Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal energy: developing a synergic integration in oil&gas fields looking forward to a decarbonized era

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Keywords: geothermal energy, hydrocarbons, decarbonisation, oil&gas

ABSTRACT

One of the main challenges of the future is the decarbonisation of the energy sector. Finding alternative energy sources to hydrocarbons, optimizing the energy production, integrating different energy sources, reducing waste heat and the environmental impacts are some of the current objectives of R&D departments of many companies.

Since '90, American and Chinese oil companies have studied the possibility of co-producing geothermal energy from oil and gas wells. In fact, the oil and gas production in its mature stage is often associated to a large amount of brines or formation waters which must be treated continuously and could not be released to the environment. Increasing the maturity of assets, the water production increases, so when the hydrocarbons wells are going to be depleted, they can be converted into geothermal wells. Regarding the use of geothermal energy, two main scenarios are available: the direct use of thermal power or the electrical power generation. The selection of the final use and the potential of geothermal production depends on the temperature, pressure and flow rate of water, which are function of local geothermal gradient, well depth, and poro-perm properties of the reservoir rocks.

The oil and gas fields in the Italian territory are distributed in thrust belt, foredeep basin, and foreland geological settings. Hydrocarbon occurrences are related to at least five major petroleum systems which are associated to both carbonate and siliciclastic reservoir rocks ranging in age from Triassic to Paleogene and from Oligocene to Pleistocene, respectively. At the end of 2017, the total number of productive wells on the Italian territory was 1613 wells, 895 wells are on-shore and 718 wells are off-shore

The possibility of a synergic integration of geothermal energy in these oil&gas fields represents a chance for Italy to increase the share of renewable energy production and to reduce the waste heat. Furthermore, the conversion of hydrocarbons fields into geothermal ones may be an opportunity to create a positive social response in the area where the oil and gas wells are located. The use of existing wells is a benefit for the oil companies, which avoid the cost of mining closure of the wells and for the geothermal companies, which avoid the cost of drilling new wells.

The paper presents a preliminary investigation on some oil and gas wells located on Italian territory based on the available information provided by the Ministry of Economic Development. Taking into account the activities or land use of the territory, a conversion strategy for the producing wells has been proposed in order to produce a vision of the potential benefits of the synergetic integration of geothermal energy in the Italian oil and gas fields.

1. INTRODUCTION

One of the main challenges of the future is the decarbonisation of the energy sector. Global changes urge a radical transformation and improvement of the energy producing systems to meet the decarbonisation targets of the European economy by 2050 and a reduction of greenhouse gas emissions. The main targets for 2030 is a reduction of 40% of greenhouse gases, an increase in renewable energy of 27% and in energy efficiency of 27%. For the 2050, the targets are higher with a perspective in Europe of reduction emissions around the 90% and an increase in energy from renewables to 75% and in energy efficiency up to 41%.

Current heating and cooling system is a major contributor to EU's greenhouse gas emissions. 47% of the final energy consumption in the EU is due to heating and cooling (domestic & industrial) and 81% of heating produced through the combustion of fossil fuels while cooling predominantly produced from electricity-driven processes (today largely generated burning coal and gas). Geothermal energy can significantly contribute to the diffusion of low carbon technologies for the generation of electricity, heating and cooling.

Finding alternative energy sources to hydrocarbons, optimizing the energy production, integrating different energy sources, reducing waste heat and the environmental impacts are some of the current objectives of R&D departments of many companies.

Since '90, American and Chinese oil companies have studied the possibility of co-producing geothermal energy from oil and gas wells. In fact, the oil and gas production in its mature stage is often associated to a large amount of formation waters which must be treated continuously and could not be released to the environment. Increasing the maturity of assets, the water production increases, so when the hydrocarbons wells are going to be depleted, they can be converted into geothermal wells. The selection of the final use (production of thermal power or electricity) and the potential of geothermal production depend on the temperature, pressure and flow rate of water, which are function of local geothermal gradient, well depth, and poro-perm properties of the reservoir rocks.

The first example of this type of solution is in Pleasant Bayou field, where in 1980 a 1 MW hybrid cycle power plant was built in order to demonstrate the possibility of using existing wells to extract both gas and hot water and to produce electricity (Riney, 1991). Since then, several studies on geothermal energy production form abandoned oil and gas fields have been conducted. In 2000, Barbacki evaluated the use of abandoned oil and gas wells of Grobla field (Poland), in order to produce thermal energy. Zhang (2008) proposed the injection of air followed by water to obtain in-situ combustion and the increase of pressure and temperature in order to produce geothermal power. In 2010 the U.S. Energy Department has reported about the installation of a 250 kW Ormat ORC power plant in the Naval Petroleum Reserve No.3, Teapot Dome Field, Wyoming, USA (Johnson and Walker, 2010; Nordquist and Johnson, 2012). Limpasurat et al. (2010) studied the opportunity to harness geothermal energy from heavy oil fields that have undergone steam-flooding and have accumulated substantial heat from steam injection: the estimated net power from a single doublet is around 14 kW. Sanyal et al. (2010) evaluated the co-production of water and gas using an abandoned gas well of Texas; the net estimated power was about 340 kW. Li et al. (2012) proposed an optimization of a combined plant composed by an ORC system, a gathering heat tracing station and an oil recovery system. Alimonti and Gnoni (2015) outlined a progressive conversion of an oil field in Villafortuna-Trecate (Italy) into a geothermal one: the authors indicated that the net power may be between 400 kW and 500 kW per well. Quite much of papers are focused on the possible application of the hot brines of Huabei oilfield in China i.e. Xin et al. (2012), Wang et al. (2016) Hu et al. (2017), Yang et al. (2017). Gosnold (2017) reports about a case of coproduction of 98 °C water from the waterflood wells in the Williston Sedimentary Basin in western North Dakota.

The heat recovery potential from oil and gas fields worldwide has been evaluated in some studies: McKenna et al. (2005) estimated that over 1 GW of electric power could be produced using the co-produced fluids in oilfields along the Gulf Coast; Bennett et al. (2012) states the use of oilfields of Los Angeles may generate 7.43 MW of net power; Wang et al. (2018) reported that 424·1018 J of recoverable geothermal energy is stored in the Chinese oilfields. Wang et al. (2018) report also a summary of the worldwide oilfield geothermal direct use projects: Austria uses the water of abandoned wells since ’70 in order to feed spa resorts; in Albania the water is used in greenhouse heating; heat trace oil gathering is carried out in China and Hungary; in China the space heating projects are numerous.

In this context, a key point for the geothermal sector is the need to reduce uncertainties on profitability and to design sustainable solution for large-scale development out of the conventional assets as well as to be deployed more rapidly. The possibility of a crossover from oil & gas to geothermal energy production represents a chance for Italy to increase the share of renewable energy production and to reduce the waste heat. 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. Starting from the available information on fields and wells provided by the Ministry of Economic Development and fields temperature from the Italian National Geothermal Database (Trumpy & Manzella, 2017), a selection of the most promising areas has been conducted. Among these fields, three case studies representative of different petroleum systems and geological setting, have been selected for a preliminary survey of the possible geothermal reuse. Taking into account the activities or the land use of the territory, a conversion strategy for the producing wells has been evaluated.

2. ITALIAN PETROLEUM SYSTEMS

In order to have a more general approach and to extent analysis by analogues, an overview of the geological settings of the main petroleum systems and the active hydrocarbons fields in Italy are described.

2.2 Italian geological systems

Hydrocarbon occurrences in Italy (fields, discoveries, and shows) are associated to both carbonate and siliciclastic reservoir rocks ranging in age from Triassic to Paleogene and from Oligocene to Pleistocene, respectively, distributed in thrust belt, foredeep basin, and foreland geological settings (Pieri & Mattavelli, 1986; 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).

Based on the main recognized source rocks (e.g., Zappaterra 1994; Ziegler and Roure, 1999; Bertello et al., 2010; Jenkyns, 2010; and references therein), at least 5 major petroleum systems (sensu Magoon and Dow, 1994) can be recognised in Italy. The approximate geographic extent of these petroleum systems and the stratigraphic distribution of the known source rocks and hydrocarbon occurrences is shown in Figure 1 (after Bertello et al., 2010). Three of these petroleum systems, mainly oil-prone, are associated to Meso-Cenozoic passive margin sedimentary covers that are mainly made up by shallow water and pelagic carbonates, evaporites, and clastics sedimented following Mesozoic extensional tectonics stages. The last two petroleum system, essentially gas-prone, are instead related to terrigenous Oligo-Miocene and Plio-Pleistocene foredeep units deposited during the developed of the Alpine and Apennines orogens. The main characteristics of these five petroleum systems (Pieri & Mattavelli, 1986; 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) are briefly summarized here below.

Middle Triassic petroleum system. It has been proven in the Western Po Plain were fractured and dolomitized shelf carbonates, hosted in thrust-related folds and sealed by marly and volcanoclastic units, are charged by the Besano Shales (Anisian/Ladinian) and Meride Limestone (Ladinian) source rocks (Type II kerogen). The Villafortuna–Trecate oil field, discovered in 1984 with a cumulative production at the end of 2000 of 188 Mbo of 43° API oil and more than 2000 MSTm3 of gas, is the largest hydrocarbon accumulation associated to this petroleum system.

Late Triassic–Early Jurassic petroleum system. This system has a wide distribution and it charged by terrigenous or mixed carbonate/terrigenous source rocks deposited in structurally controlled intraplatform basin. Due to the discontinuity of the regional seals, oil accumulations can be found in a variety of stratigraphic intervals of the Mesozoic-Early Cenozoic sedimentary cover overlying the source rock in traps generally represented by reactivated structures occurring along the foreland margin. A typical oil accumulation of this system is represented by the Gela oil field in Sicily discovered in 1956 with reserves of 130-150 Mbo.

Cretaceous petroleum system. It is well known in the southern Apennines where it is charged by an Albian–Cenomanian organic-rich carbonate source rock deposited in isolated basins developed during the Cretaceous anoxic events within the long-lasting

Apulian carbonate platform. The reservoir is made up by Cretaceous-Middle Miocene fractured shallow water limestone and dolostones sealed by shaly units in traps represented by thrust-related folds. The giant Val d'Agri oil field, discovered in 1988 with estimated reserves of about 480 Mbo of 26°-42° API oil, is a remarkable example of an accumulation associated to this system.

Thermogenic gas in Oligo-Miocene foredeep units. This system is associated to both Alpine and Apennine Oligo-Miocene foredeep units. During the orogenic processes, these units were deformed and buried at depth adequate to permit an early thermogenic generation from the gas-prone organic matter contained in the shaly levels that charged the turbidite reservoirs. Hydrocarbon accumulations, hosted in structural traps, usually consist of thermogenic gas (with some light oil and condensate). Typical examples are the Gagliano and Luna fields.

Biogenic gas in Plio-Pleistocene foredeep units. The Plio-Pleistocene foredeep unit in the Apennines and in Sicily are made up by thick (up to several thousand meters) turbidites successions. The sand-rich turbidite reservoir are charged with biogenic gas by the interbedded clay levels, characterised by an organic matter of terrestrial origin, which also provide the seal. Traps are usually structural although several stratigraphic traps have been also recognised. Illustrative example of the biogenic gas accumulations related to this system are the Porto Corsini East and Barbara field.

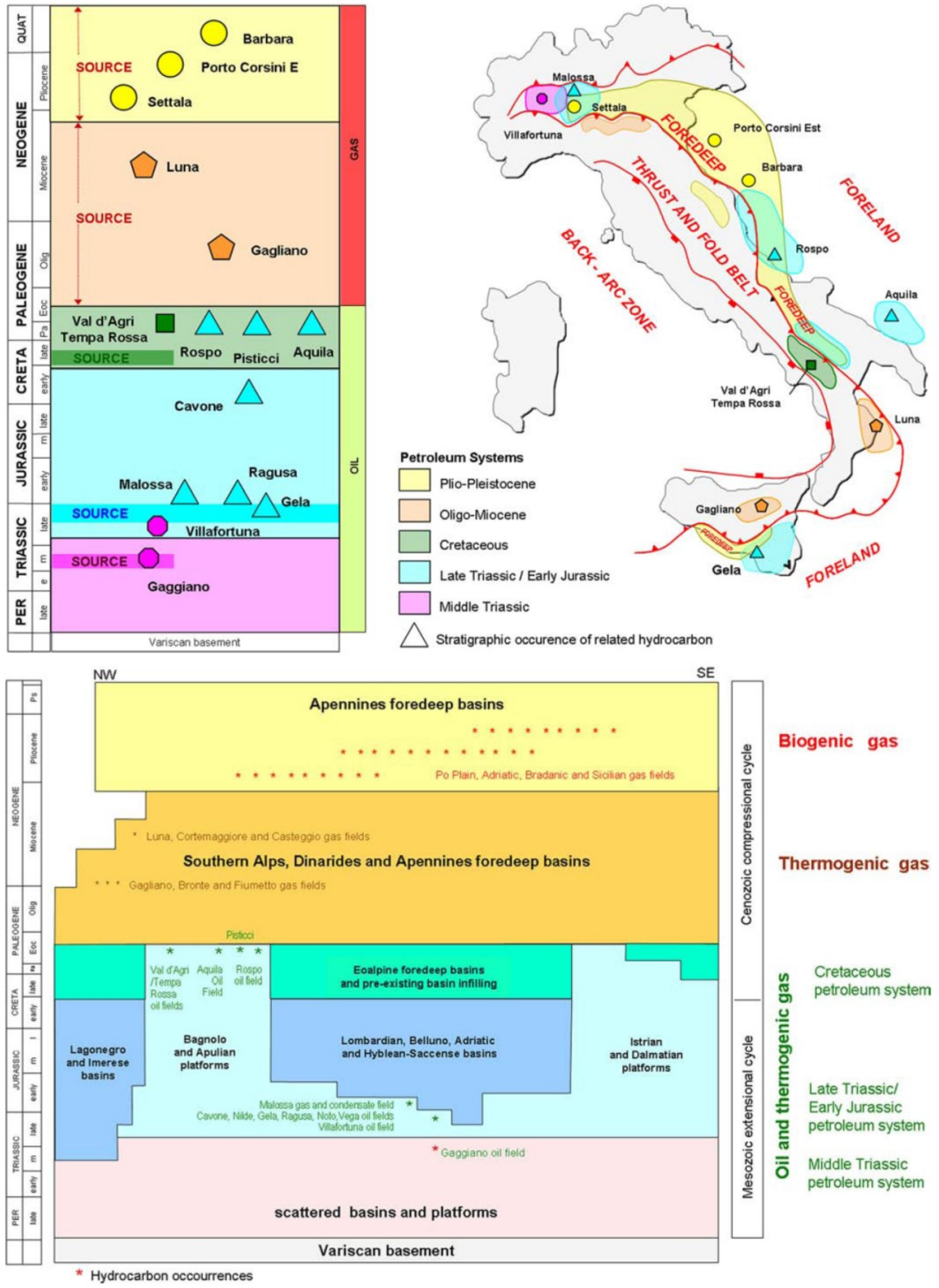

Figure 1: Geographic location of the five petroleum system recognised in Italy (above, right), stratigraphic distribution of the related source rocks and hydrocarbon occurrences (above, left), and relationships between hydrocarbon occurrences and the tectono-stratigraphic setting (below; after Bertello et al., 2010).

3. METHODS AND MATERIALS

The National Mining Office of the Italian Ministry for Economic Development provides information and data regarding productive wells, oil and gas and gas storage concessions in Italy for Hydrocarbon and Georesources (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 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 Ministry of Economic Development reports that at the end of June 2019 there are 78 research permits and 193 mining license.The last update about the hydrocarbons wells in Italy (Feb. 2019) reports 1613 wells, 895 on-shore and 718 off-shore (Fig. 2). For the purposes of this contribution, the analysis has been applied only to the onshore fields that have productive, or potentially productive, wells.

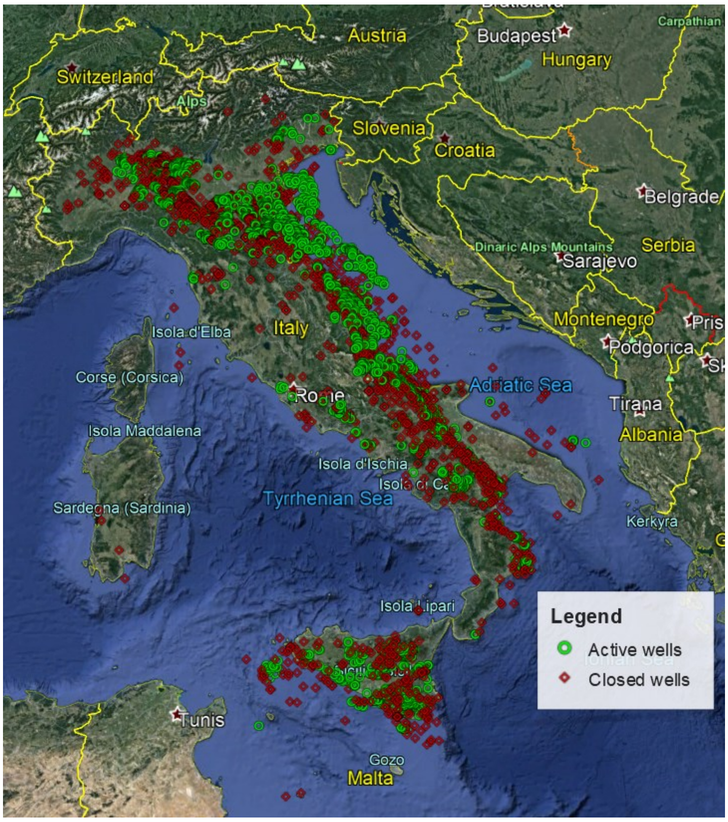

Figure 2: Hydrocarbon wells along the Italian territory.

The first step is the selection of the most promising areas by comparing it with the temperature distribution at different depth. The reference data are the temperature maps at depth -1000, -2000 and -3000 meters published by Cataldi et al. (1995) and available in the Italian National Geothermal Database (Trumpy & Manzella, 2017). The first selection criterion is to refer to the lower interesting temperature for possible uses. The chosen temperature is 70 °C and the temperature maps used in selection were at -2000 and -3000 meters. The selected fields are located in areas where the temperature estimated at -3000 m and -2000 m are higher than 70°C according to the total depth of the existing wells. Moreover, in the Bradano foredeep the selection has been extended to include also fields that overlap areas with temperature higher than 60°C at -2000 m. With the above described approach, a total of 58 fields have been selected (Fig. 3).

On these bases, some case studies have been chosen that can be considered representative of the different petroleum systems and geological setting and for which the available data allows a more detailed analysis. These case studies are the Trecate and Gaggiano fields in Northern Italy (Middle Triassic petroleum system in thrust belt in Northern Italy), the Irminio field (Late Triassic–Early Jurassic petroleum system in the Hyblean foreland domain in Sicily).

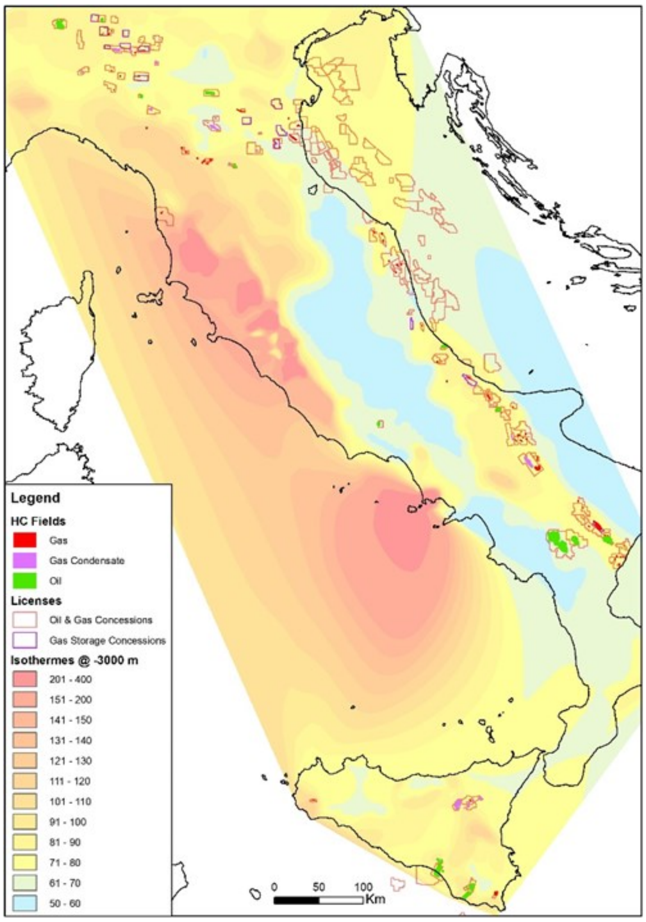

Figure 3 – Hydrocarbon fields with productive or potentially productive wells for geothermal use.

4. CASE STUDIES

4.1 Trecate

Villafortuna Trecate is a field located in Piemonte region, between the municipalities of Trecate, Romentino and Galliate (Figure 3). The larger part of the wells is near Galliate and Romentino. The idea is to propose a cascade system composed by a ORC power plant, a district heating and an aquaculture plant. The Table 1 reports the wells and the municipality that each of them will serve: 6 wells for Galliate area (G) and 3 wells for Romentino area (R). Trecate A, B and C will be use for the reinjection.

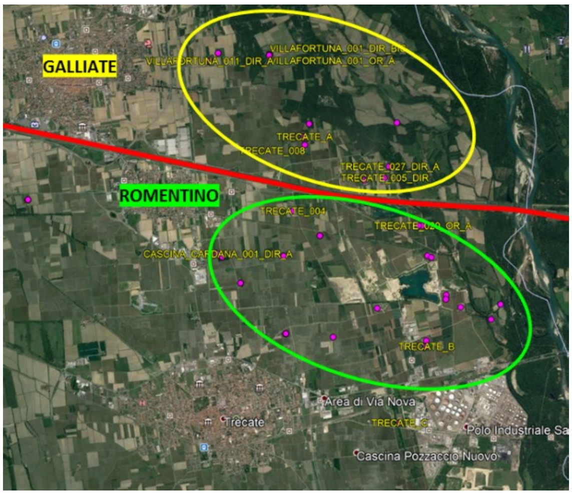

Figure 3: Villafortuna Trecate oilfield.

Table 1: Villafortuna-Trecate wells.

Well Name	Depth	Municipality
Trecate 019 X	6330	G
Cascina Cardana 001 DIR A	6131	R
Trecate 005 DIR A	5807	G
Trecate 008	6250	G
Trecate 020 OR A	5430	R
Trecate 027 DIR A	6087	G
Villaforuna 001 Bis	5328	G
Villafortuna 011 DIR A	5670	G
Trecate 004 DIR	6282	R
Treacate A	2502	re-injection
Trecate B	2061	re-injection
Trecate C	2030	re-injection

From available data and a previous analysis on productive potential (Alimonti & Gnoni, 2015), the single well can produce a flow rate of 100 kg/s of hot water having a wellhead brine temperature of 130 °C.

The Tables 2 and 3 summarize the main data of the proposed ORC plants and the economic pre-feasibility. The evaluation includes the thermodynamic analysis of the binary plant, the selection of the butane as working fluid, the sizing of the condenser and the cooling tower. In order to evaluate the number of supplied consumers, a precautionary consumption per capita of 1400 kWh has been supposed. The cost of the power plant has been calculated considering a mean value of 2000 €/kW, an energy price of 0.06 €/kWh and a working time of 7500 hours have been used to evaluate the annual revenues.

Table 2: Galliate power plant.

Inhabitants	15700
Power	6 MW
Energy produced	45000 MWh
Supplied consumers	32143
Plant cost	12 M€
Revenues	2.7 M€ per year
Payback time	4.5 years

Table 3: Romentino power plant.

Inhabitants	5635
Power	3 MW
Energy produced	22500 MWh
Supplied consumers	16071
Plant cost	6.6 M€
Revenues	1.35 M€ per year
Payback time	5 years

The results indicate that the yearly electrical demand of the Galliate and Romentino municipalities can be totally supplied by the proposed power plants, whose size guarantees a surplus of energy to be sold. The estimated annual revenues ensure the recovery of the investment in 4.5 years for the power plant of Galliate and in 5 years for the power plant of Romentino.

The district heating plant is feed by the geothermal fluid exiting from the pre-heater at the temperature of 84°C. The Tables 4 and 5 shows the DH data and economic evaluation. Assuming a heating request of 2 kW per person, the plants may guarantee the cover of thermal need of 71% of inhabitants of Galliate and 100% of inhabitants of Romentino. In order to estimate the DH plant cost, a value of 1800 €/kW has been used. Considering 3110 working hours per year and a price of thermal energy equal to 0.075 €/kWh, the investment cost is recovered in about 8 years for both of the municipalities.

Table 4: Galliate DH plant.

Inhabitants	15700
Power	22.5 MW
Inlet temperature	20
Outlet temperature	65
Supplied consumers	11268 (71%)
Plant cost	40.5 M€
Revenues	5.25 M€ per year
Payback time	7.71 years

Table 5: Romentino DH plant.

Inhabitants	5635
Power	11.2 MW
Inlet temperature	20
Outlet temperature	65
Supplied consumers	5635 (100%)
Plant cost	21 M€
Revenues	2.7 M€ per year
Payback time	7.75 years

The geothermal brine exits from the DH plants at the temperature of 50 °C, suitable for the aquaculture applications. The Tables 6 and 7 illustrate the design of the aquaculture plants and the economic pre-feasibility. The selected species for the cultivation is the shrimps, which need a constant water temperature of 35 °C. The plant is composed by indoor ponds. The annual heat requirement supplied by the geothermal energy is calculated including the heat loss from convection, radiation and evaporation. The evaluation has been carried out using the mean values for air properties: air temperature of 20°C, relative humidity of 30% and saturation pressure of 0.007 bar.

For what concern the economic evaluation, two values have been used for the installation cost, respectively 155 €/m^2 for the plant of Galliate and 163 €/m^2 for the plant of Romentino. Considering a price of 7€/kg for the shrimps, and a shrimp production of 4.5 kg/m^2 the payback period is about 5 years for both of the plants.

Table 6: Galliate aquaculture plant.

Area of the enclosed pond	4500 m^2
Heat loss from evaporation	758530 kJ/h
Heat loss from convection	758530 kJ/h
Heat loss from radiation	1417700 kJ/h
Total heat loss	10004000 kJ/h
Annual heat requirement	50826 MJ/y
Installation plant cost	697500 €
Annual revenue	141750 €
Payback time	4.9 years

Table 7: Romentino aquaculture plant.

Area of the enclosed pond	2800 m^2
Heat loss from evaporation	4870400 kJ/h
Heat loss from convection	471975 kJ/h
Heat loss from radiation	882100 kJ/h
Total heat loss	6224500 kJ/h
Annual heat requirement	31625 MJ/y
Installation plant cost	456400 €
Annual revenue	88200 €
Payback time	5.2 years

4.2 Gaggiano

The oil field of Gaggiano, is located in the south-western portion of the Province of Milan. The selected wells are located near the municipality of Tainate and Noviglio (Figure 4). The production performance, based on the analogy with the Trecate field, is more conservative with a flow rate of 50 m^3/h and the wellhead temperature of the water is estimated to be 125°C. Considering the availability of 2 production wells and 1 injection well (Table 8), and the agricultural vocation of the territory, the proposed cascade scheme is composed by district heating plant, greenhouse and aquaculture plant (Figure 7).

From the two wells is possible to obtain a thermal power of 6 MW, 2 MW will be used to feed the greenhouses and 4 MW to feed the District Heating. For both of the plants the outlet temperature of the feeding water is 70°C: this fluid will be mixed with water at 20°C in order to supply the thermal request of an aquaculture system.

Figure 4: Location of Gaggiano wells.

Table 8: Gaggiano wells.

Well Name	Depth	Use
Gaggiano_001	5009	Production
Gaggiano_001_DIR	4853	Production
Gaggiano_A	2050	Injection

The Tables 9 shows the DH data and economic evaluation. Assuming a heating request of 2 kW per person, the plant may guarantee the cover of thermal need of 40% of inhabitants of Gaggiano. Using the same hypothesis of the Trecate case study for the plant cost, energy price and total number of working hours, the investment cost is recovered in 7.4 years.

For what concern the 6000 m^2 of enclosed greenhouse in Gaggiano (Tab.10), the total installation cost is 0.33 M€. Considering as reference cultivation tomatoes, the selling price has been assumed equal to 1.0 €/kg. The annual revenues of 0.09 M€ guarantees that in 3.67 years the investment may be recovered.

Using the same evaluation procedure and the same species previously described for Galliate and Romentino aquaculture plant, the Gaggiano aquaculture plant presents a payback time of 5.11 years (Tab. 11).

Table 9: Gaggiano DH.

Inhabitants	4584
Power	3.92 MW
Inlet temperature	20
Outlet temperature	65
Supplied consumers	1960
Supplied percentage	40%
Plant cost	7.05 M€
Revenues	0.95 M€
Payback time	7.4 years

Table 10: Gaggiano greenhouse.

Area of the enclosed pond	6000 m^2
Infiltration heat loss	1361.2 MJ/h
Transmission heat loss	855 MJ/h
Peak heat loss	2216.2 MJ/h
Installation plant cost	330000 €
Annual revenue	90000 €
Payback time	3.66 years

Table 11: Gaggiano aquaculture plant.

Area of the enclosed pond	3200 m^2
Heat loss from evaporation	55562 MJ/h
Heat loss from convection	539.4 MJ/h
Heat loss from radiation	1008.1 MJ/h
Total heat loss	7113.7 MJ/h
Annual heat requirement	36143 MJ/h
Installation plant cost	515200 €
Annual revenue	100800 €
Payback time	5.11 years

4.3 Irminio

The Irminio oil field (Fig. 5) is located just near the Irminio River between the Municipality of Ragusa and Scicli. The Irminio field is in a different oil play than previous case studies and it belongs to the Late Triassic–Early Jurassic petroleum system in the Hyblean foreland domain in Sicily. There are currently 4 production wells and an oil center, where oil is separated from natural gas and water, and stored before marketing.

Figure 5: Location of Irminio wells.

Starting from the information supplied by the owner oil company an evaluation of possible use in a greener way of wells has been studied. For the same reason the company installed a cogeneration unit (CHP) with a thermal power of 570 kW and electrical production of 360 kW. The proposed solution is based on a perspective to have a view toward the future. The integration plant based on the use of produced heat both from wells and CHP is designed to produce biogas and biomass for biodiesel production.

The flow rate produced by wells at a temperature of 40 °C is sent to a heat exchanger to heat up the water fed to the anaerobic digester. To satisfy the thermal power demand of the digester, a part of the produced heat from the CHP is also supplied.

The process temperature is around 35 ° C, working with mesophilic bacteria. The digester has been designed based on the population in Scicli (262000 people) and assumed to have an organic waste production of 130 kg per capita. The residence time chosen is 30 days for the digester and 60 days for the storage tank in order to obtain a good digestion of the biomass. The daily production is 4038 m^3 of biogas. The biogas can feed the CHP unit.

The larger part of the produced hot water from the CHP is used to produce algae. The algae farm is built close to a power plant, the CO_2 produced by the power plant could be utilized as a carbon source for algal growth, and the carbon emissions would be reduced by recycling waste CO_2 from power plants into clean-burning biodiesel. Practically, all the CO^2 emitted from the cogenerator will be introduced in the indoor pond to feed the algae. In this way, it is possible to feed 1800 m^2 of ponds for algae cultivation.

For what concern the biogas power plant (Tab. 12) the total installation cost is 2.05 M€. Considering a price of electricity equal to 0.06 €/kWh, the annual revenue from electricity is 151200 €. Taking into account that almost 1000 m^3 of biogas per day are consumed to supply the CHP, the remaining 1.1 Mm^3 of biogas can be sold each year, generating an annual income equal to 0.24 M€. The total annual revenue will be around 0.4 M€ and a simple payback period of 5.2 years is obtained.

Table 12: Irminio biogas.

Installation cost	2.05 M€
Installed electrical power	360 kW
Installed thermal power	568 kW
Revenue from electricity	151200 €/y
Gas produced	1108761 m^3
Revenue from gas	243927 €
Annual revenue	395127 €
Payback time	5.2 years

Table 13: Irminio biodiesel.

Area of the indoor pond	1800 m^2
Installation plant cost	306000 €
Biodiesel produced	155000 L/y
Annual revenue from biodiesel	70060 €
Payback time	4.3 years

Considering that, in Gela refinery, Eni is building an important plant to distillate algae we can think to build only the cultivation part so that the installation cost is 170 €/m^2. The total installation cost (Tab. 13) concerning the 1800 m^2 of indoor ponds is 306 k€. The annually produced biodiesel is 155 kL and, considering a price for sold biodiesel equal to 0.452 €/L, the annual income is 70000 €. A simple payback period of 4.37 years is found. Of course, the cost for transporting algae must be taken into account for more detailed analysis.

5. CONCLUSIONS

The target of this paper is to make an evaluation of the potential benefits resulting from the refitting of depleted oil & gas wells in Italy into geothermal ones. The adopted selection method identifies 58 field: 39 fields deeper than 3000 m with a temperature higher than 70° C; 7 fields with a depth between 2000 and 3000 m and a temperature higher than 70° C; 12 fields with a temperature higher than 60° C.

Three case studies have been investigated in order to identify a second life for the hydrocarbons wells: Villafortuna-Trecate, Gaggiano, Irminio, having in total 18 wells, 13 of which are production wells and the remaining 5 are injection wells. Following are listed the achievable results of the proposed reuse solutions:

- generation of 9 MW of electrical power.
- heating supply for 18862 people thanks to DH.
- heating supply of 10500 m^2 of enclosed ponds.
- heating supply for 6000 m^2 of Greenhouse.
- disposal of 47160 tons of organic waste to produce 4037.7 m^3/day of biogas.
- cultivation of algae for the production of 150000 L/year biodiesel in a 1800 m^2 of indoor ponds.

Moreover, it is necessary to emphasize that all these results are achieved without any emission of CO2 into the atmosphere.

The main problem to make this analysis is the lack of data, which are mainly covered by the industrial secret. The possibility to have a project highlighting the advantages for the companies to reduce the abandonment cost can be a driving force to give basic data to fulfill the analysis over the Italian country.

A possible obstacle to the refitting of the wells is the legislative framework for changing the status of the concession. This aspect will be addressed with the bureau of the Ministry of the Economic Development in the same project.

Considering that in Italy more than 1600 wells are present, a national project of reuse of oil and gas field may be a great opportunity for the energy transition to the renewables and the waste heat recovering.

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