European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal potential assessment for oil&gas fields in Italy

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Keywords: Geothermal energy, hydrocarbon fields, decarbonisation, geothermal potential assessment.

ABSTRACT

The decarbonisation of the energy sector is probably one of the main worldwide challenges of the future. The main contributors to the EU's greenhouse gas emissions today are heating and cooling systems. According to the literature, heating and cooling needs in buildings and industry account for about 50% of the EU's energy consumption and only about 20% generated from renewable energy.

In this scenario, oil&gas fields can be repurposed to produce geothermal energy, a secure, clean and renewable resource. The great amount of water stored in hydrocarbon reservoirs represents, now, a waste heat that can be used, thanks to the flexibility and wide availability of geothermal energy applications. The possibility of a crossover from oil & gas to geothermal energy production represents a chance to increase the share of renewable energy production and to reuse existing infrastructures but also to reconcile the social fabric with an industrial sector considered harmful to the environment.

The most promising oil&gas fields for geothermal repurposing in Italy have been selected starting from the available information on fields and wells provided by the Italian Ministry of Economic Development, integrated with data retrievable in the scientific literature, and combined with the estimated temperatures at depth from the Italian National Geothermal Database. With this simplified approach, 42 fields have been identified at depths deeper than 2000-3000 m and with temperatures higher than 60-70 °C. However, harnessing the waste heat also of fluids at lower temperatures could have potential use for a variety of local direct geothermal applications.

To produce a vision of the geothermal energy that could be recovered by repurposing the hydrocarbons fields on the Italian territory, this work has assessed the geothermal potential stored in five representative depleted oil & gas fields, which have been chosen among the selected most promising fields for geothermal repurposing.

The volume method has been applied to these five representative fields to assess their geothermal potential. Then 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 results are encouraging, although the applied method is preliminary and it has provided only a rough evaluation, which uses the data derived from exploration and production of hydrocarbons reservoirs, whose volumes may not coincide with the geothermal reservoirs. Those volumes may be greater and only an ad hoc analysis of the data collected by the owner companies of the existing fields and wells may produce a more precise evaluation.

1. INTRODUCTION

In the coming years, energy production systems will have to be significantly improved to achieve the decarbonisation goals of the European economy. In this context, it should be considered that heating and cooling systems are among the main contributors to EU greenhouse gas emissions.

Available data show that heating and cooling in buildings and industry accounts for around 50% of EU energy consumption (e.g., Fraunhofer Institute et al., 2016). This share is covered by fossil sources for a little less than 80% while renewable sources only contribute around 20%. Since geothermal resources are almost ubiquitous, versatile, and generally abundant, the harnessing of geothermal energy can make a significant contribution to increasing the share covered with a secure, clean and renewable resource (ETIP-DG, 2020; Dalla Longa et al., 2020).

The mature phase of oil and gas wells is often characterized by the production not only of hydrocarbons but also of associated formation waters whose volumes increase with the maturity of the reservoirs until the production of hydrocarbons becomes uneconomical. Consequently, the existing oil&gas fields can be repurposed where they have bottom-hole temperatures high enough to sustain the geothermal exploitation of the reservoir fluids. In these cases, the great amount of water stored in hydrocarbon reservoirs represents, now, a waste heat that can be used, thanks to the flexibility and wide availability of geothermal energy applications as demonstrated by several studies (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; Soldo et al., 2020; Watson et al., 2020).

The target of this contribution, largely based on the results already discussed in Alimonti et al. (2021), is to provide a vision of the geothermal potential associated with the depleted oil & gas fields in Italy. Starting from the available information on fields and wells provided by the Ministry of Economic Development, integrated with other published data on hydrocarbon fields, and estimated temperature at a given depth (Cataldi et al. 1995; Trumpy & Manzella, 2017), a selection of the most promising areas have been carried out. The volume method (e.g., Cataldi et al. 1978, Doveri et al. 2010, Trumpy et al. 2016) has been applied to selected fields to assess their geothermal potential.

2. ITALIAN PETROLEUM SYSTEMS

The oil & gas fields discovered in Italy can be associated with five major petroleum systems (e.g., Bertello et al., 2010 and references therein)

Two of these five petroleum systems are essentially gas-prone and are associated with terrigenous Oligo-Miocene and Plio-Pleistocene foredeep units. The other three petroleum systems are instead mainly oil-prone and are related to Meso-Cenozoic passive margin sedimentary covers.

The fields associated with the Oligocene to Pleistocene siliciclastic reservoirs are generally located at depth of a few thousand meters. The hydrocarbon accumulations hosted in the Triassic to Paleogene carbonate reservoir have been discovered at a variable depth ranging from about 2000-3500 m in the foreland areas to more than 6000 m below the foredeep basin and in the thrust belt domain. The main characteristics of these five petroleum systems, and the associated reservoir rocks, are summarized in Table 1.

3. COLLECTED DATA AND FIELD SELECTION

The information on the fields is provided, in part, by the National Mining Office of the Italian Ministry for Economic Development (UNMIG-MISE, 2019). Data are also retrieved by the website of the project “Visibility of petroleum exploration data in Italy” (ViDEPI Project, 2019) promoted by the Ministry for Economic Development DGRME, the Italian Geological Society and the Assomineraria association. Additional information regarding the location, total depth, and completion date of the active well at the end of the year 2018 has been provided, upon request, by the Italian Ministry for Economic Development. Finally, further data on the location and characteristics of the Italian hydrocarbon fields have been retrieved from literature (e.g., Pieri & Mattavelli, 1986; Schlumberger, 1987; Sella et al., 1988; Mattavelli & Novelli, 1990; Mattaveli et al., 1993; Pieri, 2001; HIS Energy Group, 2002; Casero, 2004, Bertello et al., 2010).

The website of the Ministry of Economic Development reports that at the end of November 2019 there are 193 mining licenses of which 111 were onshore (peninsular Italy and Sicily, Fig. 1).

A first selection of the most promising onshore productive or potentially productive fields has been carried out by comparing the location and total depth with the known temperature distribution at different depths. The reference data are the temperature maps at depths of -2000 and -3000 meters below ground level (Fig. 2) published by Cataldi et al. (1995) and available in the Italian National Geothermal Database (Trumpy & Manzella, 2017).

Pursuing the goal of reducing greenhouse gas emissions to reach the 2030 targets, the main focus is on space heating. Therefore, the minimum production temperature was selected around 70 ° C. Following the criteria proposed in Alimonti et al. (2021), it has been possible to identify 42 fields at depths between 2000 and 3000 m and temperatures higher than 60-70 °C. The existing regional temperature maps have been adopted in this analysis and, therefore, the actual number of promising fields can be updated when well temperature measurements (usually not available for active production concessions) could be taken into consideration.

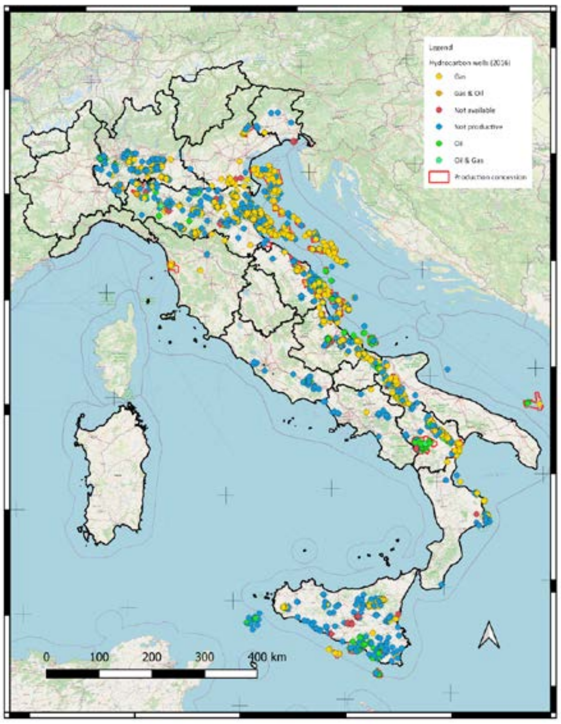

Figure 1: Hydrocarbon wells along with the Italian territory.

Table 1: Characteristics of the main reservoirs associated with the petroleum systems recognized in Italy (after Alimonti et al., 2001).

Petroleum System	Reference Field	Main Reservoir					Porosity (%)			Permeability (mD)			Note	Source
		Formation	Age	Lithology	Depth (m)	Gross Thickness (m)	Min	Max	Mean	Min	Max	Mean		
Plio-Pleistocene	Dosso degli Angeli	Porto Corsini - Porto Garibaldi	Lower-Upper Pliocene	Sand-rich turbidites	2900-3800	100	18	25	?	?	?	?	Eight overlying pools	Schlumberger (1987); Baù et al. (2000)
Oligo-Miocene	Gagliano	Collesano	Lower Miocene	Quartzitic sandstones	1650-2150	150	-	-	-	-	-	-		Schlumberger (1987); Granath & Casero (2004)
Cretaceous	Val d'Agri	Apulian Platform	Middle Miocene - Cretaceous	Fractured shallow water carbonates	c. 2000	>1000	-	-	0.2	-	-	20	Fracture	Casero (2004); Bertello et al. (2010); Nelson (2001)
							2	4	-	0.1	10	-	Matrix	
Early Jurassic – Late Triassic	Gela	Noto	Rhaetian	Laminated carbonates and euxinic shales	3000	>800	3	16	-	-	-	10	Low matrix poro-perm values improved by fractures. On production, it behaves as a homogenously fractured reservoir	Rocco (1959); Mattavelli et al. (1969); van Golf-Racht (1982); Granath & Casero (2004)
		Gela	Upper Triassic	Vuggy and fractured massive dolomites	3328				-	-	-			
	Malossa	Maiolica	Lower Cretaceous	Pelagic cherty limestone	5150	580	-	-	3	-	-	50	Fracture porosity with minor intercrystalline and moldic porosity	Mattavelli & Margarucci (1992)
		Zandobbio Dolomite	Hettangian	Calcareous and argillaceous dolomite	5520		1	13		-	-			
		Dolomia Principale	Upper Triassic	Intraclastic dolomites	5670		1	7		-	-			
Middle Triassic	Villafortuna - Trecate	Conchodon Dolomite	Hettangian	Dolomitized shelf carbonates	5700–6300	180-200	1	12	3.2	0.01	1000	27	Low porosity and permeability locally increased by fractures	Fantoni et al. (2002)
		Campo dei fiori	Rhaetian			90	0.2	11	3.2	0.01	10	0.9		
		Dolomia Principale	Norian			200	0.5	8	2.7	0.01	100	4.1		
		Monte San Giorgio	Anisian			150	0.9	7.8	3	0.01	8.5	4.1		

4. GEOTHERMAL POTENTIAL ASSESSMENT

The method proposed in Alimonti et al. (2021) for the evaluation of the geothermal potential associated with the oil&gas reservoirs is the volume method (Muffler and Cataldi 1978), largely used by several authors (Cataldi et al. 1978; Williams 2004; Doveri et al. 2010; Zaigham 2010; Chamorro et al. 2014; Limberger et al. 2014; Trumpy et al. 2016).

To obtain a realistic evaluation of the potential, a protocol considering filtering, like in the VIGORThermoGIS (Trumpy et al., 2016), has been adopted. The first step of the geothermal potential evaluation requires the calculation of the initial heat in place (HIP) (Muffler and Cataldi, 1978), related to the reference volume of the reservoir. This key parameter can be obtained by the knowledge of the geological structure hosting hydrocarbons. Although the oil companies know the reference volume, this information is generally not available for the Italian hydrocarbon fields, because it is covered by industrial secret.

However, the reference volume can be estimated knowing the area of the reservoir and its thickness that can be retrieved from public domain data (e.g., Pieri & Mattavelli, 1986; Schlumberger, 1987; Sella et al., 1988; Mattavelli & Novelli, 1990; Mattaveli et al., 1993; Pieri, 2001; HIS Energy Group, 2002; Casero, 2004, Bertello et al., 2010).

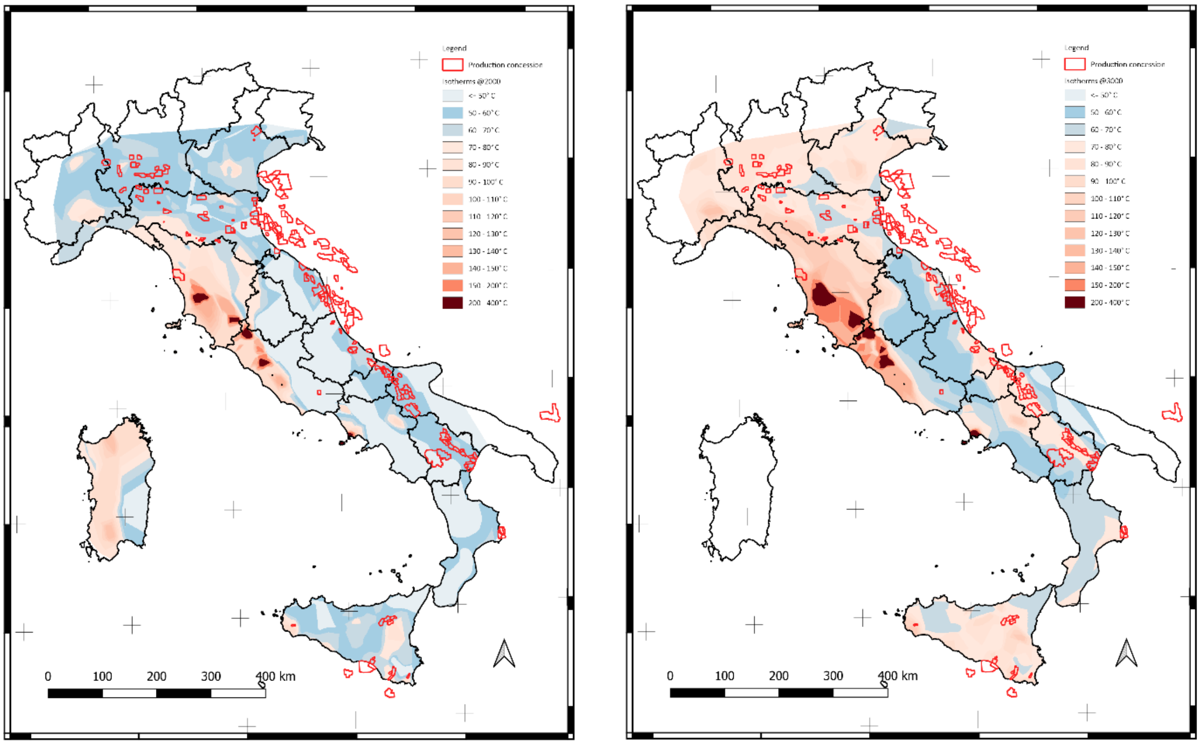

Figure 2: Temperature fields @ -2000 m (left panel) and -3000 m (right panel). The hydrocarbon production concessions are displayed in red (after Alimonti et al., 2001).

4. RESULTS AND DISCUSSION

Starting from the identified fields and the available dataset, the geothermal potential is evaluated following the methodology presented in Alimonti et al. (2021). A set of five representative fields have been selected. Table 2 reports the main parameters assumed for those sample fields according to Table 1.

Table 2 reports a series of data collected from literature for rock density and specific heat according to the main lithology of the reservoir (Comin-Chiaramonti & Mazzucchelli, 2017). For reservoir temperature, the calculation method previously presented has been used considering as reference depth the value in Table 1.

Following the three steps evaluation procedure, HIP, H_r and TP have been calculated and the results are reported in Table 3. The reinjection temperature assumed in the calculation of the Hr is 40°C having considered the application for space heating.

The obtained results are encouraging considering the possible uses of the annual power. For instance, the district heating plant of Ferrara (Italy) supplies 320 buildings thanks to a combined plant composed of a biomass plant, a methane gas boiler and a geothermal plant (Casaglia field) with an installed capacity of 14 MW and 100 °C of wellhead temperature. In Piancastagnaio (Tuscany), the greenhouse company Floramiata uses the heat supplied by the neighbouring geothermal power plant, which furnishes 175,000 MWh per year (corresponding to an installed power of about 19 MW). This energy heats 27 hectares of greenhouses.

Table 2: Selected fields and assumed parameters (after Alimonti et al., 2001).

Field	Area	Gross thickness	Rock Density		Rock Specific heat		Reservoir Temperature
			average	***range***	***average***	***range***	
	km²	**m**	**kg/m³**	**kg/m³**	**J/kg K**	**J/kg K**	**°C**
Villafortuna-Trecate	34.74	700	2500	2400-2760	816	628-1004.8	160.0
Gela	38.88	800	2450	2040-2850	729	728.5	86.6
Dosso Angeli	8.51	100	2100	1600-2680	829	728.5-929.5	70.0
Val d'Agri	36.78	1000	2550	2400-2760	816	628-1004.8	65.0
Gagliano	48.51	150	2550	2500-2600	821	699.2-942	88.5

Table 3: Geothermal potential assessment (HIP, heat in place; Hr, extractable heat; TP, technical potential; after Alimonti et al., 2001).

Field	HIP	H_r	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

**This field has been evaluated without the contribution of the water due to the lack of porosity data.*

A probabilistic approach to evaluate the uncertainty associated with the potential assessment analysis has been also conducted. The parameters influenced by uncertainty are reported in Table 4 with the associated range of uncertainty and distribution function.

Table 4: Parameter uncertainty for probabilistic evaluation (after Alimonti et al., 2001).

Parameter	**Range**	**Distribution**
Rock density	± 200 kg/m³	Normal/Gaussian
Rock specific heat	± 50 J/kg K	Normal/Gaussian
Reservoir temperature	± 5 °C	Normal/Gaussian
Reservoir Porosity	± 0.02	Normal/Gaussian
Reservoir thickness	± 0.5 m	Normal /Gaussian
Reservoir area	± 1.05 km²	Normal /Gaussian
Recovery factor	0.05 – 0.2	Uniform

The results of the analysis are summarized in Table 5 with the conventional representation with probability expectation (P10-P50-P90). The probability distribution of the TP shows a very broad range. The change in power roughly doubles each probability level. The P50 values are in agreement with the deterministic evaluation due to the choice to use the average for each parameter.

Table 5: Probabilistic evaluation (after Alimonti et al., 2001).

Field	Technical Potential (MW)		
	P90	*P50*	*P10*
Villafortuna-Trecate	387.6	788	1323
Gela	178.1	340.9	534.6
Dosso Angeli	2.1	6.6	14.6
Val d'Agri	116.6	240.6	437.7
Gagliano	40	92.4	173.4

From this preliminary analysis, the available heat stored in the discovered hydrocarbons fields is significant. The adopted approach, valid for regional-scale evaluation, is limited to a screening step to identify the more interesting hydrocarbon reservoir to be converted. The data usually available in O&G fields are quite important and a deeper and more accurate evaluation could be carried out. For instance, it is fundamental to analyze the production capacities of the existing wells. However, where the production is still ongoing, those data are often confidential. For this reason, the conducted analysis has assumed a theoretical recovery factor based on conventional geothermal exploration and evaluation. A key issue to having a more clear idea of the recoverable heat in place is the knowledge of production data as well as petrophysical parameters like permeability. In this case, a preliminary evaluation of the present recoverable heat can be improved, but it is still a limitation and a single feasibility study on each case should be developed.

3. CONCLUSIONS

The geothermal potential stored in five representative depleted oil & gas fields in Italy has been assessed. These five fields have been chosen among the most promising fields for geothermal repurposing selected by Alimonti et al. (2021). For this assessment, the volume method has been applied. Then the technical potential has been estimated, assuming a value for the recovery factor, the efficiency and the life span of geothermal plants. To overcome the uncertainty related to the reservoir parameters, the deterministic approach has been integrated with a probabilistic method, which produces not a single value but a distribution of values of the technical potential.

The overall results are encouraging, although the applied method is preliminary and it has provided only a rough evaluation, which uses the data derived from exploration and production of hydrocarbons reservoirs, whose volumes may not coincide with the geothermal reservoirs. Those volumes may be greater and only an ad hoc analysis of the data collected by the owner companies of the existing fields and wells may produce a more precise evaluation. For instance, 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. Considering that, only five fields on a total of at least 42 fields, have been included in this evaluation, the geothermal technical potential stored in the Italian oil&gas fields is significant.

Acknowledgements

Figure 2 and tables 1, 2, 3, 4, and 5 are reprinted from *Geothermics*, **93**, Alimonti, C., Soldo, E. and Scrocca, D, Looking forward to a decarbonized era: Geothermal potential assessment for oil & gas fields in Italy, 102070, Copyright (2021), with permission from Elsevier.

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