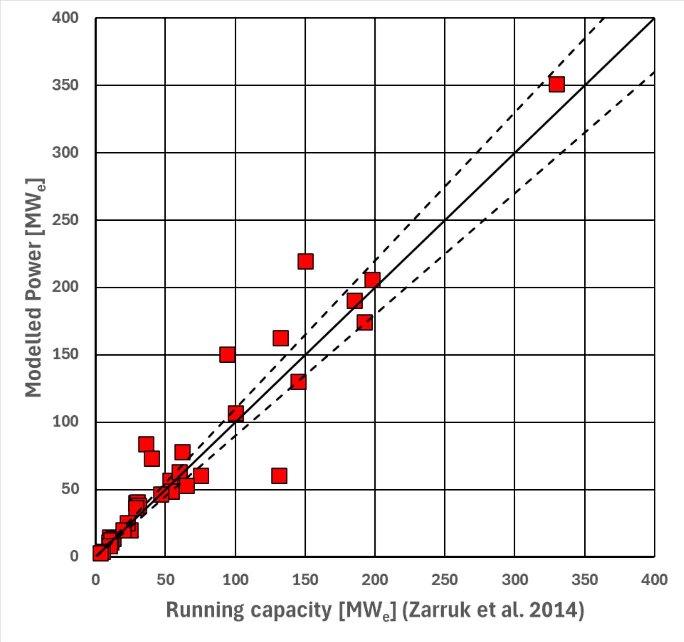
Validation

The band error in which the plant is considered well-represented is ±10%.
It was arbitrarily chosen due to the lack of information regarding the operational parameters of the plants reported. Only for some flash power plants the separation pressure and the turbine outlet pressure are indicated. Consequently, during the validation simulations, default values were used.

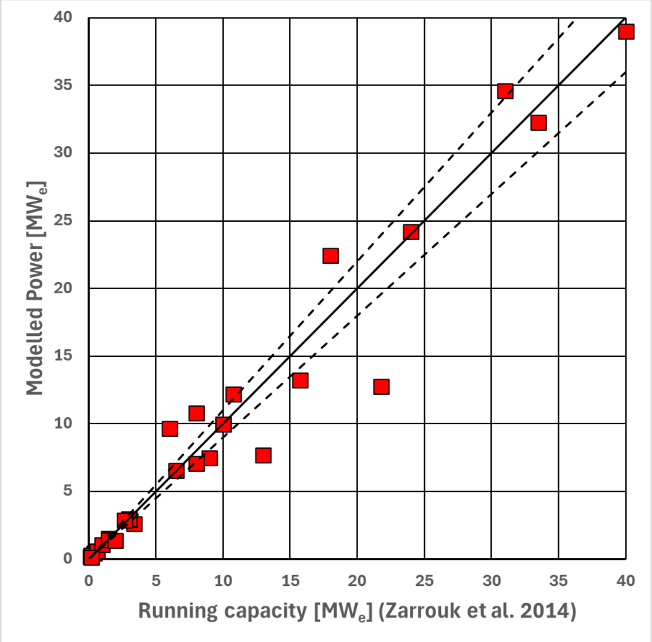
Dry Steam



Flash



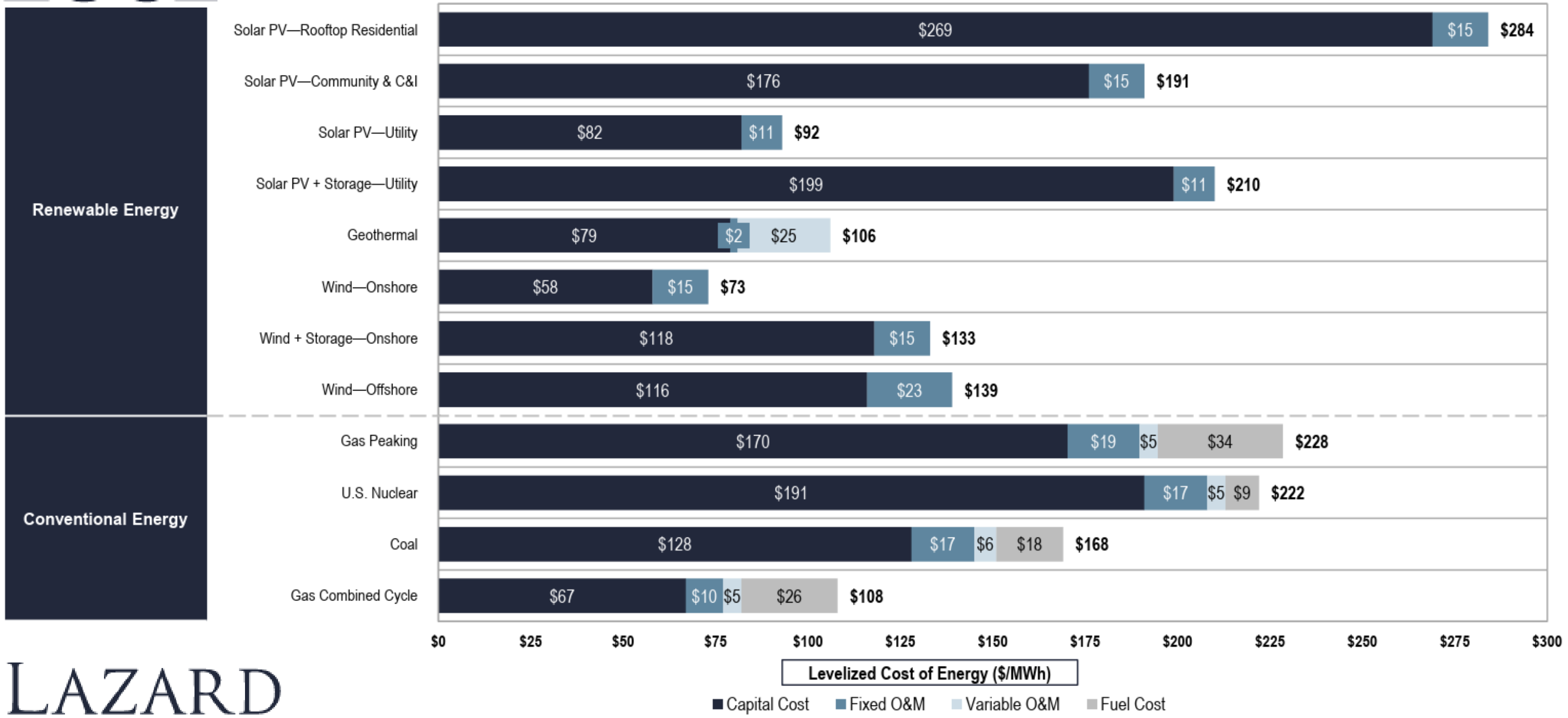
Binary



Economic assessment

LCOE

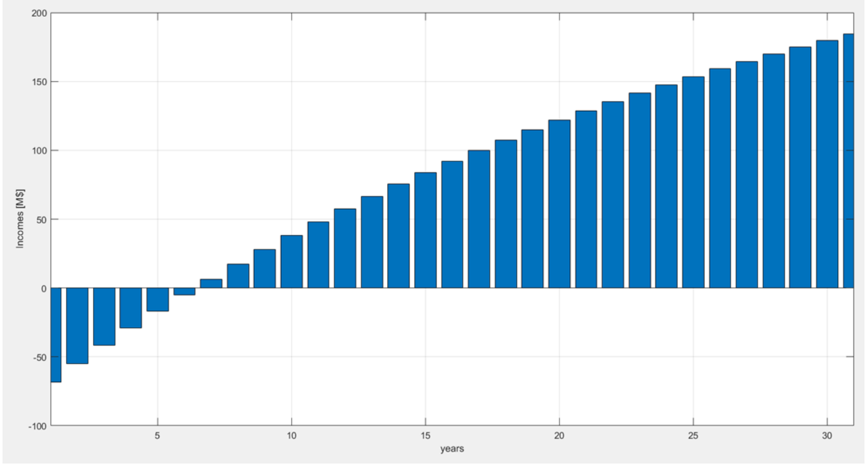
Levelized Cost of Energy Components—High End



LAZARD

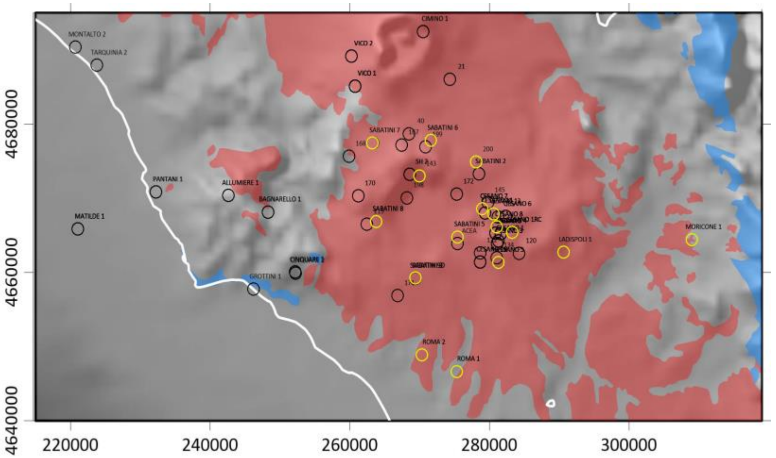
$$LCOE_{RAD} = \frac{\sum_{t=0}^{n} \frac{C_t + O_t + V_t}{(1+R_{RAD})^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+R_{RAD})^t}} \left[\frac{\$}{MWh}\right]$$

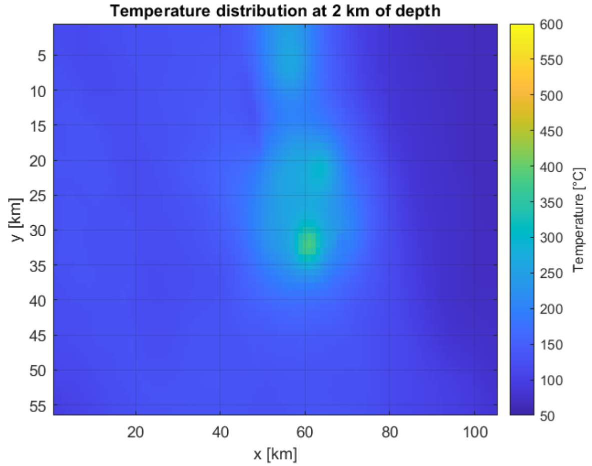
$$NPV = -CAPEX \cdot (1 - CAPEX_{incentives}) + \sum_{t=1}^{n} \frac{B_t}{(1+R_{RAD})^t}$$

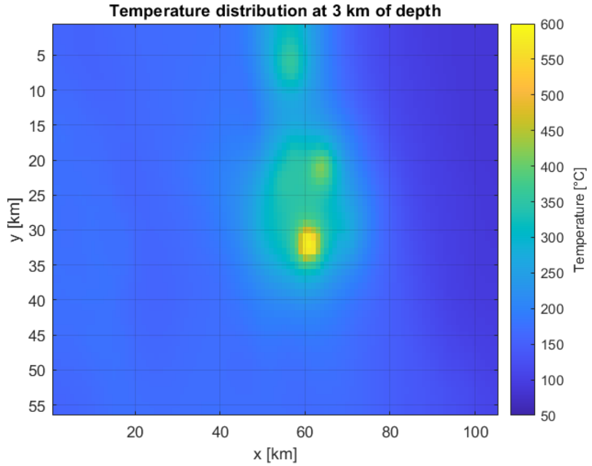


InGEO

Results

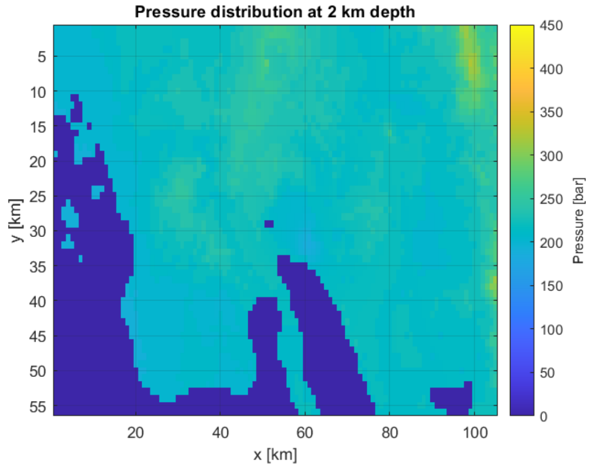


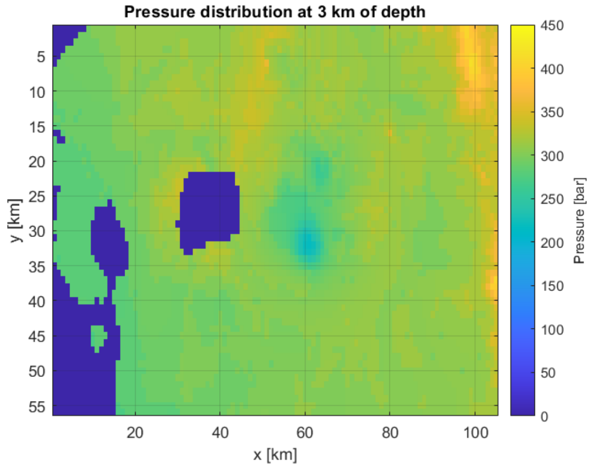




Simulations are done for:

- Permeability values of 10^{-14} and 10^{-15} $[m^2]$
- 2 and 3 kilometers of depth
- 30 years of operation





- Pressure also indicates the reservoir occurrence (driven by geological model)
- High temperature (above the supercritical conditions, enthalpy is approximated to supercritical point)

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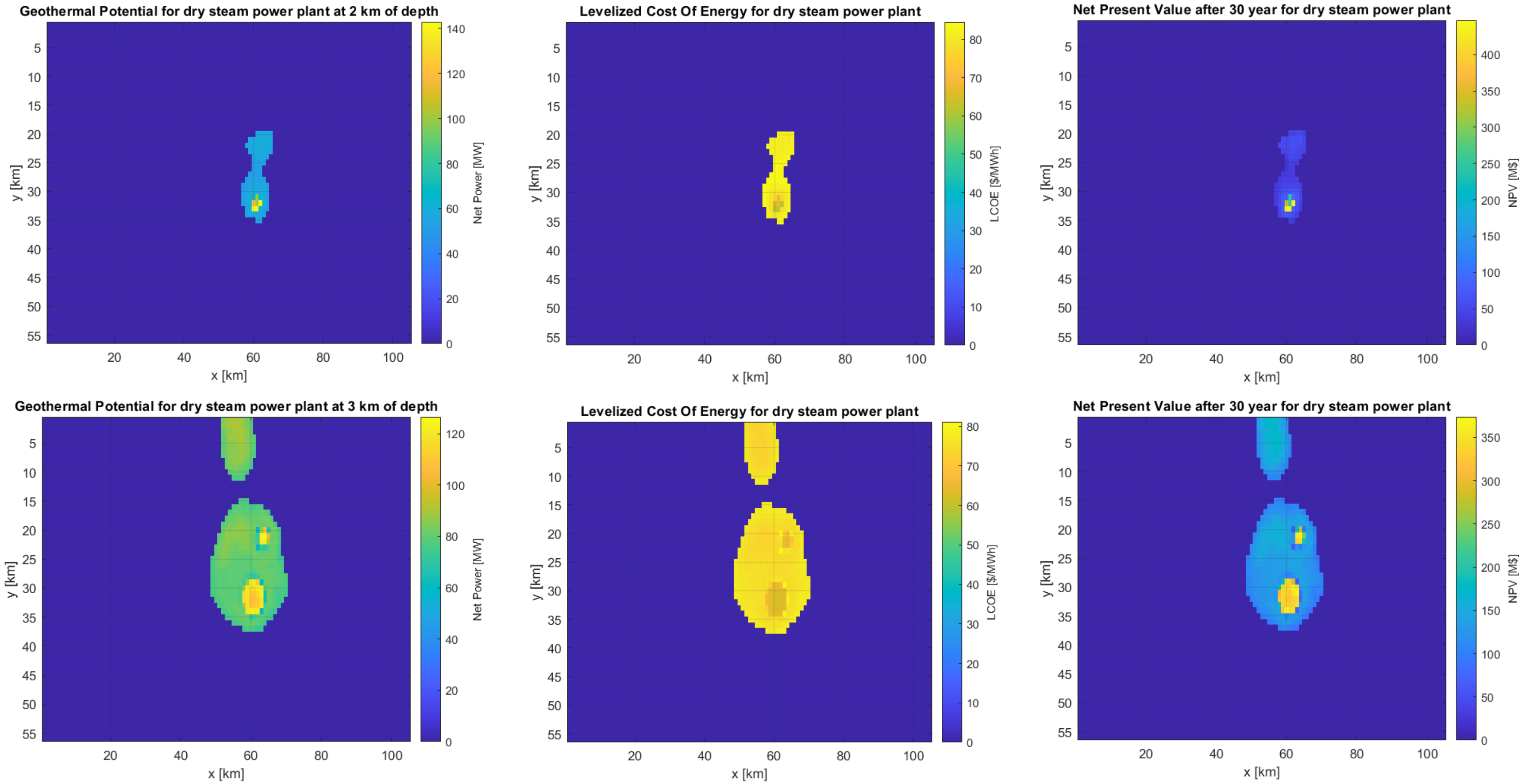
Results: Dry steam power plant

Depth = 2 km

Depth = 3 km

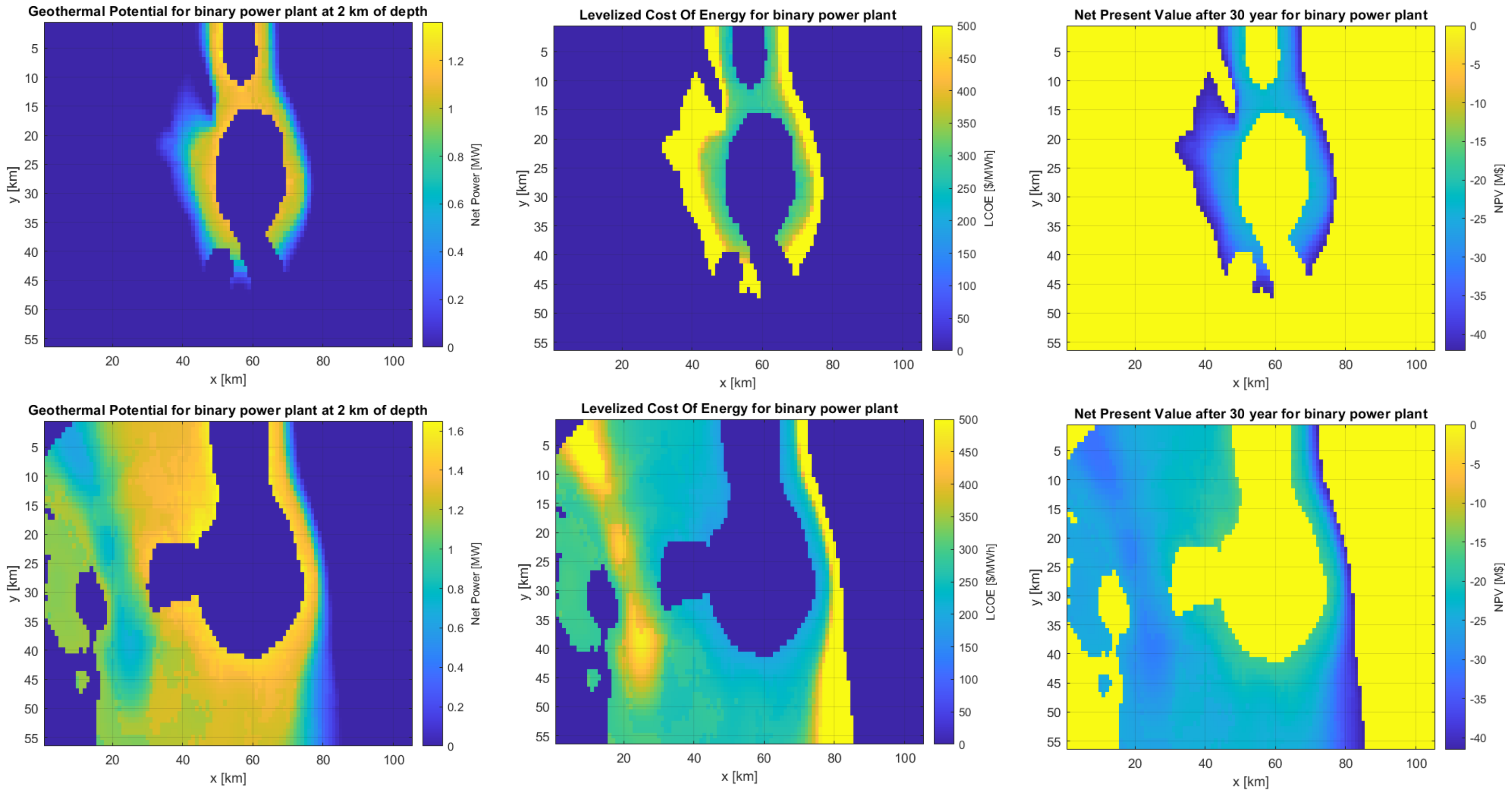


- $K = 10^{-14}\ m^2$
- 2 production wells
- 1 injection well

Results: Binary power plant

Depth = 2 km

Depth = 3 km



- $K = 10^{-14}$ m^2
- 2 production wells
- 1 injection well

Conclusions

Accurate

Thermodynamic cycle well represented

Precise

Few validation points outside the error ±10%

Lowers uncertainty

Help to reduce uncertainty, and increase the spread of geothermal energy

Powerful

Powerful tool to evaluate the geothermal potential

Capital cost play a key role, and it need to be better constrained

GRAZIE PER L'ATTENZIONE