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SUSTAINABILITY ANALYSIS OF THE BERLIN GEOTHERMAL FIELD, EL SALVADOR.

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ABSTRACT

Over the past 20 years, the Berlin geothermal field has been in commercial operation through step wise development, at the moment the installed capacity is 109.2 MW. The total mass extracted ranges up to 870 kg/s, which are delivered by 14 production wells with average discharge enthalpy of 1300 kJ/kg and average steam flow rate of 20 kg/s. Hot brine injection (180 and 140°C) is applied in the field using 19 injection wells and cold injection (ambient temperature) through the operation of one well. A high pressure pumping station is also used manly when injection by gravity is insufficient. During long term exploitation 18 bar pressure drawdown has been observed in the field and perhaps the main process observed in production wells is boiling. There is no evidence of cooling due to injection.

Since long term exploitation began sustainable development has been a very important commitment for LaGeo and during the first stages of exploitation the field management, monitoring technics and numerical modeling were soon implemented. A part of LaGeo's corporative sustainability policy is focused on defining the sustainable energy production level and monitoring performance indicators; all of which are also part of the concession contract granted by SIGET (El Salvador Electricity Regulation Authority) in year 2000.

Preliminary results indicate that the sustainable energy production level of the Berlin resource is greater than the actual installed capacity. At least 5 performance indicators are defined including: energy efficiency of the utilization, resource life, recovery time, subsidence and power plant performance. Just 3 of them are discussed in this paper, the other two are being analysed.

INTRODUCTION

Over the past 10 years LaGeo has been working on developing a sustainability protocol which is part of its corporative sustainable policy and to comply with the regulatory framework of the national electricity law and the concession contract granted by the regulatory agency Superintendencia General de Energía y Telecomunicaciones (SIGET). The main scope of the protocol is to estimate the sustainable energy production level E_0 for each exploited geothermal resource. The general methodology is based in the work presented by Axelsson and the Orkustofnun working group (Axelsson et al., 2001) and in order to define specific performance indicators we utilize the work of Bjarnadottir (2010) where specific indicators were suggested.

In this paper, we present the main aspects of the protocol and how is being implemented in the Berlin geothermal field.

SUSTANABILITY PROTOCOL

Sustainable geothermal utilization has received ever increasing attention over the decade, but the discussion has suffered from a lack of a clear definition of what it involves and from a lack of relevant policies. The word "sustainable" has in addition become quite fashionable and several authors have used it at will. A considerable amount of literature dealing with the issue has been published during the last decade.

Axelsson et al. (2001) propose for the term "sustainable production", for each geothermal system, and for each mode of production, there exists a certain level of maximum energy production, E_0, below which it will be possible to maintain constant energy production from the system for a very long time 100-300 years (Axelsson et al., 2004). If the production rate is greater than E_0 it cannot be maintained for this length of time. Geothermal energy production below, or equal to E_0 is termed "sustainable production" while production greater than E_0 is termed excessive production.

It is difficult to establish the sustainable production level E_0 for a given geothermal system. This is because the production capacity of the geothermal systems is usually poorly known during exploration and the initial utilization step, as is well known. Even when considerable production experience has been acquired estimating accurately the production capacity, and hence the sustainable production, can be challenging.

In another hand, the sustainable production level of a particular geothermal resource can be expected to increase over time with increasing knowledge on the resource, i.e. through continuous exploration and monitoring. In addition it can be expected to increase through technological advances, e.g. in exploration methods, drilling technology and utilization efficiency.

Regarding with the performance indicators which serve as a gauge on how well a system is working; they also help what direction to take if there is a problem to address. In the case of geothermal sustainability indicators should be able to measure the degree of sustainability of a given operation, the progress towards sustainability and/or whether it looks like sustainable production o utilization can be maintained as proposed.

The sustainability protocol proposed by LaGeo is as follow:

1- Assess of the sustainable level Eo using volumetric stored heat assessment as was presented by Muffler & Cataldi and other authors (Muffler and Cataldi, 1978; Sarmiento and Bjornsson, 2007) which should be assess using Monte Carlo method and 50 years of commercial utilization. The level of sustainable or excessive production will be estimated together with the evolution of the indicators, due to can't be established a priori at this early stage.

2- Establish at least the following indicators
   a. Utilization efficiency using the exergy of the whole system (field-power plant) and it should be compared with similar resource utilization.
   b. Productive lifetime is the time that the resource can sustain the present level of production which is dependent of the change on physical condition of the fluid in the resource mainly pressure drawdown and temperature changes. The lifetime is measured by numerical modeling taking into the account the present installed capacity hence total mass extraction and running the model for 50 years and to verify if it is possible to maintain certain level of steam delivered to the power plant.
   c. Recovery time or reclamation time which is the time it takes the resource in terms of pressure and temperature to recover from exploitation. It is not expected that the pressure and temperature will recover in the same timescale due to pressure and temperature diffusion behave hence the pressure will recover faster than the temperature. The recovery time is estimated through numerical modeling putting in zero the mass extraction node and running in order to recover the reservoir.
   d. Change in dissolved chemicals which are affected by pressure and temperature changes and also by inflow of injection or other cold fluids.
   e. Ground subsidence which may be a result of geothermal fluids withdrawal during the energy production. Subsidence is dependent of the pressure drawdown and geological rocks formation above the reservoir and usually is measured in specific sites by high accuracy topographic level meter.
   f. Primary energy efficiency which measure how much primary energy extracted is converted to electricity.
   g. Power plant performance indicator: Load and capacity, availability, parasitic load, vacuum pressure at the condenser and non-condensable gases.

THE BERLIN GEOTHERMAL FIELD

The Berlin geothermal field is located 110 km towards to the East of the El Salvador country where the Tecapa volcanic complex is located. The field went to commercial operation in 1992 with 2x5 MW back pressure units. Later on during 1999 went on line 2x28 MW condensing type units, 2006 went 1x44 MW and finally in 2007 went on line the 9.2 MW binary bottoming unit to complete the 109.2 MW present installed capacity.

The Figure 1 shows the well and power plant location

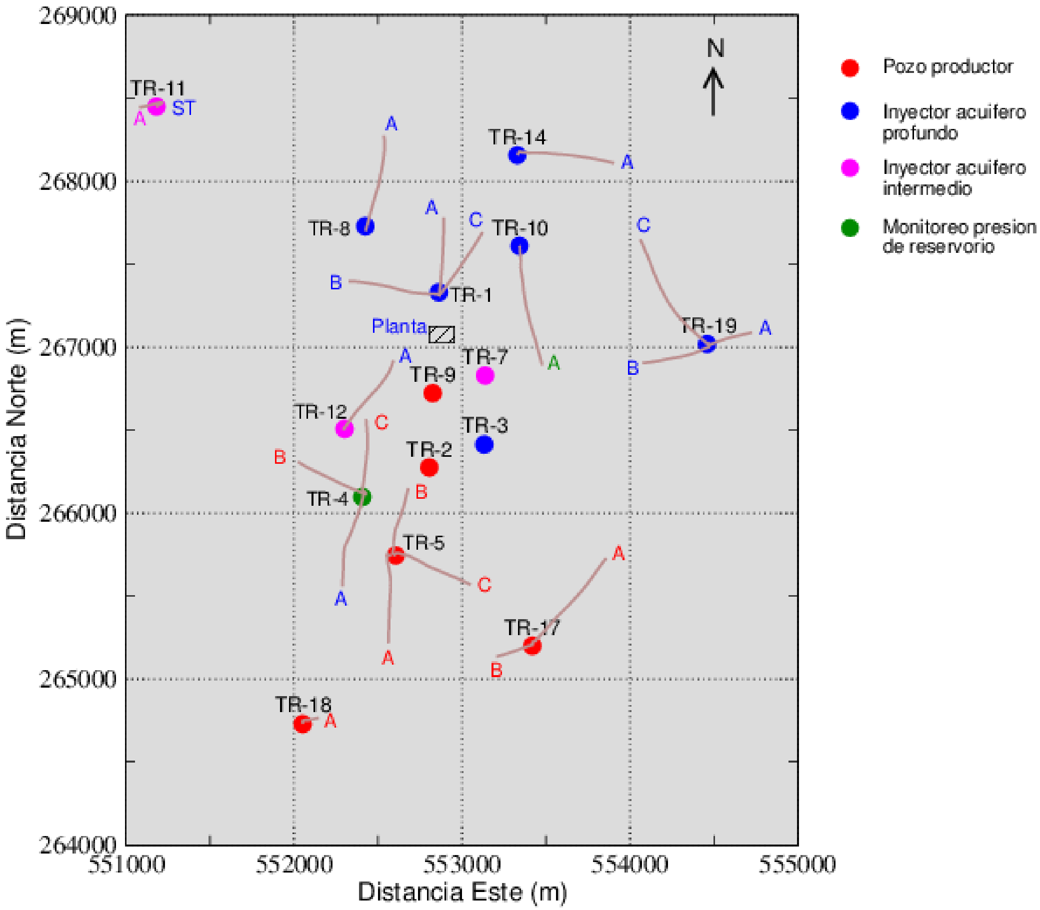


Figure 1, The well location at the Berlin geothermal field

At present, 38 wells were drilling at the Berlin field, 14 of them are producers and 20 injectors (4 are abandoned). The Figure 2 presents the total mass extracted which ranges 870 kg/s, the steam delivered to the power plant is approximately 220 kg/s and the injected brine is 650 kg/s which is partially injected using high pressure pumping system located al TR-1 site.

The total pressure drawdown is approximately 18 bar however over the last 12 years is being reduced to less 10 bar, the discharging enthalpy is fairly constant in most of producer wells and no evidence of cooling due to injection has been observed into the field however some boiling is perhaps the main process affecting the reservoir.

Some aspects affecting the sustainable production are related to calcite in well TR-18, steam cap declining at southern part of the steam field, high concentration of NCG at TR-18A and silica plugging at injection wells and pipe line in special those connected to binary unit. As part of field maintenance there are undertaken several activities to reduce the impact in this issues

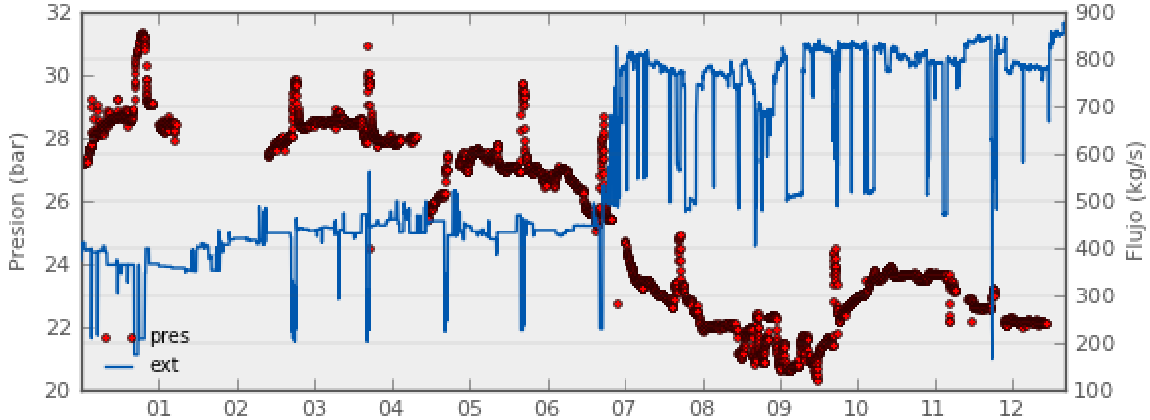


Figure 2: Pressure and mass extraction at the Berlin field

SUSTAINABILITY ANALISYS.

According with the methodology describe before, the first parameter to be calculated is the level of sustainable production Eo which was did by volumetric "stored heat" and Monte Carlo probabilistic estimation performed with Cristal Ball. The main parameters for the calculations are presented in the Table 1.

Table 1: Volumetric estimation for the Berlin field

	Parametros de entrada	Simbolo	Unidades	Distribucion	Probado Minimo	Probable Most likely	Posible
1	Porosidad	Φ	%	Triangular	20	15	5
2	Area del recurso	A	km2	Triangular	5.5	14.2	40
3	Espesor	H	m	Triangular	2100	2500	3138
4	Densidad roca	σ	kg/m3	Constante	2600		
5	Capacidad calorifica roca	Cr	kJ/kgoC	Constante	0.85		
6	Temperatura reservorio	Tr	oC	Triangular	260	290	300
7	Temperatura referencia	Ts	oC	Constante	40		
8	Densidad agua a condicion de reservorio	σ	kg/m3	Constante	900		
9	Entalpia agua a condicion de reservorio	hr	kJ/kg	Triangular	1100	1200	1350
10	Entalpia a temperatura referencia o sumidero	hs	kJ/kg	Constante	167.7		
11	Factor de recuperacion	Fr	%	Constante	20		
12	Eficiencia conversion	η	%	Constante	11		
13	Periodo de vida	T	Años	Constante	50		
14	Factor de planta	Lf	%	Constante	95		
15	Factor de conversion						

The results indicate the level of sustainable production Eo for the Berlin geothermal field could be between 235-240 MW over a period of 50 years of commercial operation and considering the percentile 90% as shown in Figure 3

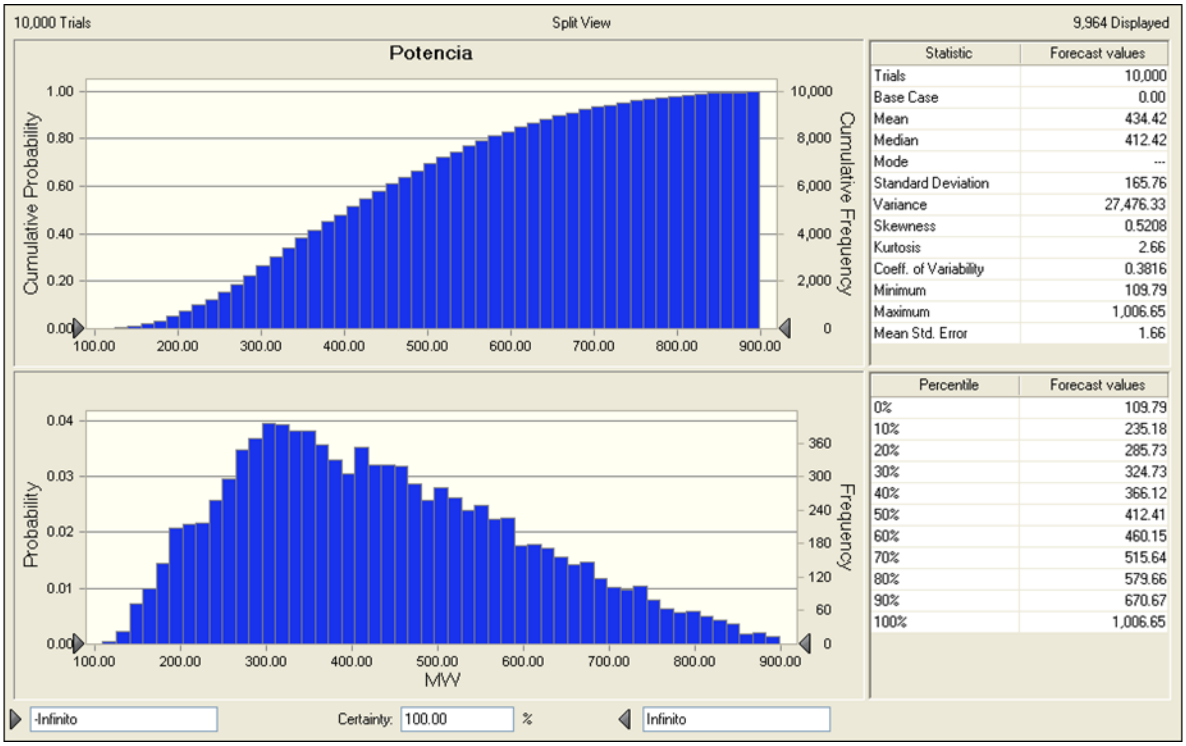


Figure 3. Estimation of sustainable energy production at the Berlin field

The present installed capacity at the field is 109 MW and the level of sustainable energy production is 235 MW therefore the operational level could be considered as sustainable.

The first performance indicator presented in this work is the Utilization Efficiency estimated by exergy. The Figure 4 presents a bench marking over 20 geothermal power plant efficiency around the world, as observed the Berlin plant is over the average.

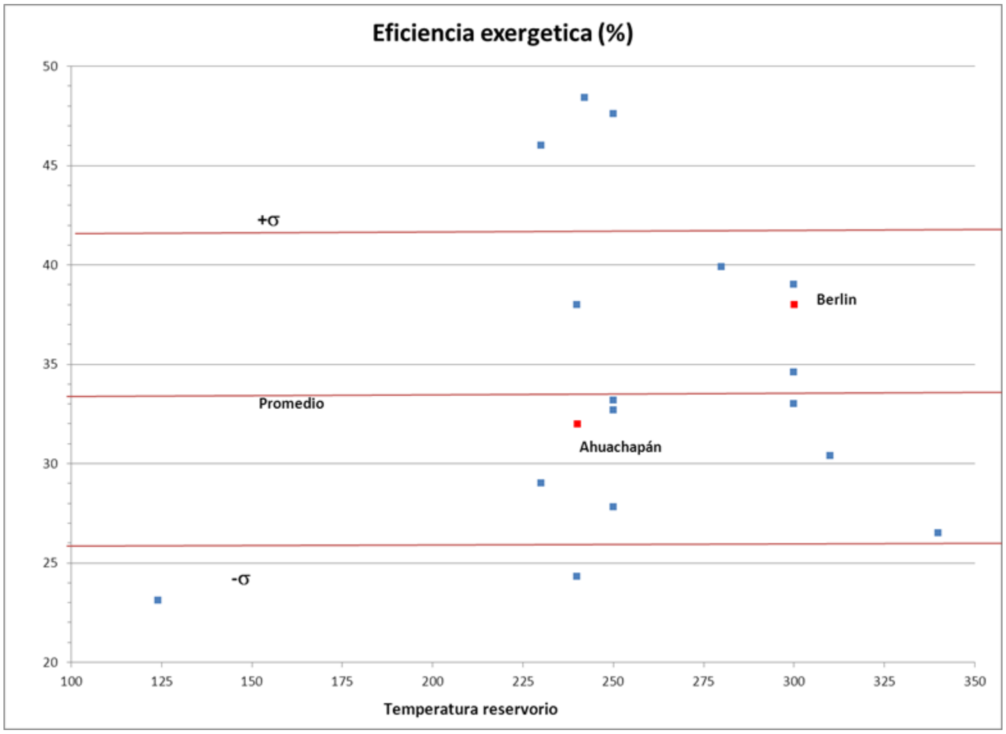


Figure 4: Exergy efficiency of power plants around the world

The second and third indicators are based in numerical modeling which is a powerful tool to estimate the Productive Lifetime and the Recovery Time: Firstly a good enough calibrated model must be available, the standard code used by LaGEO is TOUGH2 and iTOUGH2 which are running in Linux operative system, beside this, the natural state and production models are also utilized during the adjusting process and finally is utilized a coupled model (wellflow model coupled with reservoir models).

For the Productive Lifetime indicators the resource is considered as source of steam delivered to power plants without any make up wells therefore it is steam declining the main issue to be considered, for this reason the well flow model is considering with constant well head pressure (as being utilized at present time). The mass delivered by the wells is decreasing until a practical limit could reach. The limit is the steam required to operate at least one unit 28 MW (50 kg/s steam which mean 200 kg/s total mass at 0.25 dryness).

The results are shown in Figure 5, the mass flow rate is declining around 2.5 kg/s/year thus the simulation suggests it is possible to operate the geothermal field for at least 50 years with at least one power unit, considering this condition as productive lifetime.

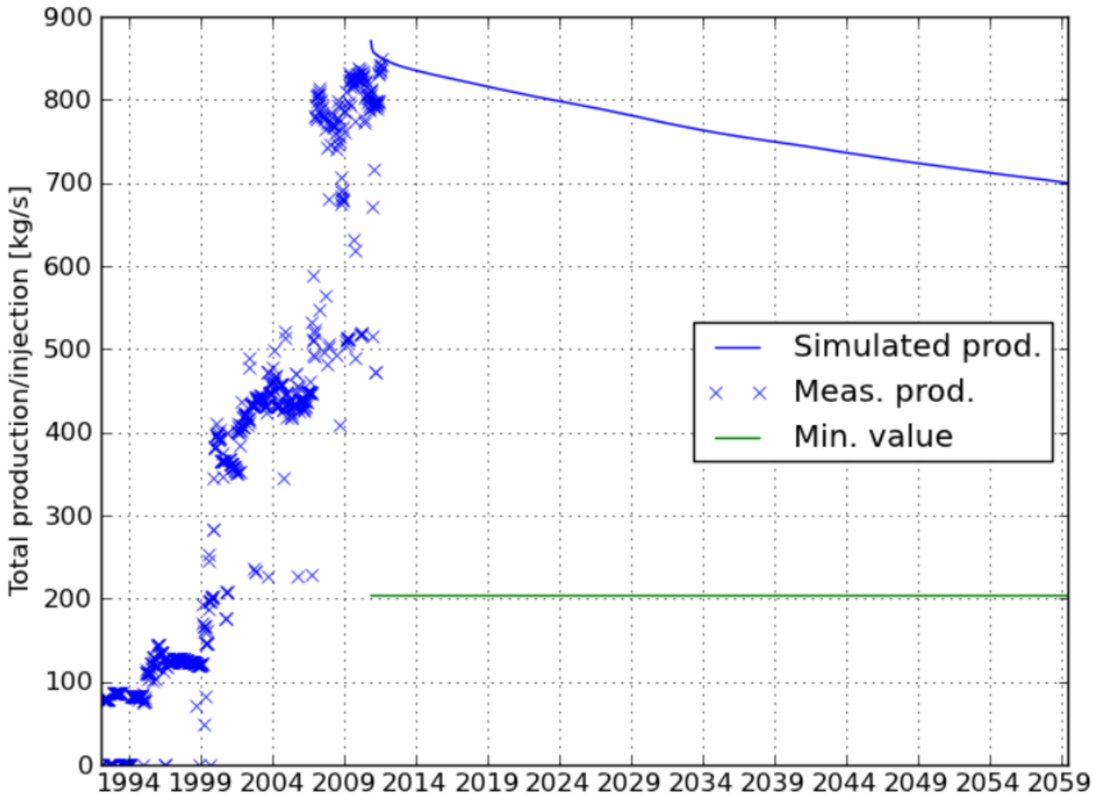
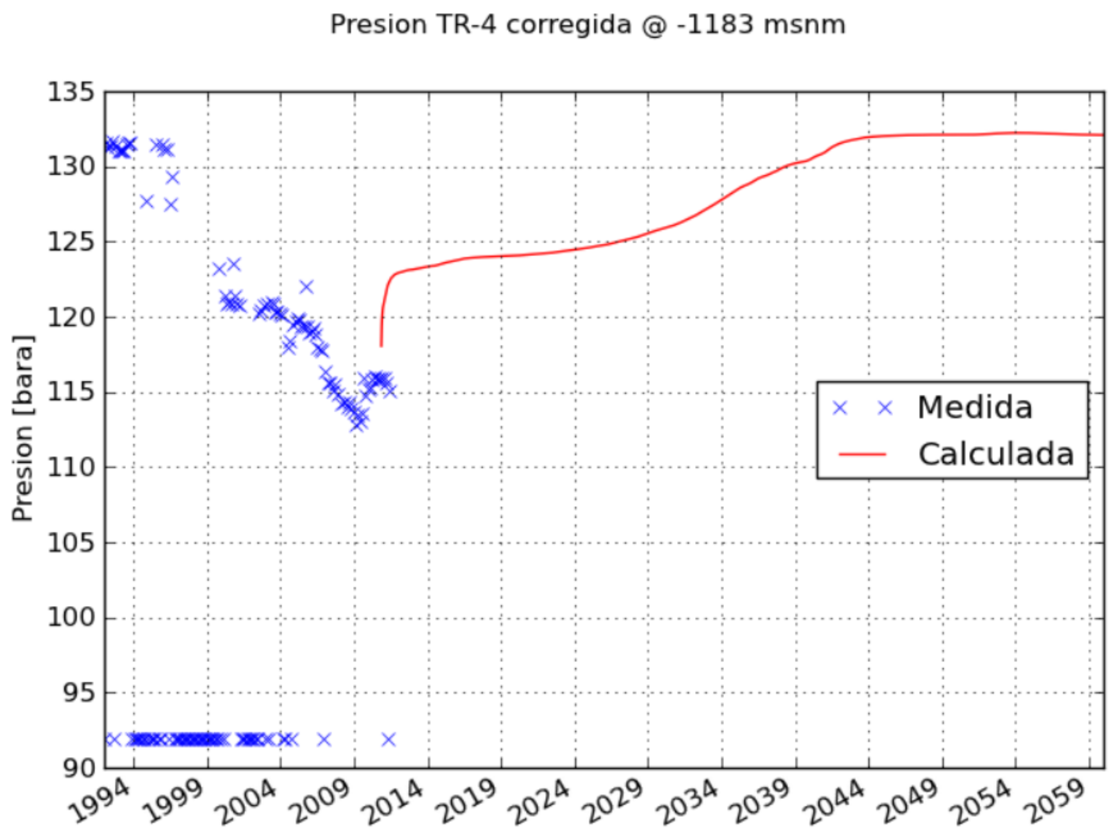


Figure 5. Productive life time Indicator of the Berlin Geothermal Field

In order to estimate the Recovery time indicator, in the numerical model, the sinks and source nodes are eliminated (mass=zero) therefore no mass and energy are delivered or injected after the thermal and hydraulic recovery began. The results are shown in the Figure 6, as observed the pressure at monitoring well is suddenly increasing until reach similar initial pressure after 33 years of recovery, therefore the utilization of the geothermal resource is recovered in short term period however it is not the case of temperature which will require more time.



CONCLUSIONS

1- The Berlin geothermal field has been in commercial operation for at least 20 years. During this period no evidence of irreversible conditions has been observed in the whole productive field. Yet LaGeo is focused on developing a more complete sustainable utilization to guarantee stable operating conditions for at least 50 years of operation.
2- Preliminary results indicate that it is possible to perform a sustainability analysis for the Berlin Geothermal field, which suggests that the utilization of the resource is done in a sustainable way.
3- Numerical modeling is being utilized as a powerful tool to estimate the sustainable operation indicators.

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