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From an Oilfield to a Geothermal One: Use of a Selection Matrix to Choose Between Two Extraction Technologies

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ABSTRACT

In current energy outlook and oil price trends, oil companies are actively seeking more innovative ways to reduce operating costs and to extend the life of their ageing fields. Mature oil fields are characterized by a large amount of co-produced water, which must be treated continuously and could not be delivered to the environment. The waste heat recovery from the produced stream could be a quite interesting option while the wells are still producing hydrocarbons. When the oil field is depleted the field could be converted into a geothermal reservoir. This study proposes an unconventional lifecycle management: a selection matrix to choose between two different technologies in order to convert a hydrocarbons field into a geothermal one. The matrix is implemented on one of the largest European oil fields, Villafortuna-Trecate oil field.

1. INTRODUCTION

The optimization of energy production sometimes moves into unexpected ways. In current energy outlook and oil price trends, oil companies are actively seeking more innovative ways to reduce operating costs and to extend the life of their ageing fields.

Mature oil fields are characterized by a large amount of co-produced hot water stored in the reservoir that must be treated and reinjected in the underground. The amount of water increases compared to hydrocarbons, until the oil field is depleted and only water is extracted. The possibility of using these hot fluids to produce geothermal energy during the final stage of the life of an oil field and then convert the field into a geothermal one, could be a quite interesting option. However it's important to identify the exploitation technology best suited to the site.

Several studies on waste heat recovery in oil field applications have been conducted (Zhang et al., 2008, Davis and Michaelides, 2009, Bu et al., 2012, Barbacki, 2000. Limpasurat et al. 2010, Sanyal et al. 2010, Xin et al. 2012, Cheng et al. 2013). The precursor of these studies is the demonstration power plant on the Pleasant Bayou field, where existing wells were used to extract both gas and hot water and to produce electricity (Riney, 1991). More recently, in the Naval Petroleum Reserve No.3, Teapot Dome Field, Wyoming, USA, a 250 kW Ormat ORC power plant was installed to utilize low-enthalpy energy from co-produced hot water. From September 2008 to the end of February 2010, the plant generated a total of 1064 MWh of electricity (Johnson and Walker, 2010). Xin et al. (2012) introduced the first power plant in China which utilizes low-temperature waste stream in the Huabei oil field, near Beijing. A 400 kW power generator, which was a binary screw expander system, has already been put into production in early April 2011. McKenna et al. (2005) assessed that over 1000 MW electric power could be created from co-produced fluids in oilfields along the Gulf Coast. Limpasurat et al. (2010) discussed the opportunity to harness geothermal energy from heavy oil fields that have undergone steam-flooding and so accumulated substantial heat from steam injection. The analysis showed that the net power generation from a single pair of injector-producer system could be around 14 kW. Sanyal et al. (2010) reported the net power generation could be 340 kW from the combination of co-produced water and gas in an abandoned gas well at Texas. Bennett et al. (2012) states the net power output from geothermal power generation in oilfields of Los Angeles basin would be around 7430 kW.

A few papers (Nalla et al., 2005, Kujawa et al. 2006, Zhang et al. 2008, Davis and Michaelides, 2009, Bu et al. 2012, Cheng et al. 2013), have presented numerical models that considers an exploitation system based on the concept of WellBore Heat eXchanger (WBHX) to existing oil and gas wells.

Starting from these studies, this paper suggests a selection matrix to choose between two different technologies in order to convert a hydrocarbons field into a geothermal one: the traditional doublet, with fluid extraction and reinjection, and the wellbore heat exchanger (WBHX), a closed loop system which prevents to extract geothermal fluids.

Both systems can be connected to an ORC plant in order to convert the thermal energy in electrical energy, otherwise the extracted heat could be used for heating and hot water production. The choice is related to cost-benefit assessments that are beyond the scope of this study: in this work the comparison between the two systems was done by estimating the thermal power.

The selection matrix is implemented on a specific case: Villafortuna Trecate field, one of the largest European oil fields. The refitting of the oil field into a geothermal one involves two steps. The first one is located in the phase of co-production of oil and water: the proposed system aims to recover the waste heat from the produced well stream in order to co-produce oil/gas and electrical energy that can be used in the field. The second step of lifecycle management begins when the wells produce only hot water and provides for the complete conversion of an oil field into a geothermal one, using the selection matrix to identify the most appropriate technology to the plant.

2. BUILDING INDEXES FOR THE MATRIX SELECTION

The aim of the paper is to build a set of index in order to have an objective comparison between two different heat extraction technologies to be applied to oil and gas fields. In the first part the two technologies are presented and after a set of indexes are discussed.

2.1 Heat extraction technologies

Two heat extraction technologies have been evaluated: the traditional doublet, with fluid extraction and reinjection, and the wellbore heat exchanger (WBHX), a closed loop system.

For both technologies, the heat flow can be described by the relation:

$$Q = c_p \rho \cdot q \cdot (T_i - T_o) \tag{1}$$

where c_p is the specific heat of the fluid, (W/kg K); ρ is the fluid density (kg/m^3), q is the fluid flow rate (m^3/s), T_i is the fluid temperature at wellhead (°C), T_o is the fluid temperature at the exit of electrical generator (°C).

In the traditional plant using an extraction well the heat carrier fluid is the geothermal one. The flow rate depends on the petrophysical properties of the rocks and can be adjusted by choke valves at the wellhead, and the fluid temperature is a function of the heat exchange in the well during the production process. Other aspects will be discussed later.

The WBHX is a closed loop system based on two coaxial tubes, the exterior annulus is for the fluid downward flow and the inner pipe is for the fluid ascent. During the downward flow the water acquires heat from the surrounding ground. At the bottom end the fluid is upward diverted and flows into the internal pipe up to wellhead. The gap between the two pipes, forming the dual shell inner tube, is filled with insulating material in order to reduce heat losses. The WBHX is based on the heat transfer by conduction into the reservoir rock and by convection and conduction into the fluid flowing in the tubes. The flow rate of the circulating fluid is fixed by the user and the fluid temperature at wellhead is determined accordingly.

2.2 Performance index

To evaluate the better technology to be adopted in the conversion process of the oil and gas field in a geothermal one, has been decided to use a system based on indexes and weights. The performance index will be obtained with the following relationship:

$$P = \sum_{j=1}^{m} I_j \cdot w_j \tag{2}$$

A set of nine indexes has been developed. Each index has a value between 0 and 1, 0 unfavorable and 1 highly favorable.

2.2.1 Thermo-energy production index I_P

In the feasibility study of a geo-thermoelectric plant the key parameter is the installed power. This is the starting point also for the economics. Therefore a ranking parameter has been established. This is based on the ratio between the evaluated thermal power and a reference value. The reference value has been chosen considering the more widespread size of power plants, for steam plants is around 20 MW and for ORC plant is between 1 and 5 MW. In Table 1 the ranking values for the thermo-energy production index are reported having assumed an ORC plant for electrical generation.

Table 1 - Thermo-energy production index

Range	$P/P_r < 0.1$	$0.1 \le P/P_r < 0.2$	$0.2 \le P/P_r < 0.4$	$0.4 \le P/P_r < 0.6$	$0.6 \le P/P_r < 1$	$P/P_r \ge 1$
I_P	0	0.2	0.4	0.6	0.8	1

2.2.2 Temperature-flow rate index I_{qT}

From equation (1), the relevance of flow rate and temperature of the produced fluid has been highlighted. Hence, the possible links between flow rate and temperature depending on technologies should be emphasized. For this reason has been proposed an indicator based on the ratio between the fluid flow rate and its flowing temperature at wellhead. The ranges have been defined using flow rates between 0 and 100 m^3/h and temperatures between 80 and 160 °C, corresponding to operative conditions for an ORC plant. The ranking values are reported in Table 2.

Table 2 - Temperature-flow rate index

Range	$q/T \le 0.055$	$0.055 < q/T \le 0.125$	$0.125 < q/T \le 0.55$	$0.55 < q/T \le 12.5$	$q/T > 12.5$
I_{qT}	1	0.75	0.5	0.25	0

2.2.3 Outlet temperature index I_{Texit}

The outlet temperature of the fluid from the wellhead is one of the main parameters. To account its relevance has been defined a parameter which correlates the outlet temperature with a characteristics temperature of the energy conversion plant. In the actual case the plant is an ORC machine, with entrance temperatures between 80 and 160 °C (VV.AA. MIT Report, 2006).

A simple criterion has been fixed: if the ratio between the outlet temperature and the double of the minimum temperature for the conversion plant, e.g ORC 80°C, is less than one the indicator is zero; if it is equal or greater than one will be one (Table 3).

Table 3 - Outlet temperature index

Range	$T_i/(2T_{min}) < 1$	$T_i/(2T_{min}) \geq 1$
I_{Texit}	0	1

2.2.4 Pumping aided production index I_{PE}

The request in pumping is obviously a reduction in energy efficiency of the power plant generation. The different technologies could require or not pumping. If pumping is needed the impact on the energy balance must be accounted. The index to rank the technology is defined on the ratio between the pumping energy and the produced energy. Therefore, a threshold equal to 15% has been fixed; for values less than the threshold the index is equal to 1 and for greater values is zero (Table 4).

Table 4 - Pumping aided production index

Range	E_p/E >15%	E_p/E ≤15%
I_{PE}	0	1

2.2.5 Re-injection index I_I

In technologies that require reinjection a part of the produced energy will be spent in this operation. Reinjection techniques should also account for technical problems. The interference between injected fluid and produced ones is one of the reasons for decreasing of geothermal fluid temperature. An example is the temperature decline measured from the PN26 well in Palinpinon field (Malate and O'Sullivan, 1991).

Other technical problems are scaling problems. Itoi et al. (1987) have observed the complete obstruction of the wells in the Otake field (Japan) due to silica scales. Stefansson (1997) reports about a partial recovery of the problem in reinjection operation conducted with hot fluids. The conversion plant could also affect the chemical composition of fluids. This is the case of steam plants where fluids are flashed. Instead, in ORC plants the geothermal fluid is not affected by composition changes.

Due to the different aspects that concern the fluid reinjection process, the reinjection index will be obtained with the following sub-indexes:

- I_{IC} accounts for injection costs and is based on energy cost. If energy pumping reinjection is less than 15% of the produced energy the index is equal to zero, otherwise is one;
- I_{ISC} takes into account the corrosion and scaling phenomena. If hazard is present the index will be equal to zero, if absent will be set to one;
- I_{IT} considers for the hazard of reinjection fluid interference. If hazard is present the index will be equal to zero, if absent will be set to one;
- I_{IK} accounts for formation damages as permeability decrease. If hazard is present the index will be equal to zero, if absent will be set to one;
- I_{ID} considers the injection location. If the injection could be in the same layer as production the index will be equal to one, if not will be zero.

2.2.6 Scale-Corrosion index ISC

One of the most frequent phenomenon in geothermal wells is scaling and corrosion. Those phenomena are related to the chemical composition of geothermal fluid, the value of pH, pressure and temperature conditions.

In common practice of process engineering the corrosive or scaling tendency of a fluid is evaluated with the Langelier Saturation Index (LSI) and the Ryznar Stability Index (RSI). Table 5 reports the reference values and consequences. Both indexes are based on the fluid pH and the saturation pH of the species, often calcium carbonate.

Table 5 - Langelier Saturation Index

LSI Index Value	Indication
2.0	Scale forming but non corrosive
0.5	Slightly scale forming and corrosive
0.0	Balanced but pitting corrosion possible
-0.5	Slightly corrosive but non-scale forming
-2.0	Serious corrosion

In plants with open loop the corrosion and scaling hazard on metal surfaces is intrinsic, particularly when working in HP/HT condition with large changes in state condition of fluids. The Pleasant Bayou hybrid plant is a clear example. The geothermal fluid was a corrosive brine with a high solid content (130,000 ppm). Therefore to maintain high efficiency level in well production the use of chemical additives was necessary.

In case of closed loops like the WBHX, the corrosion and scaling phenomena are avoided using a fluid mixture with anticorrosion and/or antiscaling additives.

The Scale-Corrosion index is based on the LSI following the ranking presented in Table 6.

Table 6 - Corrosion and Scaling Index

LSI	LSI = 0	0<LSI≤0.5	0.5<LSI≤1	1< LSI ≤ 1.5	1< LSI < 2	LSI = 2
I_{SC}	1	0.8	0.6	0.4	0.2	0

2.2.7 Environmental impact index IENV

Geothermal energy is considered a clean, sustainable and renewable energy source. The exploitation of geothermal fields have some drawback on the environment like impact on landscape, induced micro-seismicity, noise, gas emissions to atmosphere, radioactive contaminant, etc.

The use of existing oil and gas wells allows to avoid additional environmental impact of exploration and drilling operations. A major aspect in sustainability of geothermal production is the fluid extraction and reinjection. The fluid extraction could cause subsidence phenomenon. It has been observed in different geothermal plants: in Wairakei (New Zeland) the maximum observed subsidence was 15 m (400 mm/year) and in Larderello (Italy) was about 250 mm/year (Hunt, 2001; Allis, 2000; Eysteinsson, 2000; Aust and Sustrac, 1992).

The pore pressure reduction in production and increase in reinjection operations have been associated to phenomena of induced seismicity. Often events are microseisms of low energy (< 2-3 M Richter scale) and due to the redistribution of stresses in the rock mass (Hunt, 2001). In Larderello field very low magnitude events have been associated to reinjection operations (Barbier, 2002).

The noise impact of geothermal plant during operation are acceptable, typically 71-83 dB at 900 meters. The main sources of noise are electrical transformers and cooling towers. In this case can be foreseen noise containing systems.

The geothermal fluids can contain carbon dioxide, hydrogen sulfide, ammonia, methane, nitrogen, arsenic, boron, mercury, lead, zinc, manganese, lithium, as well as the radon. All those chemical elements can have consequences on the environment and constitute a hazard. Degering and Köhler (2013) have reported the radioactive isotopes in the North German Basin (NGB) and in the Upper Rhine Basin (URB). The extracted brines contain di ${}_{226}Rn$ e ${}_{228}Rn$ (2-35 Bq/m^3 in the NGB, 30-50 Bq/m^3 in the URB) and of ${}_{40}K$ (100 - 130 Bq/m^3 in the URB, 5 -250 Bq/m^3 in the NGB). The MIT report has summarized the main gaseous emissions for different energy plant (see Table 7).

Therefore, the environmental impact index will be obtained by the average of the following Boolean sub-indexes: $\mathbf{I_S}$ sustainably index, $\mathbf{I_G}$ soil index, $\mathbf{I_L}$ landscape index, $\mathbf{I_S}$ subsidence index, $\mathbf{I_{PH}}$ potential seismicity index, $\mathbf{I_N}$ noise index, $\mathbf{I_{AIR}}$ gas emissions in atmosphere, $\mathbf{I_{WATER}}$ potential water contamination index, $\mathbf{I_R}$ radioactivity index.

Table 7 - Gaseous emission from various power plants (VV.AA. MIT report, 2006)

Plant type	CO_2 Kg/MWh	SO_2 kg/MWh	NOx kg/MWh	Particulates kg/MWh
Coal-fired	994	4.71	1.955	1.012
Oil – fired	758	5.44	1.814	N.A
Gas – fired	550	0.0998	1.343	0.0635
Geothermal-flash steam, liquid dominated – USA	27.2	0.1588	0	0
Geothermal – The Geyesrs dry steam field – USA	40.3	0.000098	0.000458	Negligible
Geothermal – closed loop binary/EGS	0	0	0	Negligible
Geothermal – flash steam – Hellisheidi – Iceland	21.6	17.6	0	0
Geothermal – flash steam – Tuscany – Italy	324	1.65	-	-
Average. All European plants	369.7	1.1	0.5	0.1

2.2.8 Social impact index I_{SI}

At present, in energy plant the major aspect causing delay or stop of project is the social acceptance. The change in knowledge diffusion and the improved level of risk perception by population are at the basis.

The social impact of a plant, even when dealing with renewable energy sources is an issue that affects more and more awareness of the communities adjacent to the field itself, so that today the social acceptance is one of the factors needed to implement of any project. The ability to make an acceptable project also means knowing how to combine the technological progress and the energy needs of the countries with the environmental, social and economic areas in which you are designed. Social acceptance also requires the costs, which must be provided at an early stage of the study of economic feasibility and design, so they ought not to be evaluated successively, causing a slowdown in the implementation of the project.

Cataldi (1997) has proposed the following definition of social acceptability: *"Social acceptability of a geothermal project is the condition upon which the technical and economic objectives of the project may be pursued in due time, with the adhesion of the local communities, obtained by acting in consonance with the dynamic conditions of the environment and in the respect of the people's health, welfare and culture"*. De Jesus (1995) has proposed this definition: *"Social acceptability is attained if the project activities do not result in drastic changes from the regular conditions of the area, and if the affected sectors can see some advantages issuing from the project "*.

The two definitions have differences, but they share the knowledge that the implementation of a system must take into account the characteristics of the region in which it is realized, and finally the environmental fragility of the instances of the communities that live in that territory.

The complexity of the subject forces to define the index in a qualitative form. The index of social impact I_{SI} has been defined to have a value of 0 if the social impact is negative, 1 if the social impact is positive.

2.2.9 Cost index I_C

The conversion of an oil field in the geothermal field allows a double saving: the managers of the hydrocarbon field avoid the high costs of decommissioning of the field, while investors in the geothermal sector avoid all costs of exploration and identification of the resource costs drilling and construction of a plant ex novo inclusive of electric transmission lines. These costs generally exceed 80% of the total cost of a geothermal plant (Hance, 2005); even willing to consider only the construction costs of the wells (23% of the total cost according to Hance (2005); 20-50% of the total cost in the case of high temperature according to Stefansson (2002)) and, assuming that the conversion of a hydrocarbon field in at least one geothermal involves an upgrade to the power lines and the oil center, the investment is still profitable than to deal with the realization of a complete system.

A flow chart has been developed for the cost-benefit analysis of a conversion of the oil & gas field in the geothermal field. For the two different technologies for extraction of geothermal energy, wellbore heat exchanger and direct use, have been calculated cost of construction of a new geothermal field and the cost of converting an oil field in a geothermal one. The purpose is to verify from the economic point of view the actual convenience of a project for refitting.

So for the assignment of a score to the cost index I_C, the parameter payback time of investment have been chosen, with payback times of highly positive if less than 3 years and no interest if over seven years :

Table 8 - Cost index

Range	**$t_{pb} \leq 3$ y**	**3 y $< t_{pb} \leq 4$ y**	**4 y $< t_{pb} \leq 5$ y**	**5 y $< t_{pb} \leq 6$ y**	**6 y $< t_{pb} \leq 7$ y**	**$t_{pb} > 7$ y**
I_C	1	0.8	0.6	0.4	0.2	0

3. CASE STUDY: VILLAFORTUNA-TRECATE OIL FIELD

The Villafortuna-Trecate oil field was discovered in 1984 in the northern Italy, in the Padana district. The site is characterised by a normal geothermal gradient (2.8°C each 100 m depth), the main reservoir is at 5700-6100 m depth and is characterized by a temperature of about 166 °C and an average static pressure of 850 bar. Production data highlight the actual production tail and the end of field life. Several wells are always open and only few are producing with different water cuts.

The first phase of lifecycle management of Trecate oil field evaluates the integration of the electrical energy production in the oil and gas production plant. The task of the heater is to compensate the lesser heat capacity of the oil.

In Liu et al. (2013) a one-dimensional reservoir model was built to describe a single production well in the Villafortuna-Trecate oil field. The 1-D model has been implemented with TOUGH2. No well flow models have been considered. Thus, has been decided to evaluate the delivery capacity of a single well based on the available data in literature. Due to the highly mature status of the field, the well behaviour has been evaluated for water cut from 50% up to 100%. The well performance analysis has been conducted using Prosper software. The well completion design has been assumed as described in Botto and De Ghetto (1994).

As surface equipment, a choke valve has been inserted assuming its opening between 0.25 to 1 inches. The model reproduces a deliverability of the well of 850 m^3/d at choke opening of 0.33 inches. The wellhead pressure and temperature are respectively 250 bar and 125 °C.

To evaluate the recoverable thermal power the following relationship has been used:

$$Q = \left(c_{pw}\rho_w q_w + c_{po}\rho_o q_o\right)\cdot\left(T_i - T_o\right) \tag{3}$$

where c_{pw} is the specific heat of water, equal to 4186 W/kg K, ρ_w is the water density (kg/m^3), q_w is the water flow rate (m^3/s), c_{po} is the specific heat of oil, equal to 2286 W/kg K, ρ_o is the oil density (kg/m^3), q_o is the oil flow rate (m^3/s), T_i is the inlet temperature to the ORC, T_o is the outlet temperature from the ORC

The deliverability of the producer has been evaluated with water cuts between 0.5 and 1.0 and choke openings between 0.25 and 1 inches. Different management scenarios of energy production system are available. A first scenario is to select the nominal power of ORC facility less than the maximum one, e.g. 4 MW. During the well life water cut increases. Consequently, to maintain the thermal power production constant, the choke valve will be closed to reduce the flow rate. No heater is required in this case. An alternative scenario is to select an ORC facility with an installed power of 5 MW, equal to the maximum one. At lower water cuts the available thermal power is less than the installed one. Thus, to compensate this difference a part of the produced gas will be used as fuel into the heater.

Approximately 50 wells have been drilled in the oil and gas field. Only 8 wells are currently in production. Therefore, in the following analysis have been decided to assume 8 wells available as the worst case and 20 wells as the best one. Table 9 shows the results for first scenario (without the heater) and second scenario (with the heater).

Table 9 – Maximum power in the first phase of life cycle management

FIRST SCENARIO	Thermal Power	Electrical Power	SECOND SCENARIO	Thermal Power	Electrical Power
1 well	4 MW	400 kW	**1 well**	5 MW	500 kW
Worst case (8 wells)	32 MW	3,2MW	**Worst case (8 wells)**	40 MW	4 MW
Best case (20 wells)	80 MW	8 MW	**Best case (20 wells)**	100 MW	10 MW

Table 10 shows the values of available power with a direct type technology and with the heat exchanger applied to the field of Trecate converted into geothermal field. The WBHX plant uses all the wells still active, while the direct use plant was assumed to use direct producer-injector ratio of 1:1.

Table 10 – Potential power in the second phase of life cycle management

Direct USe	Thermal Power	Electrical Power	WBHX	Thermal Power	Electrical Power
1 well	5 MW	500 kW	**1 well**	1.5 MW	130 kW
Worst case (4 prod. wells + 4 inj. wells)	20 MW	4 MW	**Worst case (8 wells)**	12 MW	1 MW
Best case (20 prod. wells + 20 inj. wells)	100 MW	10 MW	**Best case (40 wells)**	60 MW	5.2 MW

The evaluation of the costs for the installation of Trecate was calculated per single well; the cost of energy used to estimate the cash flow was 0.16 € / kWh (price per customer in Italy). Two other economic scenarios were analyzed: the first assuming the sale price of € 0.05 / kWh (guaranteed minimum purchase price for 2014 in respect of geothermal plants up to 1.5 GW) and the second for 0.08 € / kWh. The results (Table 11) show that for the case study, a project of converting from oil field in the geothermal field is evaluated only if the cost of electricity sales approaches to 0.16 € / kWh.

Table 11 - Payback time

Energy Price	Payback Time Direct Use	Payback Time WBHX
0.05 €/kWh	21 years	>30 years
0.08 €/kWh	8 years	>30 years
0.16 €/kWh	4 years	13 years

4. APPLYING THE DECISION MATRIX TO VILLAFORTUNA-TRECATE OIL FIELD

To apply the matrix selection criteria to the case study some assumptions were necessary. Since no data were available on the chemical composition of the formation waters, it was not possible to calculate the I_{SC} and I_{ISC} with the Langelier Index, and then was made a qualitative assessment by assigning negative score 0 to the technology with the direct use as it involves the extraction of fluids potentially fouling and the positive score 1 to WBHX that does not require the extraction of geothermal fluid. The environmental impact indicators have positive value for the WBHX, while in the case of the technology of direct use has been evaluated as possible the risk of subsidence, seismicity induced and impact on groundwater especially since it is not possible to re-injection into the same level of production. Instead, the land use and the impact on the landscape was assessed with the score 1 for both technologies because we are considering two conversion projects that offer new possibilities of use of part of a territory already changed and in a state of abandonment, thus avoiding alteration of other landscapes. Even the noise index I_N is positive for all geothermal plants because, as already discussed in detail in the previous chapter, do not produce noise levels in excess of allowable limits.

Table 12 – Environmental Index and Injection Index

ENVIRONMENTAL INDEX		
INDEX	**DIRECT USE**	**WBHX**
I_{SR}	0	1
I_G	1	1
I_L	1	1
I_S	0	1
I_{PH}	0	1
I_N	1	1
I_{AIR}	1	1
I_{WATER}	0	1
I_R	0	1
$\mathbf{I_{ENV}}$	**0.44**	**1.00**

INJECTION INDEX		
INDEX	**DIRECT USE**	**WBHX**
I_{IC}	0	1
I_{ISC}	0	1
I_{IT}	0	1
I_{IK}	1	1
I_{ID}	0	1
$\mathbf{I_I}$	**0.20**	**1.00**

Table 13 shows the decision matrix with the indices that compose it. The quality index of social impact has been assigned a positive value to both plants because the conversion of a field, with the inherent possibility of using skilled labor previously employed in the oil field of Trecate, represents an opportunity work that generally favors the social acceptability of projects. In addition, the installation of a geothermal power plant in an area where there is already a system for the extraction of hydrocarbons, does not generate problems impact on the environment or changing the nature of the territory, which may negatively affect the social acceptability of projects. For the calculation of the final score, the choice of the weights to be assigned to different indexes affect the final evaluation of the projects. By assigning a weight equal to unity for all indicators, the WBHX is the system with the final index greater than that of the other case.

Table 13 - Decisional Matrix - Villafortuna Trecate Oilfield – Base Case

DECISIONAL MATRIX			
INDEX	**DIRECT USE**	**WBHX**	**WEIGHT**
I_P	0.20	0.00	1
I_{QT}	0.40	1.00	1
I_{Texit}	0.00	0.00	1
I_E	1.00	0.00	1
I_I	0.20	1.00	1
I_{SC}	0.00	1.00	1
I_{ENV}	0.44	1.00	1
I_{SI}	1.00	1.00	1
I_C	0.80	0.00	1
FINAL INDEX	**0.46**	**0.51**	

Table 14 presents the variation of the final evaluation of the project if a greater weight was assumed to economic-productive indexes (case A) or, on the contrary, to social and environmental issues (case B). In the first case has been assigned a weight of 2 for indexes I_P, I_C and a unitary weight to all other, obtaining as best choice the technology with Direct Use. Instead, if the feasibility of the project is subject to the social and environmental issues, assigning a weight of 2 indexes I_{ENV} and I_{SI}, the final score of the heat exchanger in the well exceeds the 10 points of the technology of direct type.

CONCLUSIONS

This article proposes the use of a selection matrix to identify the best technologies of extraction of geothermal energy: a plant for direct use with production and injection wells, or the wellbore heat exchanger (WBHX) in which there is no production of geothermal fluid.

To quantify all the aspects that characterize the two projects, ranging from technical to economic, environmental and social issues, we have adopted a system of indexes and weights for which the final score is calculated using an index based on a weighted average of indexes that have the value between 0 and 1.

Table 14 - Decisional Matrix - Villafortuna Trecate Oilfield – Cases A and B

DECISIONAL MATRIX - Case A				DECISIONAL MATRIX - Case B			
INDEX	**DIRECT USE**	**WBHX**	**WEIGHT**	**INDEX**	**DIRECT USE**	**WBHX**	**WEIGHT**
I_P	0.20	0.00	2	I_P	0.20	0.00	1
I_{QT}	0.50	0.75	1	I_{QT}	0.50	0.75	1
I_{Texit}	0.00	0.00	1	I_{Texit}	0.00	0.00	1
I_E	1.00	0.00	1	I_E	1.00	0.00	1
I_I	0.20	1.00	1	I_I	0.20	1.00	1
I_{SC}	0.00	1.00	1	I_{SC}	0.00	1.00	1
I_{ENV}	0.44	1.00	1	I_{ENV}	0.44	1.00	2
I_{SI}	1.00	1.00	1	I_{SI}	1.00	1.00	2
I_C	0.80	0.00	2	I_C	0.80	0.00	1
FINAL INDEX	**0.47**	**0.42**		**FINAL INDEX**	**0.51**	**0.61**	

The matrix of choice was implemented on a specific case: Villafortuna-Trecate, one of the largest oil fields in Europe, now come to the end of life and that is envisioned to convert into a geothermal field. In fact, the possibility of avoiding the high costs of closure of a plant can be an attractive option for the oil companies. On the other hand the opportunity to use an existing system to extract geothermal fluids and produce energy, bypassing the costs of exploration and excavation of wells, it becomes an opportunity for investors in the geothermal sector.

In the application of the selection matrix, the choice of the weight to assign to the different indexes affects the final evaluation of projects. The base case assigns unitary weight to all indicators and the outcome from the matrix indicates WBHX a better technology.

The final score in the evaluation of a project will vary if a greater weight is assigned to the economic-productive (case A) or on the contrary to social and environmental issues (case B). In case A the selected technology is the direct use and in case B is the WBHX.

The result of the application of the developed matrix is quite interesting. The relative importance of specific issues in evaluation procedure highlights the importance of the social-environmental aspects in the technology selection.

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