Geothermal District Heating Investigation of Retired Oil/Gas Wells as Higher-temperature Renewable Heat Sources

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ABSTRACT

Presented in this paper is our investigation on the potential of usingexisting natural gas and oil wells in the USA to provide high quality geothermal heat. Geothermal heat is renewable energy that can be used from higher temperature sources for direct heating. In the USA and other less thermally active regions, it is most commonly harvested from shallow ground heat exchangers leveraging seasonal average seasonal temperature to maximize heat pump performance. Drilling deeper would provide higher temperatures, but for most projects the drilling and heat pump are significant costs - up to 90% of the total cost of a geothermal system for wells beyond 600m. The state of Pennsylvania has 66,000 active natural gas and oil wells with depths typically greater than 1000m, so how much might we harvest from these wells? Analyzing the recently released data from National Geothermal Data System (NGDS), we found bottom temperatures of 17,467 Pennsylvanian wells with 95% having depths from 1000m to 2500m and 70% having temperatures above 80 ˚F (26.6˚C) that could be used in low temperature, low exergy, district heating systems. In this context, linking them to a district heating system would therefore be providing essentially free heat without any drilling costs. This study aims to characterise the geothermal potential that can be exploited and identify potential locations for pilot projects. This is done using criterias including spatially varied demographic profile, heating demand and variable heat loss through possible distribution pipelines. We identified a possible 10% of the heating demand in the state of Pennsylvania could be covered by the 17,476 oil/gas wells should they all become dedicated to geothermal post active-production stage. Cities like Pittsburgh could have a substantial portion of their heating demand supplied. Finally, upon decommissioning, many of these wells often become pathways for methane leakage as sealing is required, but not well incentivised - which would be addressed by further utilisation in our proposed district concept.

Keywords: *geothermal, district heating, distributed energy systems*

1. INTRODUCTION

Our attention towards geothermal systems is very polarized in the current mar- ket. There are emphasis on harvesting the geothermal energy in the form of power generation, eliciting Enhanced Geothermal Systems (EGS) that only counts at the depths deeper than 2km, or on the other side, Ground-source heat pump(GSHP) systems for residential purposes that rarely goes beyond 600ft(182.88m). The in-between is rarely addressed since it is in an awkward area where the temperature recovered is relatively warm while the costs can be exceedingly high. At a depth beyond 600 feet, the majority of the costs can be attributed to drilling, which can make up to 90% of the total costs of the system, mounting to a total of $500,000 for a system with 1000 feet system. A possible way of reaching the desired depth without investing heavily on the capital cost for geothermal systems is to enlist the boreholes that are out-of commission. This paper sets out to provide an estimate of such geothermal potential from existing oil/gas wells that have been recently made public by the National Geographic Database System(NGDS).

2. BACKGROUND

The state of Pennsylvania has a long history of harvesting oil and gas from the underground. The Marcellus Shale basin was, in fact, found among the conventional boreholes that were thought to have been depleted once. First recognized by the USGS in 2003, the actual capacity of Marcellus Shale basin is expected to reach a mean undiscovered natural gas resource of 84,198 billion cubic feet according to the USGS fact sheet, essentially helped achieving the longed energy independency for the United States.

It is also known, however, that abandoned/depleted wells, despite being plugged with concrete, can be the source of fugitive emissions. This was brought to the attention of researchers when first identified by a PhD thesis in

Princeton University. Her research indicated that even wells that are considered sealed can still have emissions coming out from the bottom of the wells.

Many studies have been done to ensure the proper sealing of the aban- doned/inactive boreholes, mostly treating them as a problem to be fixed. But what about taking an active step back and looking at the problem proactively and try to harvest the heat that is available at the bottom of the boreholes? Similar thoughts were pursued by [13] in 2006 using mine water to cool buildings, exploiting the underground mine water's temperature for better performance of geothermal heat pumps.

3. METHODOLOGY

3.1 Visualizing geothermal potential

To visualize the potential that is available from the 17,467 boreholes, a simple extrapolation of the temperature at different depths using linear regression and a resolution of every 100m and plotted in Figure 1.

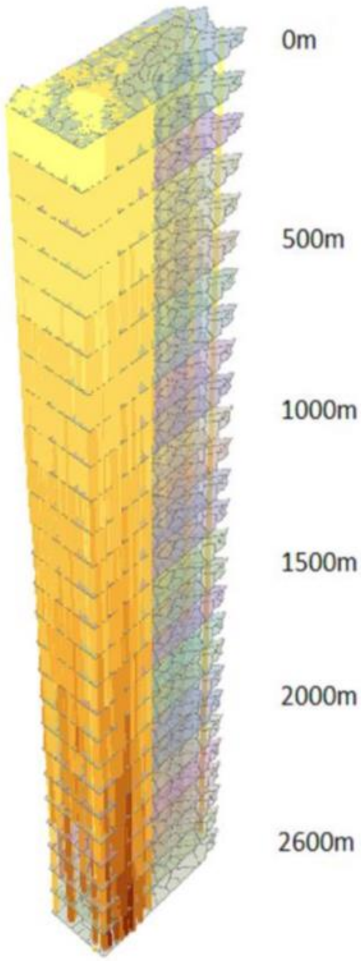

Figure 1: Geothermal potential visualization from 17,467 boreholes through linear extrapolation in ArcScene in Pennsylvania, United States

As the geothermal potential is visualized in three dimensions in ArcScene, aside from the quantitative results that could have been obtained from the data analysis of the temperature profiles in the well logs, the increase of temperature along depths of the boreholes became qualitatively more apparent as the general temperature increase beyond 1,000 meters beyond 20 Celsius can be easily observed - not enough for enhanced geothermal system (EGS), but more than adequate for considering using the geothermal heat for heating rather than power generation. But exactly how much heat can be generated from the 17,467 wells? It is important to identify the available heat that can be harnessed from the boreholes.

3.2 Identifying the available heat

To estimate the supply temperature from boreholes, three cases were established based on different assumptions were used to cover the industry convention, academic estimation and ideal production conditions: For Case 1, the heat extraction rate from the boreholes was assumed to be 50W/m, which would allow the calculation of the flow rates for different boreholes. Case 2 builds on the estimation of the heat extraction from the geothermal heat flow estimation from Pollack et al. at 87 MW/m 2 to obtain the temperature available from boreholes with the flow rates obtained from Case 1. Case 3 then combines the assumptions from Case 1 and 2 with the 2Sol Coaxial Borehole Heat Exchanger from 2Sol and propose an idealized model that idealize the temperature extracted from the boreholes. The accumulated resulting available heating power can be found in Table 1.

	Case 1	**Case 2**	**Case 3**
Heat Extraction Rate	50W/m	87W/m^2	87W/m^2
Heat Exchanger Type	Double U-Tube	Double U-Tube	2Sol CoAxial
Flow Rate (L/s^{-1})	7	7	7
Total Heating Power Available (Q_{tot} in GW)	2.47	0.61	0.05

Table 1: Assumptions used to estimate supply distances for three different cases

The available heat numbers are then put into ArcMap for spatial analysis to identify the suitability of the different estimation methods as well as the temperature availability at ground surfaces using the volumetric flow rate and return water temperature as suggested by[7]. We may therefore obtain the heat map of Pennsylvania for the three different cases under the scenario of supplying different temperatures across different counties as shown in Figure 2. This can be used to further analyze the potential of heat supplied to specific households using the overlap with demographic map. To estimate the supply distances, a number of assumptions were made to obtain reasonable accuracy of estimations. As the boreholes would provide up to 13.25 kW of heat, the distribution pipes were assumed to be of a medium sized 80 mm nominal distribution pipes buried with a ground temperature of 8 Celsius. The media pipes are assumed to be placed vertically with the return pipe located closest to the group surface, giving lower heat loss comparing to having the forward pipe on tops or horizontal setup. Assuming the thermal conductivity to be 0.0265 W/(mK), which would give an average heat loss of 18.08W/m according to [4] from Danfoss, which is consistent with [5].

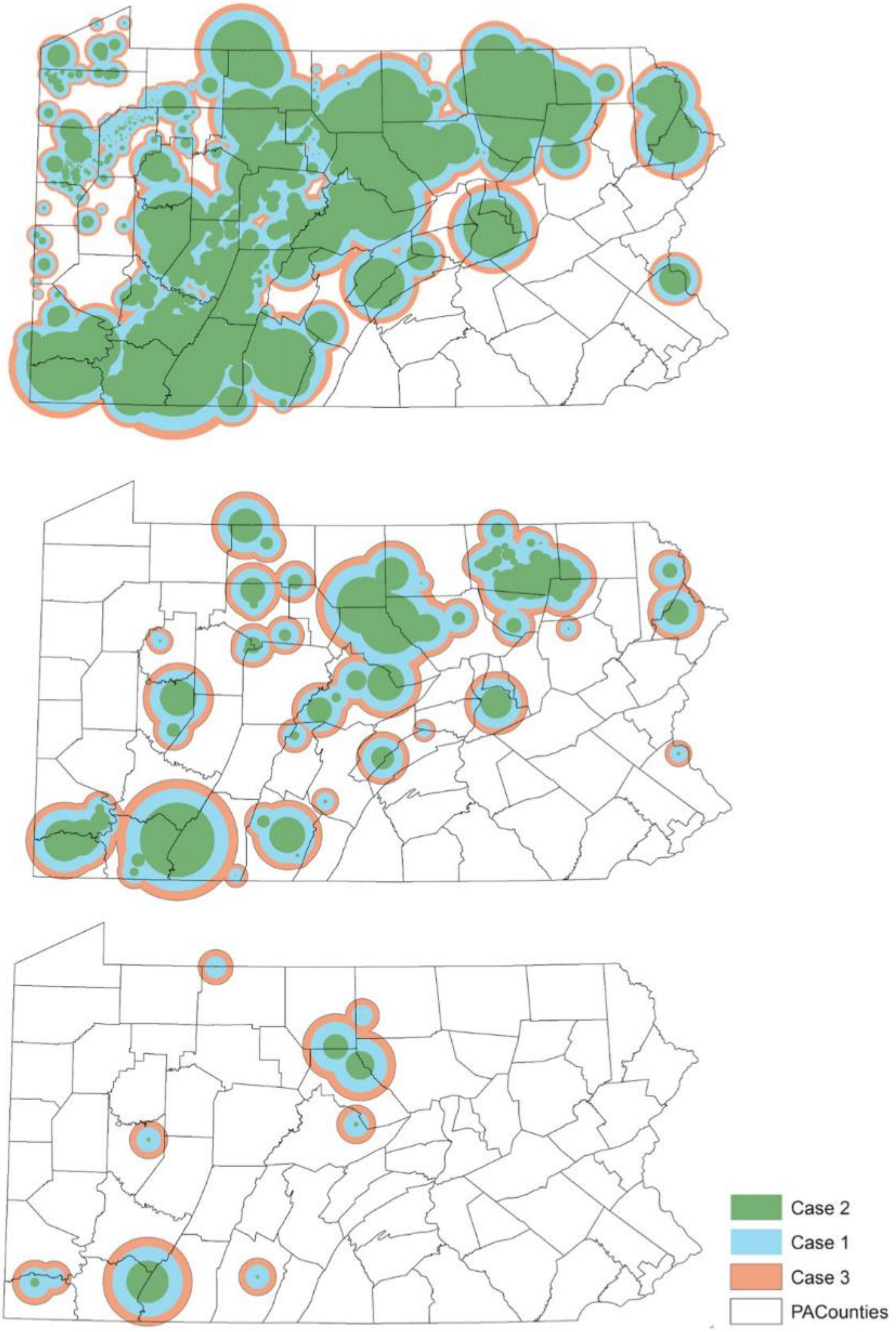

Figure 2: Coverage of supply temperature at 17 ˚C for heat pump assisted heating (top), 30˚C for LowEx direct district heating (middle) and 45 ˚C for direct district heating(bottom)

3.3 Estimating households covered

To better understand the scope of the problem, the demographic profile of Pennsylvania from the 2010 US census is used to compare against the supply distances from Case 2 to determine the possibility of coverage of the supplied areas. Of the total households of 4,777,003 in Pennsylvania, the total amount of house- holds that can be supplied with different temperature availabilities are therefore determined as indicated in Figure 3:

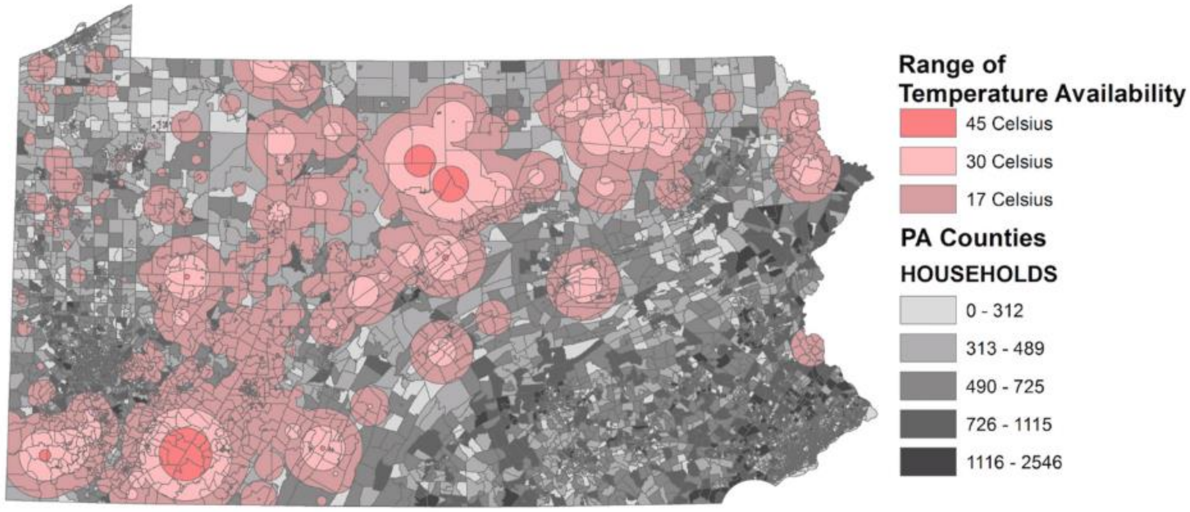

Figure 3: Potential households coverage map using different supply criteria assuming Case 2 scenario.

To put it into a more quantitative interpretation, the information in Figure 3 can be summed up into Table 4.3 as the following:

Supply Temperature (˚C)	17	30	45
Percentage of Total Households (%)	858,487	199,019	15,043
Primary Energy Saved (TBTU)	30.3584	6.78	0.53
Million Dolalrs Saved (Million US$)	632.458	141.25	11.04

Table 2: Comparison of performance under three supply criteria assuming Case 2 scenario.

4. RESULTS AND ANALYSIS

Using simplified assumptions on the power output from the boreholes and the heat loss along assumed distribution lines, it is estimated that using one-fifth of the boreholes (once they are depleted of oil/gas) available in Pennsylvania, up to 17% of the population of Pennsylvania can be supported using small-scale heat pumps, or a 5% of households can be heated without any additional costs of electricity using LowEx district heating. This is a preliminary investigation done to estimate the scope of the project so a few assumptions were made to sim- plify the analysis, and require further analysis. Further research would include and not limit to: More refined modeling of the distributional losses along the pipelines to provide better power generation and electricity costs estimates such that better return of investment (ROI) can be obtained; better sub-surface ex- traction estimation techniques that is more tolerant towards different subsurface geological conditions. It would also be valuable to include considerations of the costs that will incur to layout the distribution pipelines to obtain a reasonable ROI for the consideration of investors as well as local authorities.

Despite these limitations, the supply range that was achieved in this paper does come from a mere fifth of all boreholes that are currently active in Pennsylvania. With the increasing number of boreholes that are to be developed in the Marcellus Shale, this number could be continuously on the rise. It is important that we continue to look for means to benefit from the wells beyond production and estimate the potential that is buried underground to gain access to free heat while ensuring no fugitive emissions are escaping from the abandoned wells.

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