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Geopressured Geothermal Resources in Mexico

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ABSTRACT

Hydrothermal systems associated with oil deposits have attracted the attention of developers. The feasibility of their exploitation has been promoted with new innovative technologies, and in the near future they will play an important role in geothermal energy production. In this work, the Analytic Hierarchy Process is applied using GIS to define the most suitable wells in an oil province to be used for geothermal exploitation. In the oil fields in Mexico hot wells occur in Cuenca de Burgos and the Campeche-Tabasco area, where temperature gradients above 70ºC/km have been reported in deep oil/gas wells owned by Petróleos Mexicanos. This region possesses high medium enthalpy geothermal potential with the advantage that there are numerous wells that could be used to exploit these resources without having to include in the project the drilling expenses. The explored petroleum provinces in Mexico occupy almost 15% of the whole territory but here we will focus in two areas: the northern one contains the Burgos and Sabinas basins that produce mostly gas and are hosted in a thick Cenozoic dominantly siliciclastic marine sequence, which is well known by the petroleum reservoir engineers; and the southeastern province that contains oil reservoirs with significant carbonate and siliciclastic marine record. These zones have wells where fluid temperature is reported to present values above 100°C and geothermal gradients as high as 70°C/km. The largest expense in geothermal projects is drilling and development of the geopressured resources would most likely depend on the wells abandoned by the oil industry. These resources have not been considered for exploitation, but they could increase the geothermal reserves of Mexico significantly.

1. INTRODUCTION

The use of wells drilled to exploit hydrocarbon reservoir for geothermal exploitation/utilization is attracting attention of investors in many oil producing countries (VanWees et al., 2015). The oldest reference is from Davis and Michaelides (2009) doing a computational simulation to determine the production of geothermal energy by injecting and recovering a secondary fluid from abandoned oil wells.

The abundance of BHT in oil fields provides valuable information to evaluate the possibility to exploit those low- to medium-enthalpy geothermal resources and it is not uncommon that oil and gas wells are drilled in formations with temperatures above 100°C (Richardson & Blackwell, 2016). Additionally, detailed description of the stratigraphy, porosity and permeability in oil wells favors evaluation of wells for further geothermal use after oil reserves have been exhausted.

Evaluations have been done in many oil fields to estimate the feasibility of geothermal energy exploitation after abandonment of the oil fields or simultaneously with hydrocarbon exploitation (Esposito and Augustine, 2011; Soldo and Alimonti, 2015; Wang et al., 2016; Caulk and Tomac, 2017) and some suggest innovative technologies to enhance heat recovery (Cheng et al., 2016; Cui et a., 2016; Macenic and Kurevija, 2018; Mehmood et al., 2019) or evaluate the financial feasibility of geothermal exploitation in oil wells (Bu et al., 2012; Van Wees et al., 2015). In recent publications, evaluation of the favorability for geothermal exploitation of geopressured-geothermal systems in sedimentary basins has been proposed using geographic information systems (Santilano et al., 2019). Evaluations demonstrate the economic and technical feasibility of using abandoned oil wells to utilize geothermal energy and in the near future this could be a widely spread use of geothermal resources.

2. APPLICATION OF GIS IN GEOTHERMAL AND OIL EXPLORATION

Evaluation of the results of geothermal exploration using GIS was first reported by Prol-Ledesma (2000), until then most studies had been focused on the use of Remote Sensing applied to investigation of geothermal resources. GIS application takes into account geoscientific, environmental, economic and social criteria among others. The use of GIS for the prospection and evaluation of geothermal resources has increased, as geothermal is considered as a source of clean and renewable energy that can be used to eliminate fossil fuels dependence. On the other hand, the use of GIS in oil industry occurs in all its phases, from exploration to the end of its cycle. Spatial analysis, consultations, data integration and deployment of information generated in form of maps and reports have been fundamental in the oil industry.

In this work, we use GIS to identify geothermal indicators of the study area applying an Analytic Hierarchy Process (AHP), and as a result we generate a map that shows which wells are suitable to be reused for geothermal energy. The identification of the geothermal indicators will be made by transforming the georeferenced data, which are initially in tables, into thematic maps that allow visually identifying useful geothermal variables and overlaying them to generate new information that serves as a starting point to complete the following objectives. We will apply the AHP methodology to the selected criteria taking into account the diverse alternatives that will be selected from the information generated during the process of identification of geothermal indicators. Based on the AHP results, it will be determined which well(s) are the best options to be reused for geothermal energy exploitation and the results will be shown in maps in a format that allows printing or sharing them through a WebGIS.

3. OIL AND GAS PRODUCTION IN MEXICO

Mexico started exploration for oil at the end of the XIX century, exploitation started in the beginning of the XX century and for a short period Mexico was the second world oil producer. The exploitation of the oil resources was performed mostly by foreign companies until the oil resources were nationalized in 1938; since then the government owned oil company Petróleos Mexicanos (PEMEX-Mexican Oil Company) has been the only company allowed to exploit the oil and gas resources. During a brief period of a few years in this decade, private exploitation of oil was allowed through changes in the Energy regulations; however, this year the new government has confirmed the exclusion of private investment in the exploitation of oil resources.

3.1 Petroleum provinces

In the last 80 years, PEMEX has done exploration work throughout the Mexican Territory and drilled hundreds of wells. Geological and geophysical exploration defined probable reserves in areas that cover about 15% of the whole Mexican Territory (Fig. 1). The identified petroleum provinces are distributed in the following areas: Mexican zone of the Gulf of Mexico, Central Northern part (Chihuahua-Sabinas), Gulf of California and western Baja California Peninsula (Fig. 1).

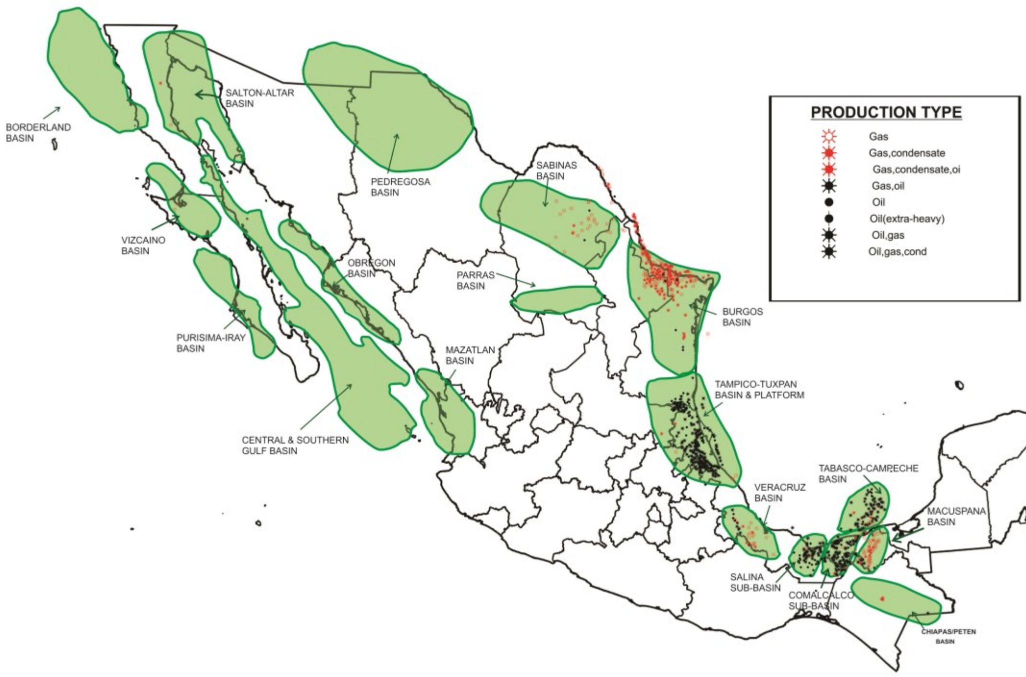

Figure 1: Oil fields and exploration wells (http://www.thomasldavisgeologist.com/resources/Mexico.pdf).

The Mexican zone of the Gulf of Mexico Basin (GOMB) extends onshore into several oil- and/or gas-producing basins: Burgos, Tampico-Misantla, Veracruz, and Sureste and the deep-water Gulf of Mexico (Guzmán & Márquez-Domínguez, 2015). The Sureste (Southern-east) Basin includes the Salina del Istmo, Comalcalco-Chiapas-Tabasco, Macuspana, Sonda de Campeche, and Litoral de Tabasco fields that are mostly oil producers. The north-central provinces include the Sabinas basin, which is an important gas producer and the Chihuahua province. The Deep Gulf of Mexico, Gulf of California, Baja California Peninsula, Chihuahua, Sierra Madre Oriental, Chiapas and Plataforma de Yucatán are not producing provinces, there are only 5 producing provinces in the continental area that are shown in Figure 2 and they are all restricted to the eastern part of Mexico. The Deep Gulf of Mexico province is included as a reference.

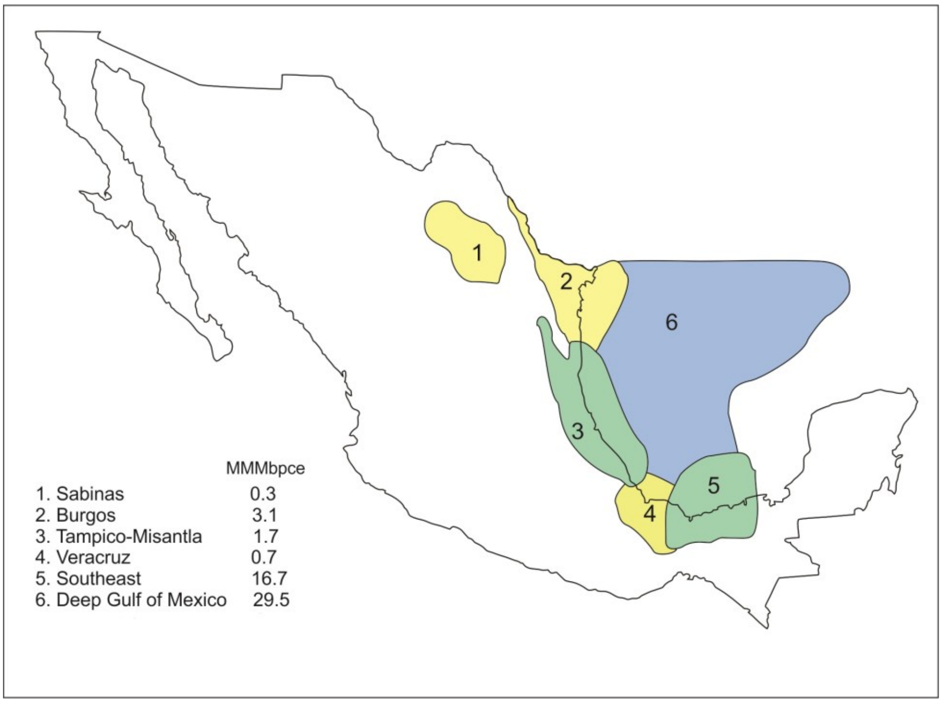

Figure 2: Producing petroleum provinces.

The five producing provinces are well characterized, and most exploration and exploitation wells that have been drilled or will be drilled are located within these provinces (Fig. 3). In Mexico, oil wells abandonment is not only determined by its state of maturity or exhaustion, but also related to the government's PEMEX poor management strategies that caused the closure of 4,021 oil wells in the country. Mexican government reported that in 2012 there were 12,187 wells operating and by 2018 only 8,166 operated both on land and offshore (Fig. 3), mainly due to lack of oil and gas production, lack of resources for maintenance, water invasion, mechanical accidents, low permeability, low profitability and depletion of primary exploitation (CNH, 2017). Many of those wells could be used for exploitation/utilization of geothermal energy.

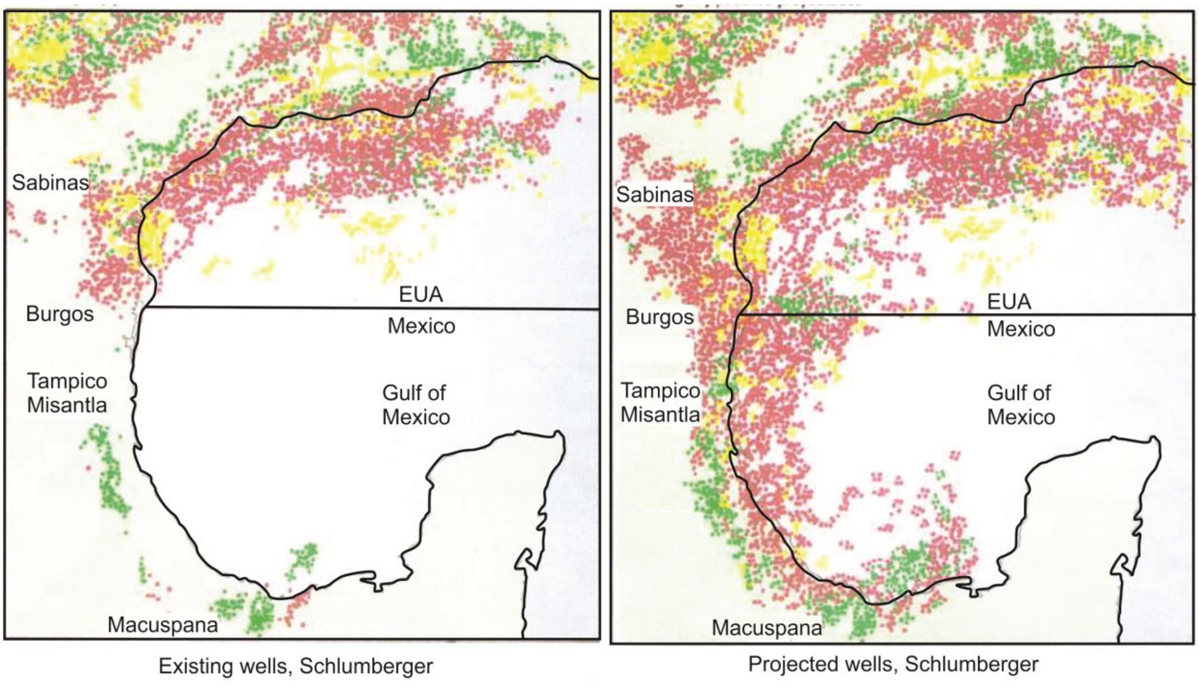

Figure 3: Drilled and planned oil wells (modified from Bahena, 2008; red dots-gas, green dots-oil, yellow dots-gas, condensate, oil).

3.2 Geological setting of the producing provinces

Producing Mexican oil fields in north-eastern Mexico are hosted in Mesozoic basins linked to the formation of the Gulf of Mexico. The tectonic evolution of the NE part of Mexico has been described in three main stages (Cuevas et al., 1988; Eguiluz de Antuñano et al., 2000):

1) The initial Mesozoic rifting stage that generated a series of grabens and horsts.

2) The second stage dominated by tectonic subsidence that favor deposition of the underlying Upper Mesozoic sequence (from Late Jurassic to Late Cretaceous)

3) Subsidence termination due to deformation related to the Ouachita Orogeny (Late Cretaceous to Tertiary)

South-eastern gas fields in the Gulf coast occur in Tertiary sandstone (Miocene) and oil fields are in Cretaceous, Paleocene, and Jurassic carbonate strata. Some small oil accumulations occur in Miocene sandstone reservoirs on salt structures in the Isthmus Saline basin of western Tabasco State (Peterson, 1983).

Most oil/gas producing basins host recent alkaline volcanic activity (Aranda et al., 2005) that extends in northern Mexico to the Gulf of Mexico coast. This volcanic activity generates high heat flow anomalies (Prol-Ledesma et al., 2018) that result in increasing geothermal gradients that affect the oil/gas provinces and conform the geopressured geothermal province (Prol-Ledesma & Morán-Zenteno, 2019).

3.3 Geothermal gradient in the petroleum provinces

Hot wells have been reported in Cuenca de Burgos and the Campeche-Tabasco area. Evidence of high temperature wells in the Sureste province is documented by Schlumberger (Schlumberger, 2015), where temperatures above 160ºC were measured in exploration wells that required special drilling technology. Geothermal gradient measurements in wells in the Burgos province confirm temperature gradients from 50 to 70ºC/km (Eguiluz de Antuñano, 2009); this is important information as Burgos Basin is the most important gas producer in Mexico in terms of non-associated gas production: since 2000 it contributes 21 percent of national gas production (PEMEX, 2013). The heat flow values in the geopressured geothermal province are between 70 – 90 mW m^{-2} (Prol-Ledesma & Morán-Zenteno, 2019).

4. GEOTHERMAL EVALUATION OF OIL/GAS WELLS IN A PETROLEUM PROVINCE IN MEXICO

Preliminary evaluation of oil wells as geothermal producers requires the availability of information on Geothermal Gradient, Heat Flow and Porosity to determine which wells represent the best alternatives for their reuse with geothermal energy. The selection of the study area is based on the occurrence of a high geothermal gradient and the accessibility of abandoned wells. According to CNH (Hydrocarbon National Commission-CNH in Spanish), in the Burgos basin there were a total of 7,754 wells drilled in 2014, of which 4,273 were in operation. However, at least in the study area most wells are abandoned or closed when they still could be producing, according to data from the CNH (2017). Geothermal gradient, heat flow and porosity data available from the CNH data base were included in the heat flow map of Mexico, as well as reports from oil exploration (Eguiluz de Antuñano, 2009; Prol-Ledesma et al., 2018). Available data on Mexican oil/gas fields is scarce; however, an attempt to evaluate the most favorable wells to start geothermal energy utilization is presented by using GIS multicriteria models.

Burgos Basin was selected as it is considered the main non-associated gas producing basin in the country and the activity is centered on an area of 30,000 km (PEMEX 2013) where a total of 7,754 wells drilled, of which 4,273 were in operation; therefore, many wells could be used for geothermal energy exploitation. Study area belongs to the Eocene Wilcox oil system in which the main hydrocarbon is humid gas and the predominant lithology is sandstones with high permeability (Eguiluz de Antuñano, 2009).

4.1 Input data

BHT downhole temperature measurements are available for 176 oil/gas wells (Prol-Ledesma et al., 2018) and temperature gradients as high as 70º/km have been measured and porosity data have been reported for 19 wells (Eguiluz de Antuñano, 2009; CNH, 2017). A geothermal gradient map was constructed from the reported data (Fig. 4).

Porosity values were obtained from available data for oil wells by CNH (2017). Eguiluz de Antuñano (2009) reported that Burgos Basin porosity varies between 16 and 30%. An interpolation was made using CNH wells porosity data (Fig. 5). Additional data includes maps of: topography, geology, hydrology, population and roads that include the economic parameters (Fernández de la Vega Márquez, 2019).

Multi Criteria Analysis was the methodology applied to determine which wells are more favorable to be reused to exploit geothermal energy within the Burgos Basin of north-eastern Mexico. The 6 criteria defined are:

• Geothermal Gradient: The temperature variation with depth in Earth's crust as an indicator of the depth to be attained for economic exploitation of geothermal energy.

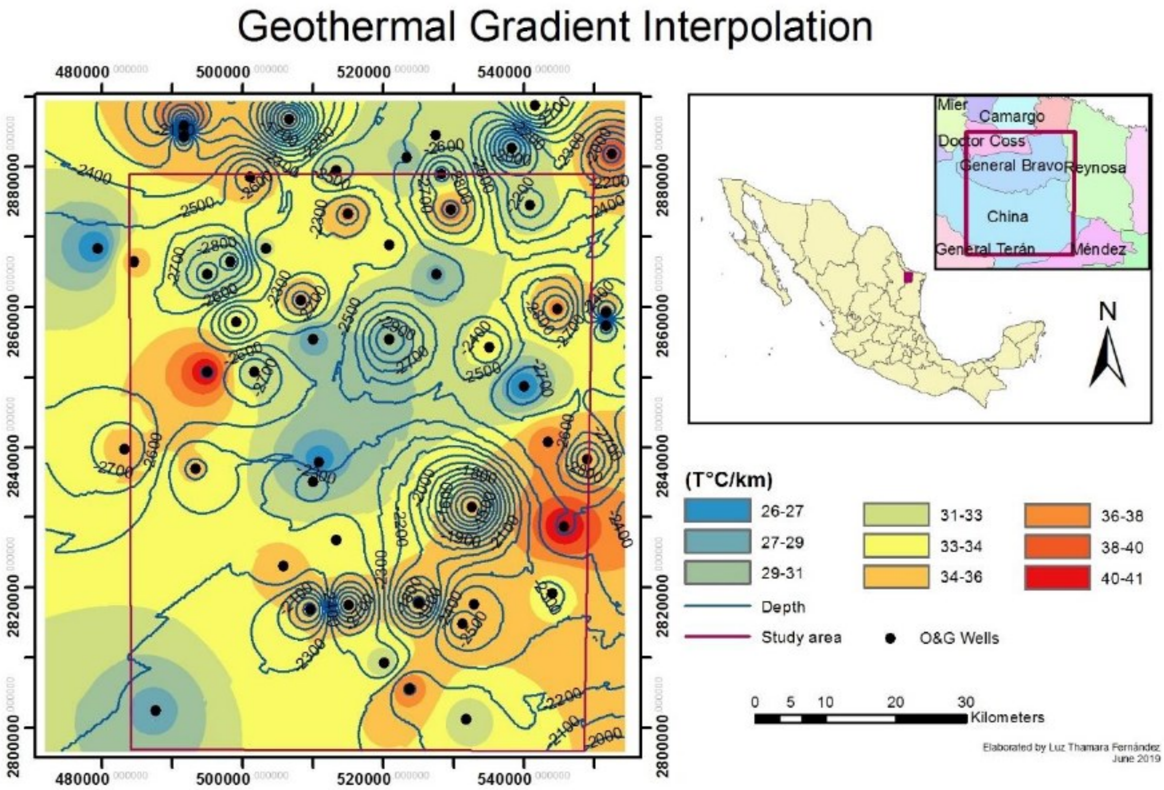

Figure 4: Geothermal gradient map for the Burgos Basin (Data from Prol-Ledesma et al., 2018).

• Heat Flow: This parameter is useful as an estimation of the natural energy discharge at the Earth's surface in the study area.

• Porosity: Understood as the space available within the rock serving as a store for fluids or gas. This parameter is available but not necessarily indicative of the connected porosity that is related to permeability.

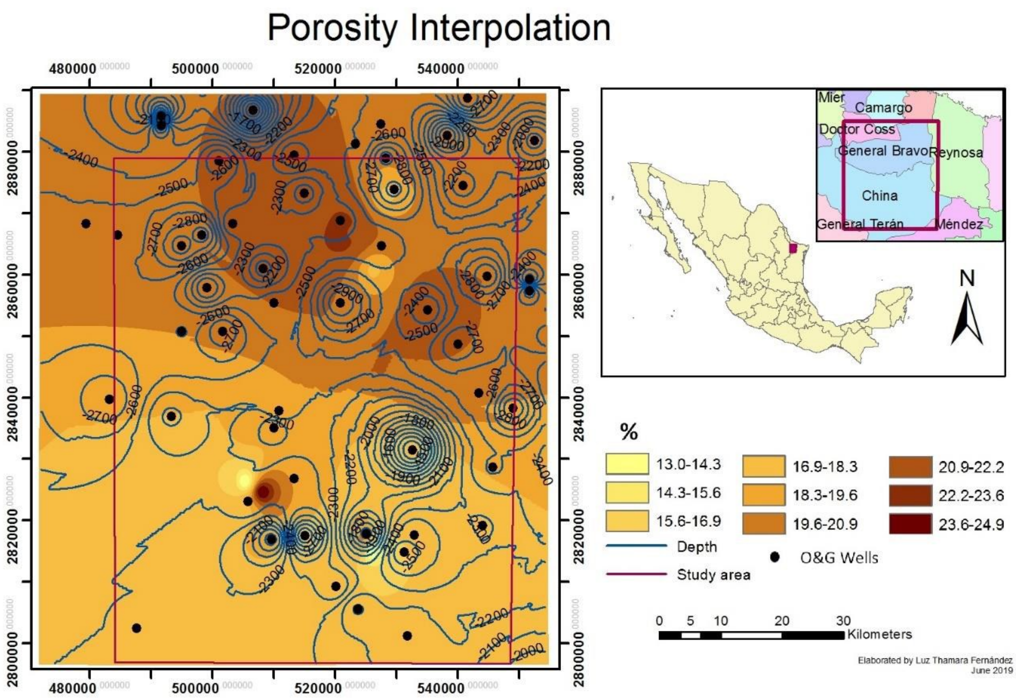

Figure 5: Porosity and depth isolines (Data from CNH, 2013).

• Depth: Length to the bottom of the well below the ground surface, with respect to a horizontal reference plane (true vertical depth).

• Population: Understood as the number of inhabitants in a locality.

• Accessibility: It is determined as distance to population centers and roads.

These criteria were combined using the Analytic Hierarchy Process to determine which wells are likely to be reused with geothermal energy using the Criteria comparison matrix shown in Table 1.

Table 1 Criteria comparison matrix.

	Heat Flow	Geothermal Gradient	Porosity	Population	Depth	Accesibility
Heat Flow	1	2	9	7	3	5
Geothermal Gradient	1/2	1	9	5	3	7
Porosity	1/9	1/9	1	1/9	1/7	1/5
Population	1/7	1/5	9	1	1/5	1/3
Depth	1/3	1/3	7	5	1	3
Accesibility	1/5	1/5	5	3	1/3	1
	2.28	3.84	40	21.11	7.67	16.53

4.2 Results

The weights of each criterion were calculated; in order to do this, another matrix was established, were new values are obtained by dividing each importance value between the total sum of each column in comparison matrix, this is a normalization process. Subsequently the values of each row were added and with that result an average value was obtained, that value is known as a priority vector or eigenvector (W) and it is what determines the weight of each variable that makes up the criterion (Table 2).

Table 2 Criteria Normalization and Weighting.

	Heat Flow	Geothermal Gradient	Porosity	Population	Depth	Accesibility	Weight	Ranking
Heat Flow	0.44	0.52	0.23	0.33	0.40	0.30	0.37	**1**
Geothermal Gradient	0.22	0.26	0.23	0.24	0.40	0.42	0.24	**2**
Porosity	0.04	0.03	0.03	0.005	0.02	0.01	0.02	**6**
Population	0.06	0.05	0.23	0.05	0.03	0.02	0.07	**5**
Depth	0.14	0.09	0.18	0.24	0.13	0.18	0.16	**3**
Accesibility	0.09	0.05	0.13	0.14	0.04	0.06	0.09	**4**

The Random Consistency Index for the different criteria and their classes. As expected, the criterion that obtained the greatest weight was Heat Flow (W = 0.37).

Weights were the same for the geothermal gradient and heat flow criteria, as well as porosity and depth. Accessibility (W = 0.09) is an economic criterion also since distance between geothermal resource or well in this case, and the place of use should be as short as possible especially if the geothermal deposit is not a high temperature one and the application is focused on direct use. Heat and pressure losses decrease at a lower distance. Clearly the cost also decreases as shorter pipes, fewer pumps, valves and other equipment are required.

After whole weighting process and taking as reference each criteria, the well with best suitability for geothermal use is Alternative MEXICO-BHT-000033 since meets the highest weights in 3 of 6 criteria considered (Population = 0.52, Heat Flow = 0.29, Geothermal Gradient = 0.27, Porosity = 0.18, Accessibility and Depth = 0.04). Remaining wells stand out in two or only one of the criteria. Results are shown in Figure 6.

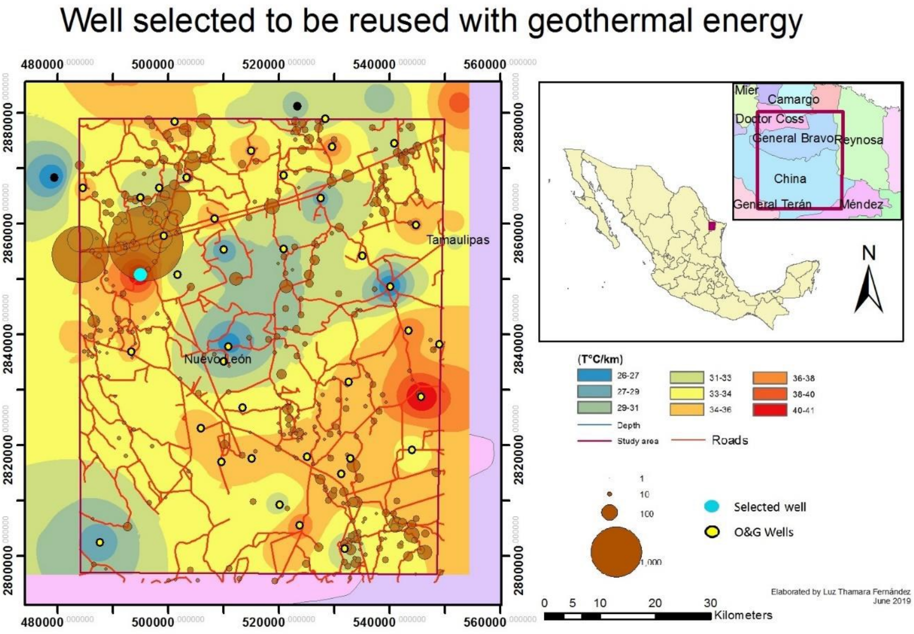

Figure 6: Selected well as most favorable for geothermal exploitation after Analytic Hierarchy Process application.

5. CONCLUSIONS

Geographic Information Systems and Multicriteria Analysis techniques, such as the Hierarchical Analysis Process (AHP) constitute efficient tools to identify the most suitable oil wells to reuse it with geothermal energy. The application of the method depends of the available information; in this case, the analysis was restricted to few parameters: heat flow, geothermal gradient and porosity. The area and thickness of the hot/permeable strata are important parameters to evaluate the energy potential. However, the definition of the most suitable well to start geothermal energy production is an important step to prove the feasibility of the reuse of oil/gas wells to produce clean energy.

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REFERENCES

Aranda-Gómez, J.J., Luhr, J.F., Housh, T.B., Valdez-Moreno, G., Chávez-Cabello, G., 2005. El volcanismo tipo intraplaca del Cenozoico tardío en el centro y norte de México: una revisión. Boletín de la Sociedad Geológica Mexicana LVII, 187–225.

Bahena, D., 2008. Los Mares de México. Energía (FTE de México), 8, 1–6.

Bu, X., Maa, W., Li, H., 2012. Geothermal energy production utilizing abandoned oil and gas wells. Renewable Energy, 41, 80-85

Caulk, R.A. & Tomac, I., 2017. Reuse of abandoned oil and gas wells for geothermal energy production. Renewable Energy, 112, 388-397.

Cheng, W.L., Liu, J., Nian, Y.L., Wang, C.L., 2016. Enhancing geothermal power generation from abandoned oil wells with thermal reservoirs. Energy, 109, 537-545.

CNH-Comisión Nacional de Hidrocarburos, 2017. Pozos productores de petróleo y gas asociado. Viewed 11th April 2019. Available at https://datos.gob.mx/busca/dataset/pozos-productores-de-petroleo-y-gas-asociado

Cuevas, L.J.A. 1988. Análisis de subsidencia e historia térmica en la Cuenca de Sabinas, Noreste de México: Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 34, p. 56-100.

Cui, G., Zhang, L.,Ren, B., Enechukwu, C., Liu, Y., Ren, S., 2016. Geothermal exploitation from depleted high temperature gas reservoirs via recycling supercritical CO2: Heat mining rate and salt precipitation effects. Applied Energy 183, 837–852.

Davis, A. & Michaelides, E., 2009. Geothermal power production from abandoned oil wells. Energy 34, 866–872.

Eguiluz de Antuñano, S., 2009. The Yegua Formation Gas play in the Burgos Basin, Mexico. In: Bartolini, C., Román Ramos, J.R. (Eds.), Petroleun Systems in the Southern Gulf of Mexico. AAPG Memoir 90, pp. 49–77.

Eguiluz de Antuñano, S., Aranda-Garcia, M., Marrett, R., 2000. Tectónica de la Sierra Madre Oriental, México. Bol. Soc. Geol. Mex. 53, 1–26.

Esposito, A.& Augustine, C., 2011. Geopressured Geothermal Resource and Recoverable Energy Estimate for the Wilcox and Frio Formations, Texas. Geothermal Resource Council Annual Meeting San Diego, California. October 25, 2011.

Fernández de la Vega Márquez, L.T., 2019. Geographical Information Systems and Analytic Hierarchy Process for the evaluation of Oil and Gas wells for geothermal use. MSc. Thesis in Geographical Information Systems, University of Aberdeeen. 75pp.

Guzmán, A.E. & Márquez-Domínguez, B., 2015. The Gulf of Mexico Basin South of the Border: The Petroleum Province of the Twenty-First Century. AAPG Memoir, Volume 74. Petroleum Provinces of the Twenty-first Century (Eds.)Downey, M.W., Threet, J.C., Morgan, W.A. American Association of Petroleum Geologists. https://doi.org/10.1306/M74775C17

Macenic, M. & Kurevija, T., 2018. Revitalization of abandoned oil and gas wells for a geothermal heat exploitation by means of closed circulation: Case study of the deep dry well Pcelic-1. Interpretation, 6, 1–9.

Mehmood, A., Yao, J., Fan, D., Bongole, K., Liu, J., Zhang, X., 2019. Potential for heat production by retrofitting abandoned gas wells into geothermal wells. PLoS ONE 14, 1–19. https://doi.org/10.1371/journal.pone.0220128

PEMEX, 2013. Provincias Petroleras de México. PEMEX Exploración y Producción. 10 pp.

Peterson, J.A., 1983. Petroleum Geology and Resources of Southeastern Mexico, Northern Guatemala, and Belize. US Geological Survey Circular 760. 50 pp.

Prol-Ledesma, R.M., 2000, Evaluation of the reconaissance results in geothermal exploration using GIS. Geothermics, 29, 83-103.

Prol-Ledesma, R.M., Carrillo-de la Cruz, J.L., Torres-Vera, M.A., Membrillo-Abad, A.S.. Espinoza-Ojeda, O.M., 2018. Heat flow map and geothermal resources in Mexico. Terra Digitalis, 2, 2, 1-15. DOI: 10.22201/igg.25940694.2018.2.51.105, ISSN: 2594-0694

Prol-Ledesma, R.M., Morán-Zenteno, D.J., 2019. Heat Flow and Geothermal Provinces in Mexico. Geothermics. ISSN 0375-6505. 78, 183-200. https://doi.org/10.1016/j.geothermics.2018.12.009.

Richardson, M., & Blackwell, D., 2016. Low-temperature sedimentary geothermal exploration. Proceedings 38th New Zealand Geothermal Workshop 23 - 25 November 2016 Auckland, New Zealand.

Santilano, A., Trumpy, E., Gola,G., Donato,A., Scrocca, D., Ferrarini, F., Brozzetti, F., de Nardis, R., Lavecchia, G., Manzella, A., 2019. A Methodology for Assessing the Favourability of Geopressured-Geothermal Systems in Sedimentary Basin Plays: A Case Study in Abruzzo (Italy). Geofluids. Volume 2019, Article ID 4503943, 28 pp. https://doi.org/10.1155/2019/4503943

Schlumberger (2015) Case Study: Mexico improves trajectory and saves 9 days with Ultrahigh-temperature RSS. 14-DR-0219

Soldo, E. & Alimonti, C., 2015. From an Oilfield to a Geothermal One: Use of a Selection Matrix to Choose Between Two Extraction Technologies. Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015

Van Wees, J.D., Kramers, L., Mijnlieff, H., De Jong, S., Scheffers, B., 2015. Geothermal and Hydrocarbon Exploration: the Double Play Synergy. Proceedings World Geothermal Congress 2015. Melbourne, Australia, 19-25 April 2015. 1-6 pp

Wang, S., Yan, J., Li, F., Hu, J., Li, K., 2016. Exploitation and Utilization of Oilfield Geothermal Resources in China. Energies, 9, 798-810; doi:10.3390/en9100798

http://www.thomasldavisgeologist.com/downloads.html#Mexico accessed 23 july 2019.