Hydrocarbon wells potentially suitable for geothermal repurposing in Italy: a first assessment

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ABSTRACT

Global changes urge a radical transformation and improvement of the energy production systems to meet the very ambitious and challenging decarbonisation targets of the European economy by 2050. In this context, the possible repurposing of depleted hydrocarbon wells for geothermal heat production represents a promising contribution, with an approach inspired by the circular economy, to the decarbonisation of energy production systems.

The mature stage of oil and gas wells is often characterized by the production of hydrocarbons and associated formation waters, which must be treated continuously being often reinjected into the reservoir. Usually, the volume of produced water increases with the maturity of the fields until the production of hydrocarbons becomes uneconomic and the wells are cemented and closed. However, according to their depth and the local geothermal gradient, these oil and gas wells could have bottom-hole temperatures high enough to sustain the geothermal exploitation of the reservoirs fluids. Therefore, when the hydrocarbon wells are going to be depleted and where a geothermal potential exists, the conversion into geothermal wells could be a reasonable alternative to the mining closure, which will compromise the possibility to repurpose the existing wells for geothermal applications.

Many existing Italian oil and gas (O&G) wells are approaching the end of their economic lifespan. This irreversible process necessarily requires an in-depth and systematic assessment of their conversion potential for heat production.

To identify the most promising hydrocarbon wells suitable for geothermal repurposing we have combined information on onshore wells and fields made available by the Italian National Mining Office for Hydrocarbons and Georesources, which have been integrated with data retrieved in the scientific literature, with the estimated temperatures at depth derived from the Italian National Geothermal Database. According to the latest available data, there are 892 active wells in Italy located onshore in the existing mining licenses with different operational status (i.e., productive wells, potentially productive wells, reinjection, monitoring or other purposes),

With this simplified approach, we have selected wells, associated with 42 hydrocarbons fields with depths deeper than 2000-3000 m and with temperatures higher than 60-70 °C, which have the potential to be repurposed for geothermal application. For five of these oil & gas fields, the geothermal potential has been evaluated, by applying the volume method. An estimation of the geothermal energy that could be recovered by repurposing the exiting hydrocarbons fields has been obtained.

Finally, we discuss how the use of a screening matrix, based on a review of the approach already proposed by Soldo and Alimonti (2015), can allow an analysis of the existing wells to define the more appropriate technology for their geothermal repurposing.

1. INTRODUCTION

The ambitious and challenging objectives of decarbonisation of the European economy by 2050 and the threats to the security of our country's energy supply caused by the recent geopolitical crisis require a radical transformation and improvement of our energy systems. The energy transition, the carbon neutrality, and the resilience of the production system require a fast replay that has to consider a reassessment of national energy resources, in particular regard to renewable geothermal resources.

Finding alternative energy sources to hydrocarbons, optimizing energy production, integrating different energy sources, and reducing waste heat and the environmental impacts are some of the current objectives for a successful energy transition in modern industrial societies. For these purposes, it should be considered that the oil and gas production in its mature stage is often associated with a large volume of formation waters, which must be treated continuously and could not be released into the environment. Increasing the maturity of hydrocarbon fields, the water production increases as well. So, when the hydrocarbon wells are going to be depleted, they can be converted into geothermal wells. Several studies have been focused on geothermal energy production from depleting hydrocarbons fields and on the progressive conversion of a depleted hydrocarbon field into a geothermal one (e.g., McKenna et al., 2005; Alimonti and Gnoni, 2015; Alimonti and Soldo, 2016; Liu et al., 2018; Wang et al., 2018; Maurel et al., 2020; Olufemi et al., 2020; Soldo et al., 2020; Watson et al., 2020; Alimonti et al., 2021). In this context, a key point for the geothermal sector is the need to reduce uncertainties on profitability and to design sustainable solutions for large-scale development out of the conventional assets as well as to be deployed more rapidly.

The target of this work is to produce a vision of the potential benefits resulting from the reuse of depleted oil & gas wells in Italy. The possibility of a crossover from oil & gas to geothermal energy production represents a chance for Italy (as also as other countries with hydrocarbon production) to increase the share of renewable energy production and reduce the waste heat.

Starting from the available information on hydrocarbon fields and wells provided by the Ministry of Economic Development (UNMIG-MITE, 2021), and estimated temperature at depth from the Italian National Geothermal Database (Trumpy and Manzella, 2017), a selection of the most promising fields and wells has been conducted.

The evaluation of the geothermal potential of Italian fields is the key element in introducing the repurposing of O&G infrastructures in the transition energy issues. To analyze the wells, a screening matrix coupled with a fast calculation model for the thermal and electrical power has been developed. The screening identifies the different solutions indicating the most promising for each case.

2. FIELDS AND WELLS SELECTION

The National Mining Office for Hydrocarbons and Georesources of the Italian Ministry of Ecological Transition provides information and data regarding productive wells and oil and gas licenses in Italy (UNMIG-MITE, 2021). Data are also provided by the website of the project "Visibility of petroleum exploration data in Italy" (ViDEPI Project, 2021) promoted by the MISE-DGRME, the Italian Geological Society and the Assomineraria association (Assoenergia today). Additional information on the location and characteristics of the Italian hydrocarbon fields have been retrieved from literature (e.g., Pieri and Mattavelli, 1986; Schlumberger, 1987; Sella et al., 1988; Mattavelli & Novelli, 1990; Mattavelli et al., 1991; Mattaveli et al., 1993; Anelli et al., 1996; Pieri, 2001; Casero, 2004; Bertello et al., 2010; Cazzini et al., 2015 and references therein).

According to the latest update (21 September 2021) provided by the Italian Ministry of Ecological Transition, excluding well devoted to gas storage projects, there are 1622 active wells in Italy, 892 of which are located onshore in the existing mining licenses (UNMIG-MITE, 2021). These onshore wells have a different operational status that includes 437 productive wells, 415 potentially productive wells, 394 wells dedicated to gas storage projects, plus 40 additional wells for other purposes (such as reinjection and monitoring). For this contribution, we have selected only the onshore fields and the associated active wells. We have then cross-checked the position of these fields with the available information on the temperature at depth. To get these results, and taking into consideration that this is a first pass national screening, we have adopted a simplified approach using the temperature maps at depths -1000, -2000 and -3000 meters below ground level published by Cataldi et al. (1995), also available in the Italian National Geothermal Database (Trumpy and Manzella, 2017).

Pursuing the goal of reducing greenhouse gas emissions to reach the 2030 targets, the main focus is on space heating. Therefore, for the selection procedure, the minimum subsurface temperature has been set to 70° C (60° in the Bradano foredeep in Southern Italy) With this approach, we have identified the most promising wells which have been drilled in 42 fields (Fig. 4). Among these fields, 10 fields have a temperature higher than 60 °C and 9 fields have a temperature higher than 70 °C at a depth between 2000 m and 3000 m, while 23 fields have an estimated temperature higher than 70 °C at a depth greater than 3000 m (Figure 1).

However, it should be noted that the exploitation of waste heat from even lower temperature fluids could have potential use for a variety of local direct geothermal applications (e.g. agro-industry and other primary and tertiary sector applications).

3. GEOTHERMAL POTENTIAL ASSESSMENT

To provide a first-order estimation of the geothermal energy that could be recovered by repurposing the exiting hydrocarbons fields, the geothermal potential has been evaluated for five representative depleted oil & gas fields in Italy by applying the volume method, as described in detail by Alimonti et al. (2021). To overcome the uncertainty related to the reserves parameters, a deterministic approach has been integrated with a probabilistic method.

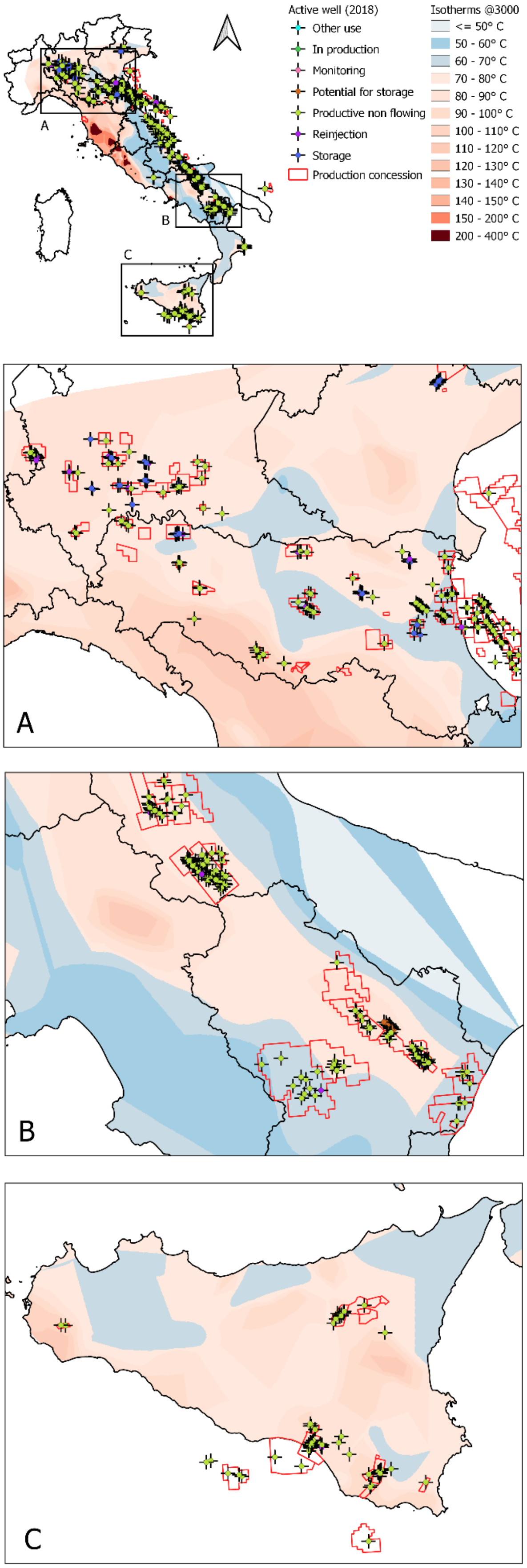

Fig. 1. Production Concessions (in red) with productive or potentially productive wells overlaid with an estimated temperature map at - 3000 m below sea level (modified after Alimonti et al., 2021).

The results of this analysis are summarized in table 1. Following the three steps evaluation procedure, the heat in place (HIP), the extractable heat (Hr), and the technical potential (TP) have been calculated. The reinjection temperature assumed in the calculation of the Hr is 40°C having considered the application for space heating. The technical potential has been estimated, assuming a value for the recovery factor, the efficiency and the life span of geothermal plants. This passage from geothermal potential to technical power is crucial to quantify the effective impact generated by the repurposing of Italian oil&gas fields into geothermal ones.

The adopted approach contains several simplifications (e.g., it considers hydrocarbons reservoirs whose volumes may not coincide with the geothermal reservoirs), and it should be considered valid for an evaluation on a regional scale. With the detailed production and petrophysical data usually available for hydrocarbon fields (e.g.,), a more thorough and accurate assessment at the scale of the single field could be carried out (e.g., Alimonti & Gnoni, 2015; Soldo et al., 2020). However, notwithstanding these limitations, it should be noted that the results of this preliminary analysis show that the available heat stored in the existing hydrocarbon reservoirs is significant (table 1).

Table 1: Geothermal potential assessment (HIP, heat in place; Hr, extractable heat; TP, technical potential).

Field	HIP	Hr	TP	Annual TP
	PJ	*PJ*	*MW*	*MW*
Villafortuna-Trecate	814.8	724.3	765.4	25.5
Gela	351.0	265.4	280.7	9.4
Dosso degli Angeli	5.8	4.8	4.1	0.1
Val d'Agri	323.8	202.4	213.9	7.4
Gagliano*	110.0	84.0	88.8	3.0

**The evaluation is done without the contribution of the water due to the lack of porosity data*.

3.3 Repurposing scenarios

The next step focuses on the analysis of single wells to define the most promising repurposing scenario. Five different possible application scenarios have been identified (Hranić et al., 2021).

Scenario 1 – "Do nothing"

This scenario refers to plugging all the wells and dismantling the surface facilities. Following the Italian mining law, this scenario requires a cost of hundreds of thousands of € in terms of abandonment cost per well. This scenario takes place when the operating life of an oil field has reached its end or, as in some European countries happens when the government states the closure of petroleum activities.

Scenario 2 – "Heat doublets"

The developed scenario concerns a very common scenario for geothermal projects named "doublet".

The heat is extracted from geothermal fluids produced from a first well (production well) while these fluids are then reinjected into the reservoir using a second well (injection wells). The main challenge that concerns the geothermal industry is associated with the capital-intensive costs of drilling geothermal wells and the associated risk. Hence, the repurposing of the existing depleted petroleum wells where the reservoir hosts geothermal fluids can dramatically reduce the project costs. This scenario relies on the temperature range that can use and the energy needs based on the heat demand of the type of building.

Scenario 3 – "Heat via DBHE"

The alternative scenario to heat production is the so-called one well or borehole heat exchanger. This solution uses a working fluid injected through the annular space and produced at the wellhead through production tubing or vice versa. The borehole heat exchanger removes the possible interaction with the underground bodies due to the absence of fluid production and injection.

Scenario 4 – "ORC power production"

This scenario represents the electric power generation using the Organic Rankine Cycle (ORC). The electricity can be produced using the production and injection wells or using the deep borehole heat exchanger. The power capacity is determined primarily by the production rate, the temperature of produced water, ambient temperature, water salinity, and conversion efficiency of the geothermal power plant.

3.4. Modeling and selection matrix

To carry out a rapid evaluation and selection of the more favourable scenario for well repurposing, very simple modelling has been developed. Concerning the DBHE, the calculation of the possible extractable heat is based on the approach proposed by Soldo and Alimonti (2015), where, following several simulations, two correlations have been derived. One gives the outlet temperature from the DBHE and the second one gives the heat flow. Both correlations are depending on the geothermal gradient (GG) and the flow rate through it. The correlations are reported in table 2. The two correlations should be used together to obtain the evaluation of the extractable heat.

Table 2: DBHE correlation for fast evaluation

Flow rate (m^3/h)	**Temperature correlation (°C / km)**	**Heat flow correlation (W / km °C)**
10	$-0.0022\ GG^2 + 0.622\ GG$	$-0.0000003\ GG^2 + 0.0001\ GG$
20	$-0.002\ GG^2 + 0.5012\ GG$	$-0.0000004\ GG^2 + 0.00008\ GG$
30	$-0.0018\ GG^2 + 0.4363\ GG$	$-0.0000002\ GG^2 + 0.00006\ GG$
50	$-0.0016\ GG^2 + 0.3699\ GG$	$-0.0000001\ GG^2 + 0.00004\ GG$

For heat doublets, a simplified model for calculation of maximum flowrate has been developed using the same information on wells as for the DBHE. The information on permeability and thickness of the productivity layer was added to the database record. An example of the fields considered in well record is the following:

- Casing diameter (in),
- Reservoir Pressure (bar)
- Reservoir temperature (°C)
- Depth (m)
- Permeability (mD)
- Thickness (m)

The doublet solution assumes the removal of the present completions, e.g. tubing, leaving the full bore flow. Other assumptions are the wellhead pressure equal to the double of the saturation pressure of the geothermal water, as minimum pressure, and the temperature difference across the heat exchangers.

For both solutions the evaluation of the possible electrical production has been done by adopting the correlation on the ORC efficiency given by Liu et al. (2013) and fixing a temperature threshold of 80 °C when the fluid temperature is below no electrical production is admitted. This threshold value has been fixed following the present ORC technology and has found that entrance temperatures lower than 80 °C are not interesting in terms of efficiency.

The development of a selection matrix to give a tool to guide the selection of the more promising technology for the repurposing of a given asset has been described in Soldo and Alimonti (2015). A set of nine performance indexes was developed to evaluate the different aspects of the project:

1. Thermo-energy production index I_P
2. Temperature-flow rate index I_{qT}
3. Outlet temperature index I_{Texit}
4. Pumping aided production index I_{PE}
5. Re-injection index I_I
6. Scale-Corrosion index I_{SC}
7. Environmental impact index I_{ENV}
8. Social impact index I_{SI}
9. Cost index I_C

The total performance index will be obtained with the weighted average of the nine performance indexes.

In the application of the selection matrix, the choice of the weight assigned to the different indexes affects the final evaluation of projects. The final score in the evaluation of a project will vary if a greater weight is assigned to the economic issues- (setting A) or, on the contrary, to social and environmental issues (setting B). For setting A the selected technology is the direct use and, for setting B is the DBHE.

In the present analysis, the performance indexes will be limited to the potential evaluation taking only the first three performance indexes that can be obtained with the limited available data without any specific study.

A sample application is the Villafortuna-Trecate field. The reference well for this field is Cascina Cardana 1. Using the collected data the Thermo-energy production index I_P, Temperature-flow rate index I_{qT} and, Outlet temperature index I_{Texit} were calculated.

The results indicate a very similar value for the Doublet scenario and the DBHE scenario. The more promising scenario in thermal production is the DBHE with a PI of 0.38 vs. the Doublet with a PI of 0.3.

4. CONCLUSIONS

The adopted selection method identifies 42 fields: 23 fields deeper than 3000 m with an expected temperature higher than 70° C; 9 fields with a depth between 2000 and 3000 m and a temperature higher than 70° C; 10 fields deeper than 2000 m with a temperature higher than 60° C. However, it should be noted that due to the adopted simplified approach the estimated number of fields can result slightly different where the actual temperature measurements could be taken into consideration.

The evaluation of the geothermal potential of five selected fields shows significant technical potential. As an example, the technical potential of the Villafortuna-Trecate field is in the range of 388 ÷1330 MW. The estimated power of the Dosso degli Angeli field, which is the smallest one, is in the range of 2.1 ÷ 14.6 MW. Based on these results, the overall geothermal technical potential stored in the Italian oil&gas fields is quite encouraging.

The use of a selection matrix, reviewed concerning the work of Soldo and Alimonti (2015), allows analyzing the existing wells and defining the more appropriate technology for their geothermal repurposing.

These results confirm the relevant benefits resulting from the repurposing of existing hydrocarbon wells for geothermal applications.

Rather than terminating or removing economic activities on ageing onshore oil and gas wells, the repurposing approach tries to look at options to bring new economic pressure on these production sites. More sustainable applications are available as a heating solution at different levels (i.e., homes or industry) or for power production and other outputs. Thus, creating opportunities able to contribute to a stable and sustainable energy ecosystem, and facing the industry several challenges and opportunities. It is worth noting that all these results are achieved without any emission of CO^2 into the atmosphere. The same results also highlight the advantages for the local communities to produce a renewable energy source from the existing infrastructures while the possibility for the companies to reduce the abandonment cost can be a driving force to make available the basic data required to carry out a more detailed analysis over the Italian countryside. Considering that 892 active oil and gas wells are present onshore in Italy, a national assessment their potential geothermal repurposing may be a great opportunity for the energy transition to the renewables.

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