

Feasibility, Design and Authorization of a Zero Emission Geothermal Power Plant in Italy Case Study: “Casa del Corto” Project

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ABSTRACT

Since the beginning of 2000, European legislation recognizes geothermal energy as a strategic and sustainable source of renewable energy that could be helped with greater incentives in case of lower emissions. Therefore, private investors have studied and proposed innovative project solutions for the exploitation of medium enthalpy geothermal resource, with zero emissions to the atmosphere. This paper describes the Italian Geothermal Project “Casa del Corto”, presented to Italian National Mining Office for Hydrocarbons and Georesources in 2014, which foresees the construction of a 5 MW ORC (Organic Rankine Cycle) power plant with total fluid reinjection. The Geothermal Project Casa del Corto is located on the eastern edge of the large geothermal anomaly of Mt. Amiata (Tuscany), about 3-4 km east of the geothermal field of Piancastagnaio (Concession of Enel Green Power). The project foresees that the geothermal fluid be confined in a closed loop system. This opportunity is important both from environmental point of view and social acceptance: possible pollutants present inside the geothermal fluid are not released into the environment and are directly reinjected in the same geothermal reservoir. The project also follows the “best practices” implemented in Italy by the “Guidelines for the usage of medium and high enthalpy geothermal resources” prepared in agreement between the Ministry of Economic Development and the Ministry of the Environment.

1. Introduction

Since the beginning of the year 2000, European legislation recognizes geothermal energy as a strategic and sustainable source of renewable energy that could be helped with greater incentives in case of lower emissions. Furthermore, the Italian high population density, the conformation of the land and the presence of valuable agriculture impose environmental constraints generally not present in other areas of geothermal development. In this context the geothermal project Casa del Corto has been developed as a small size power plant with the aim of minimizing environmental and social impact.

Casa del Corto Geothermal Pilot Power Plant is therefore an innovative 5 MW Zero Emission project with a reduced visual impact. In the following the main characteristics of the project and the proposed technical solutions are discussed.

The Casa del Corto Research Permit (RP) of around 5 km² is located on the eastern edge of the great geothermal anomaly of Mt. Amiata (Italy, Tuscany) close to an industrial and an urbanized area contiguous to the steam dominated geothermal field of Mt. Amiata where 121 MWe are installed as shown in Figure 1 below.

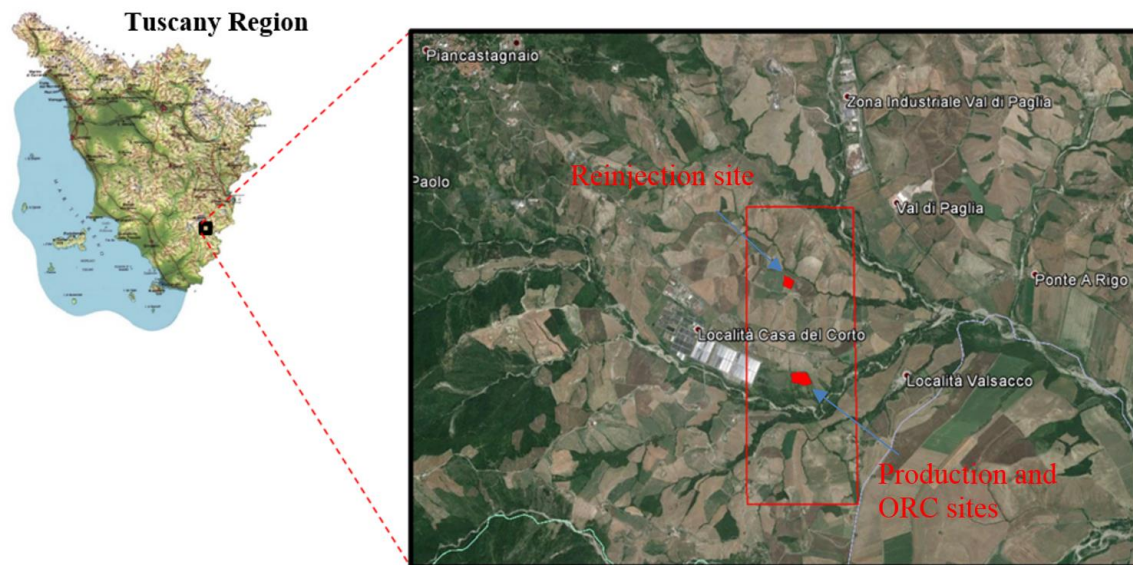


Figure 1: Location of Casa del Corto Research Permit

The community living around the project site and local authorities are very sensitive to any possible transformation of the present economic and social activities dominated by rural tourism and production and sale of wine and food products.

Population and local authorities are worried about the emission of Carbon Dioxide (CO₂) and pollutants in the atmosphere such as Hydrogen Sulphide and Mercury (H₂S and Hg), land occupation and visual impact that may be perceived as negative elements for their traditional economics development.

The project therefore aims to reduce the concerns of the population and authorities through several innovative technological solutions such as: geothermal fluid production using high temperature electrical submersible pumps (ESP), buried pipelines at high pressure, spill detection, possible energy recovery by means of a hydraulic turbine and visual impact mitigation.

Besides these environmental aspects, the design solutions of Casa del Corto project proposes a technology that enables mitigation of carbonate scaling properties of the geothermal fluid.

In fact, the use of an ESP, placed below the flash level allows maintaining the fluid pressure at a higher value than non-condensable gases bubble pressure. In this way, the CO₂ evolution from the liquid will be prevented. As a consequence, the CaCO₃ precipitation will be impeded (see *Parag. 3.1*).

Due to these innovative solutions, the "Casa del Corto" project has been classified as being of national interest and is authorized by a national procedure, to obtain direct access to Feed In Tariff (FIT) system.

2. Geological and Geothermal Conceptual Model

The geological - structural setting of the area around the volcano of Mt. Amiata has been characterized thanks to the geothermal development of the Bagnore and Piancastagnaio geothermal fields (Productive Area in Figure 2a). Instead, the published data have been integrated by the scientific community with thematic insights (geological, hydro-geochemical and geophysical) that gave rise to geological-structural interpretations (Batini *et al.*, 2003; Barelli *et al.*, 2010; Brogi *et al.*, 2015; Ferrari *et al.*, 1996; Giannelli *et al.*, 1988; Pandeli *et al.*, 1988).

The stratigraphic sequence of Mt. Amiata area shown in Figure 2a (from surface to bottom) has been reconstructed on the base of wells data and geological studies (Batini *et al.*, 2003; Barelli *et al.*, 2010; Brogi *et al.*, 2015). Figure 2b shows the hydraulic properties of the geological formations. The main water surface body is a phreatic aquifer hosted in the Volcanic Complex. Two water dominated geothermal systems concern both shallow and deep reservoirs, hosted in the Tuscan Nappe (Carbonate end evaporitic sequence; TN) and in the Metamorphic Complex (mainly phyllites; MRU₂) respectively. In the Casa del Corto RP the Volcanic Complex (V; see Figure 2) is not present, and therefore not even the superficial aquifer.

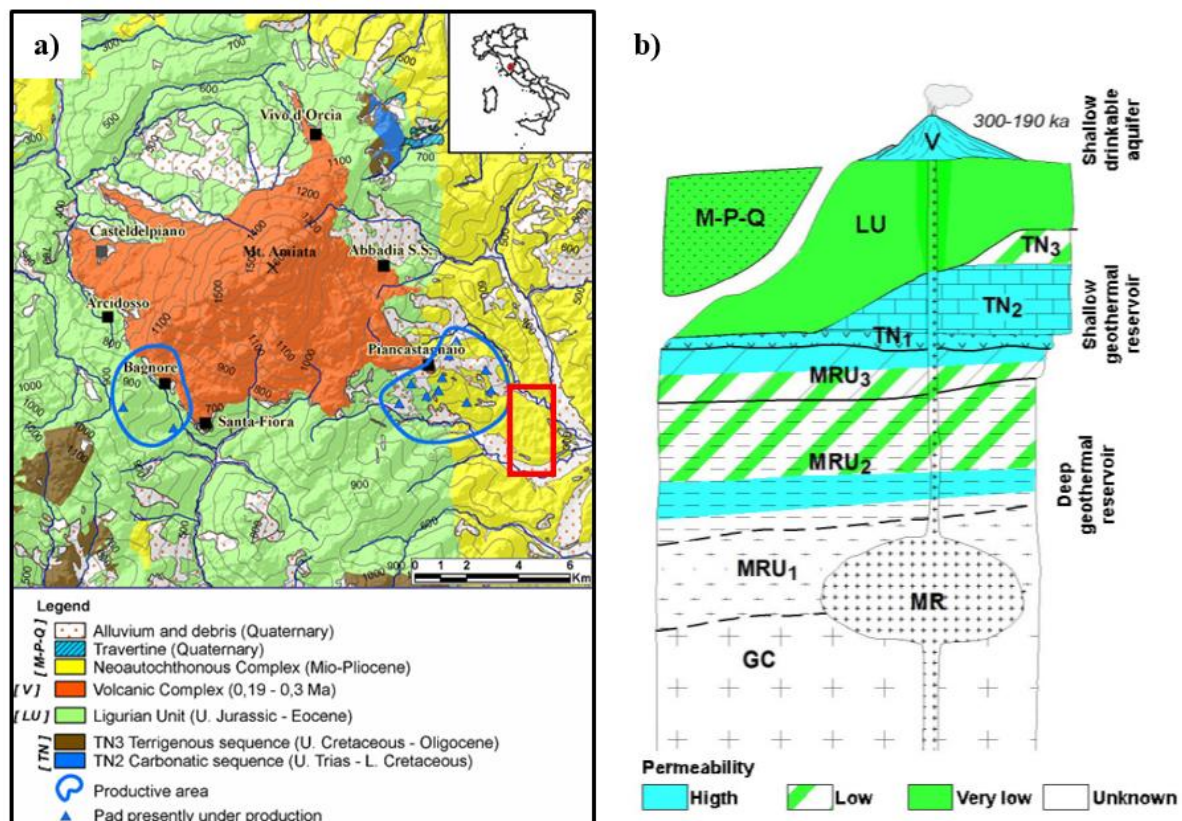


Figure 2: a) Geological Map of the Amiata area. In red the Casa del Corto RP (from Barelli *et al.*, 2010, modified); b) Geologic and hydrogeologic sketch. V: Volcanic Complex; M-P-Q: Neoaucththonous and Quaternary Complex; LU: Ligurian Unit; TN: Tuscan Nappe Unit – TN3: mainly terrigenous sequence - TN2: mainly carbonate sequence - TN1: evaporitic sequence (anhydrite and dolostone); MR: Magmatic Rocks; Triassic Metamorphic Complex - MRU3: Verrucano Group (metapelites); Paleozoic Metamorphic Complex - MRU2: graphitic phyllites and metasandstones – MRU1: Micaschist Unit - CG: Gneiss Complex (from Barelli *et al.*, 2010)

Although separated by a thick impervious layer, shallow and deep reservoirs are hydraulically connected: all the pressure measurement in existing geothermal wells of Mt. Amiata (Bagnore and Piancastagnaio) belong the same hydrostatic pressure trend with a piezometric level at about +230 m above sea level (a.s.l.). This pressure remained constant over the years and was not influenced by the geothermal exploitation of the fields of Bagnore and Piancastagnaio (Barelli *et al.*, 2010). The fluid's temperature of the first reservoir is around 175 - 180 °C (Baldi *et al.*, 1993).

The shallow reservoir in the Casa del Corto RP area, hosted in the Tuscan Nappe (anhydrite and dolostone) has a thickness of about 500 m and overlays Metamorphic Basement as shown in Figure 3 below.

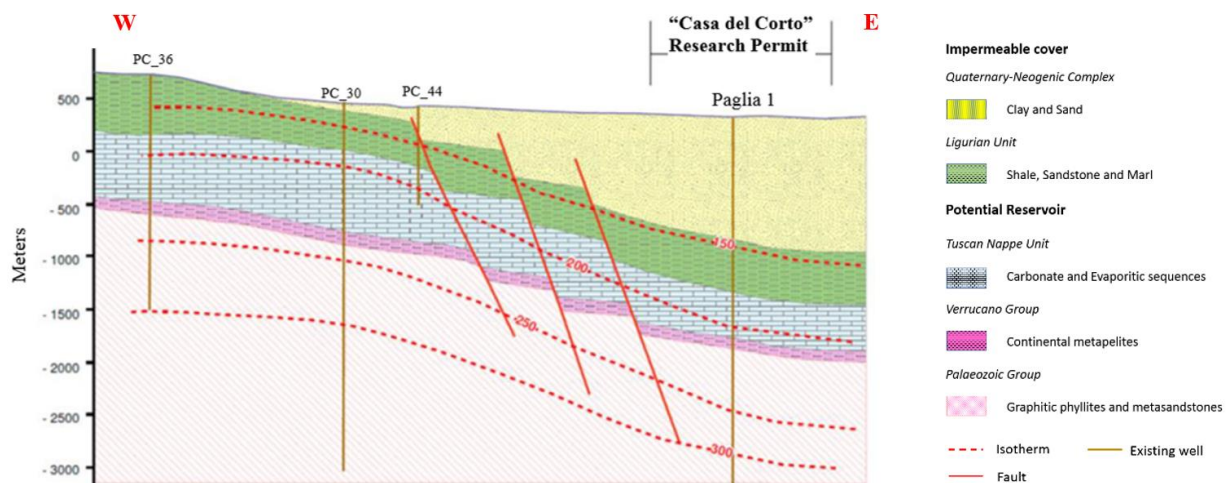


Figure 3: Conceptual geological cross section W-E passing through the Research Permit (RP)

The interpretation of temperature profiles of the existing wells drilled near the RP suggest a convective circulation between 1,600m and 2,000m depth inside the Tuscan Nappe and an average temperature of about 180 °C clearly defining the presence of a geothermal reservoir with a static level at 230 m a.s.l. and therefore at around 90 m from ground level.

These data and the assumed technical profile of the productive wells allowed to predict the production characteristic curve by means of a well simulator (Barelli *et al.*, 1982). The design flow rate was calculated as 150-200 t/h per well.

3. Project description

Based on the above considerations it was decided to design a total reinjection ORC power plant fed by submersible pumps capable of stabilizing production and avoiding Calcium Carbonate scaling. Three production wells and three reinjection wells were estimated necessary for a net production of 5 MWe.

The Casa del Corto project will be therefore constituted by the following main sections:

- One production well pad (called CC1) with 3 wells;
- The ORC power plant;
- One reinjection well pad (called CC2) with 3 wells.

The ORC plant will be installed next to the production well pad. The reinjection well pad will be located approximately 1.5 km far away the power plant area in the north direction. The plant location is presented in Figure 1 and proposed lay out is shown in Figure 4.

The power plant will be connected to the MV national grid by an aerial 15 kV line of a length of 5.3 km.

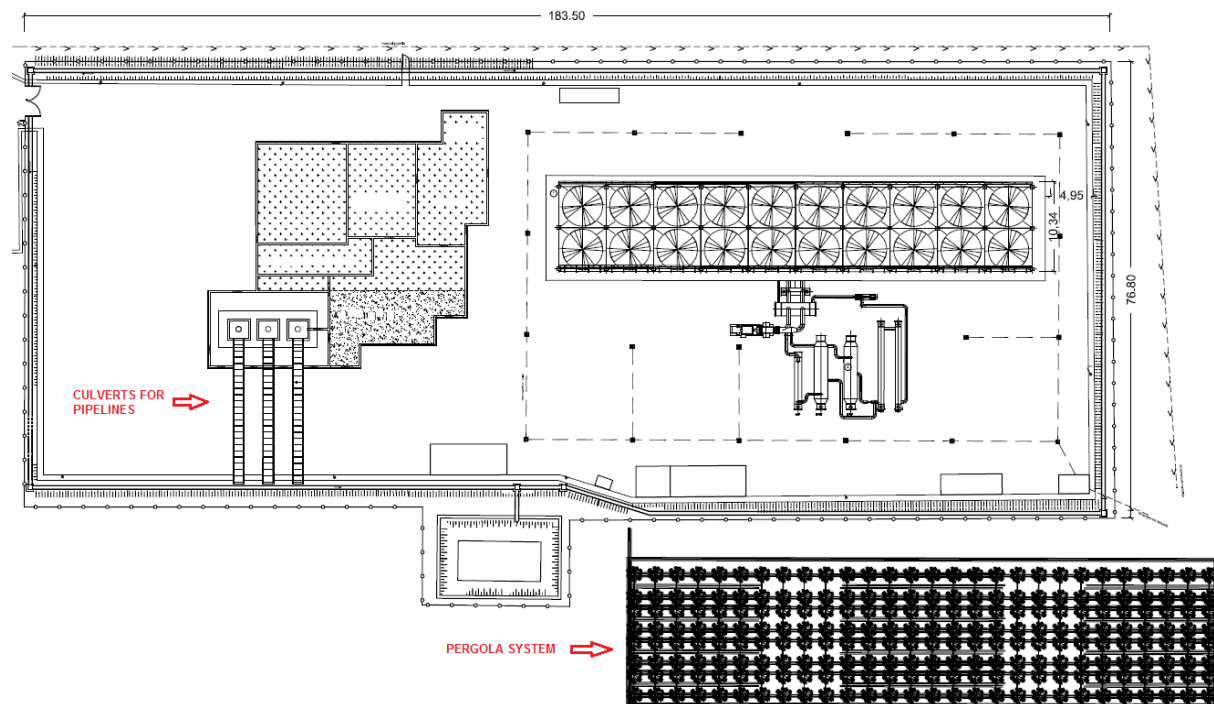


Figure 4: Proposed Lay out

The following table shows the main technical data of the Casa del Corto power plant.

TECHNICAL DATA	
Production temperature	180°C
Reinjection temperature	100°C
Operating pressure	60 bar
Flow rate per well	155 t/h
Total production flow rate	465 t/h
Pipeline diameter	16 inches
Gross Power	7,55 MWe
Net Power	5,0 MWe
Gross efficiency	17,30%
Auxiliary consumption	2,55 MWe

Table 1: Casa del Corto project main technical data

3.1 Electrical submersible pumps

The geothermal fluid is produced by ESP. The main purpose of the ESP is to keep the fluid at a pressure higher than the incondensable gas bubble pressure (*Corsi R. 1986*). This way the fluid is maintained in liquid form, CO₂ is not released from the geothermal solution. In fact, the following equation (1) will not shift to the right and the conversion of calcium bicarbonate to calcium carbonate is impeded and carbonate scaling in the well, pipelines and other plant equipment is prevented.



However, use of ESP in such a hard operating conditions, which are depths of 1,000m and temperatures of 180°C, may reduce operation reliability.

The cooling system of the motor has to be designed properly to avoid pump failures because of overheating and reduce the number of un-planned maintenance outages. In fact, lifting operations can be very long and expensive due to the installation depth and pump size. The proper design of ESP is therefore one of the main challenges of this project.

The Table 2 below, summarizes the required technical characteristics of the ESP.

Parameter	Value
Flowrate	155 t/h
Head	75 bar
Delivery Pressure	155 bar
Absorbed power	600 kW

Table 2: ESP technical characteristics.

Moreover, Table 1 and 2 explicitly indicate that the operating pressures of the geothermal fluid are quite higher than normal.

This implies the necessity to foresee high rating for all the equipment in contact with the geothermal fluid and components with higher thicknesses than ones routinely installed in geothermal installations.

One advantage of ESP is that it can maximize the geothermal fluid flowrate that can be obtained from each well. In this way, the only limit to the flowrate is the productivity index of the well itself since the required pressure to lift the fluid up to the wellhead to overcome pressure losses and geodetic head will be provided by the pump head.

Maximizing the flow from each well may minimize the total number of required wells, consequently reducing the capital investment of the project.

3.2 Reinjection pipelines

The reinjection will be performed by means of pre-insulated underground pipelines to reduce visual impact. Pipelines are placed at a depth of 1.5 m below ground level to avoid pipeline damage by agricultural machinery used to plow the land.

This type of solution is extensively used for the district heating systems but, in this case, the operating pressure is higher, and the fluid is more aggressive. Therefore, the pipeline design has taken into account these peculiarity in the selection of materials and rating.

On the other side pre-insulated pipe guarantees lower installation time. Pipe and insulation are installed at the same time and, thanks to the recent joint systems, the welding time and the durability of joints itself, has reached a very high level of reliability with a simple and standard welding procedure.

The risk of soil contamination in case of spill is drastically reduced by utilizing a monitoring system for leakage detection that intervenes before geothermal water reaches the soil. In case of leakage, the foam humidity causes a decrease of the electrical resistance that shall be detected by two copper wires installed in the polyurethane foam layer capable of sending a signal to the central control system.

This monitoring system is also able to detect the spill location allowing for an easier and quick repair operation.

A high corrosion allowance value and a periodic monitoring through ultrasonic non-destructive tests (every 6 months), are furthermore foreseen, to prevent spills occurrence.

3.3 ORC Power Plant

The ORC is a double pressure level cycle to increase heat recovery.

The cycle also includes an organic/organic recuperator, to increase the performance, and to limit the capacity required for the air condenser that is, as well known, the biggest equipment and with the highest electric consumption of this kind of plants.

Moreover, an experimental “Pergola system” will be realized with the purpose to render available some heat for agricultural purposes and to mitigate the visual impact of the power plant.

The system entails the addition of a heat exchanger installed between the recuperator and the air condenser. This exchanger heats water circulating in a secondary pipelines system partially underground (by structures with a maximum height of 2.6 m). In this way the soil can be kept at a constant temperature of 20-30 °C, allowing for the cultivation of typical summer crops throughout the year.

4. Environmental Impact

Environmental aspects connected to geothermal project developments are receiving increasing attention in Europe and in particular in Italy. In July 2016 the Italian Ministry of Economic Development and the Ministry of the Environment issued “Guidelines for the usage of medium and high enthalpy geothermal resources” to enable implementation of geothermal projects with minimum environmental impacts.

Casa del Corto Project substantially follows all the recommendations briefly summarized below.

4.1 Air Emission

Casa del Corto Geothermal Power Plant is a total reinjection plant. Therefore, during normal operations, no gaseous pollutants are emitted to the atmosphere. Air emission will be limited only to production tests and to the very small losses of organic fluid of the ORC system.

The working fluid selected for the Rankine cycle is the penta-fluoro-propane. It is non-flammable, non-toxic fluid, with a low Global Warming Potential value and a zero Ozone Depletion Potential.

Furthermore, operating procedures are also set up to avoid emissions into the atmosphere during plant shut down.

4.2 Underground Impacts

Theoretically, the geothermal project exploitation could produce the following effects:

- reservoir cooling due to reinjection;

- induced seismicity which entails micro-seismicity related to all the operational phases of the exploitation, including reservoir connection and fluid reinjection into the reservoir;
- subsidence.

A 3D numerical model has been developed using the software Tough2^(R) to evaluate pressure and temperature variations in the reservoir due to the production of 450 T/h at 180 °C and reinjection of 450 t/h at 100 °C. Figure 5a shows the geothermal conceptual numerical model assumed as basis of evaluation.

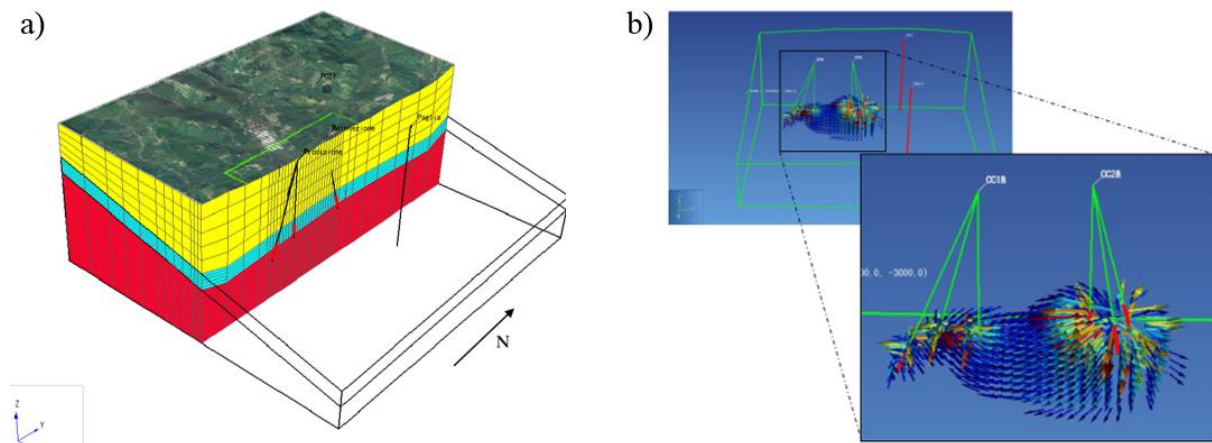


Figure 5: a) 3D Conceptual Model subdivided in three layers (yellow: impermeable cap; blue: geothermal reservoir; red: substratum) and with wells. b) Fluid vectors direction from reinjection (CC2B) to production (CC1B) wells.

The simulation results predict a variation of ± 4.5 bar near reinjection and production wells respectively after 30 years of production/reinjection. These results imply that, after more than 30 years of production/reinjection, the fluid migration (Figure 5b) from the high-pressure area (re-injection) to the low-pressure zone (production), is about 95% of the total production flow (450 t/h). It means that the variation of pressure of ± 4.5 bar will remain almost constant for more than 30 years of geothermal exploitation.

Reservoir Cooling

The model estimated a temperature decreases at the production wells of less than 0.5 °C. after both 30 and 50 years of fluid reinjection at 100 °C. As a result, the thermal effects due to re-injection can be considered negligible.

Induced Seismicity

Fluid extraction and reinjection may generate stress field alteration in the subsurface because of pore pressure variation, isostatic disequilibrium, and poro - and thermo-elastic effects, and hence, in turn, may produce seismicity (Manzella et al., 2010; Evans K.F., et al., 2012; McGarr A., 2014).

The simulation results were used to evaluate the potential seismic effect magnitude (M_w) according to the following Lay and Wallace equation (1995):

$$M_w = \frac{2}{3} \log \left(\frac{16}{7} \Delta \sigma r^3 \right) - 6 \quad (2)$$

where:

$\Delta \sigma$ = stress drop;

r = radius of an equivalent circular fault.

The stress drop ($\Delta \sigma$), according to McGarr equation (McGarr 2014), resulted 3.6 bar; r was assumed 287 m (considering the circular fault intersection with a reservoir volume of $1.01 \text{E}^8 \text{ m}^3$ affected by a $\Delta P \geq 3 \text{ bar}$, as obtained by simulation).

The solution of equation (1) produces a value of M_w of -4.7 .

Therefore, the production/reinjection flow rates considered for Casa del Corto geothermal field, should not induce any significantly seismicity perceivable by the population.

Subsidence

Subsidence was also evaluated as 2 cm of soil elevation variation after 30 years of production nearby the production wells.

4.3 Land take and Landscape

The plant layout has been designed to limit its land footprint. The 6 wells (3 productive and 3 re-injective) will be drilled over two drilling pads for a total of 16.000 m^2 of land utilizing one vertical and two deviated wells in each pad.

As anticipated reinjection pipeline will be underground to reduce visual impact and the Pergola System will help to insert the plant in the agricultural dominated Landscape as roughly shown in Figure 6.



Figure 6: Rendering of the Power Plant and the Pergola System.

5. Future work

The Casa Del Corto project presents some innovative solutions that must be verified and improved with the experience of operation.

Following the first results of operation, we foresee installing a down hole generator in the reinjection wells for the recovery of the hydraulic energy of the reinjected fluid (Enedy *et al.*, 2009).

This generator is practically a modified down-hole submersible pump that works as a turbine and has been successfully experienced in 2009 by Northern California Power Agency (NCPA) in a reinjection well of the Geysers geothermal field.

This solution in our case is particularly convenient taking into account the considerable operating pressure of the geothermal fluid but its feasibility has to be verified taking into account the casing diameter for the Casa del Corto project (the casing is 9" 5/8 instead of 13" 3/8 used in the NCPA experiment).

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