

Geothermal Repurposing of Depleted Oil and Gas Wells in Italy [†]

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Abstract: The decarbonisation of the energy sector is probably one of the main worldwide challenges of the future. Global changes urge a radical transformation and improvement of the energy-producing systems to meet the decarbonisation targets and a reduction of greenhouse gas emissions. The hydrocarbon industry also contributes to this transition path. In a mature stage of oil and gas fields, the production of hydrocarbons is associated with formation waters. The volume of produced water increases with the maturity of the assets and the geothermal repurposing of depleted oil and gas wells could be an alternative to the mining closure. In the described transition scenario, the geothermal energy seems very promising because of its wide range of applications depending on the temperature of extracted fluids. This flexibility enables us to propose projects inspired by a circular economic vision considering the integration in the territory and social acceptance issues. In Italy, since 1985, 7246 wells have been drilled for hydrocarbon, of which 898 are located onshore with a productive or potentially productive operational status. This paper presents a preliminary investigation of oil and gas fields located onshore in Italian territory based on the available information on temperature distribution at different depths. Then, taking into account the local energy demand, existing infrastructure, and land use of the territory, a conversion strategy for the producing wells is proposed for three case studies.

Keywords: geothermal energy; hydrocarbons; decarbonisation; oil and gas

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 and reduce greenhouse gas emissions. The main targets for 2030 are a reduction of 40% of greenhouse gases, an increase in renewable energy of 27%, and an increase in the energy efficiency of 27%. For 2050 the targets in Europe are higher, with a reduction in emissions of around 90%, an increase in energy from renewables to 75%, and an increase in energy efficiency to 41%.

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

Finding alternative energy sources to hydrocarbons, optimizing energy production, integrating different energy sources, and reducing waste heat and 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 cannot be released into the environment. Increasing the maturity of hydrocarbon fields increases water production as well. So, when the hydrocarbons wells are going to be depleted, they can be converted into geothermal wells. Some studies evaluated the potential heat recovery from oil and gas fields worldwide. Ref [1] estimated that the use of co-produced fluids in oilfields along the Gulf Coast could produce over 1 GW of electric power. Ref [2] stated that the use of oilfields of Los Angeles may generate 7.43 MW of net power and [3] reported that 4,241,018 J of recoverable geothermal energy is stored in the Chinese oilfields. Moreover, [4] reported a summary of the worldwide oilfield geothermal direct use projects: Austria has used the water of abandoned wells since 1970 to feed spa resorts; in Albania, the water is used in greenhouse heating; heat trace oil gathering is carried out in China and Hungary; and in China, the space heating projects are numerous. 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 functions of the local geothermal gradient, well-depth, and poro-perm properties of the reservoir rocks.

The first example of co-production or geothermal application of gas wells is the pilot plant in Pleasant Bayou field where, in 1980, a 1 MW hybrid cycle power plant was built to demonstrate the possibility of using existing wells to extract both gas and hot water and to produce electricity [5]. Since then, several studies on geothermal energy production from abandoned oil and gas fields have been conducted [6–25].

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. The possibility of a crossover from oil and 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 and gas wells in Italy. Starting from the available information on fields and wells provided by the Ministry of Economic Development and on-field temperatures from the Italian National Geothermal Database [26], a selection of the most promising areas has been conducted. Among these fields, three case studies representative of different petroleum systems and geological settings have been selected for a preliminary survey of the possible geothermal reuse. Taking into account the local energy demand, existing infrastructure, and land use of the territory, a conversion strategy for the active wells has been evaluated.

2. Italian Petroleum Systems

An overview of the geological settings of the main petroleum systems in Italy, and the associated active hydrocarbon fields, has been carried out to properly frame the detailed analysis of our case studies.

Hydrocarbon occurrences in Italy (fields, discoveries, and shows) are associated with both carbonate and siliciclastic reservoir rocks ranging in age from the Triassic to the Paleogene and from the Oligocene to the Pleistocene, respectively, distributed in thrust belt, foredeep basin, and foreland geological settings (Figure 1) [27–35].

Based on the main source rocks ([34,36–38] and references therein), at least five major petroleum systems [39] 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 are shown in Figure 1 (after [34]). Three of these petroleum systems, mainly oil-prone, are associated with Meso-Cenozoic passive margin sedimentary covers that are made up of shallow water and pelagic carbonates, evaporites, and clastics sedimented following the Mesozoic extensional tectonic stages. The last two petroleum systems, essentially gas-prone, are instead related to terrigenous Oligo-Miocene and Plio-Pleistocene foredeep units deposited during the development of the Alpine

and Apennines orogens. The main characteristics of these five petroleum systems [27–35] are briefly summarized in Table 1.

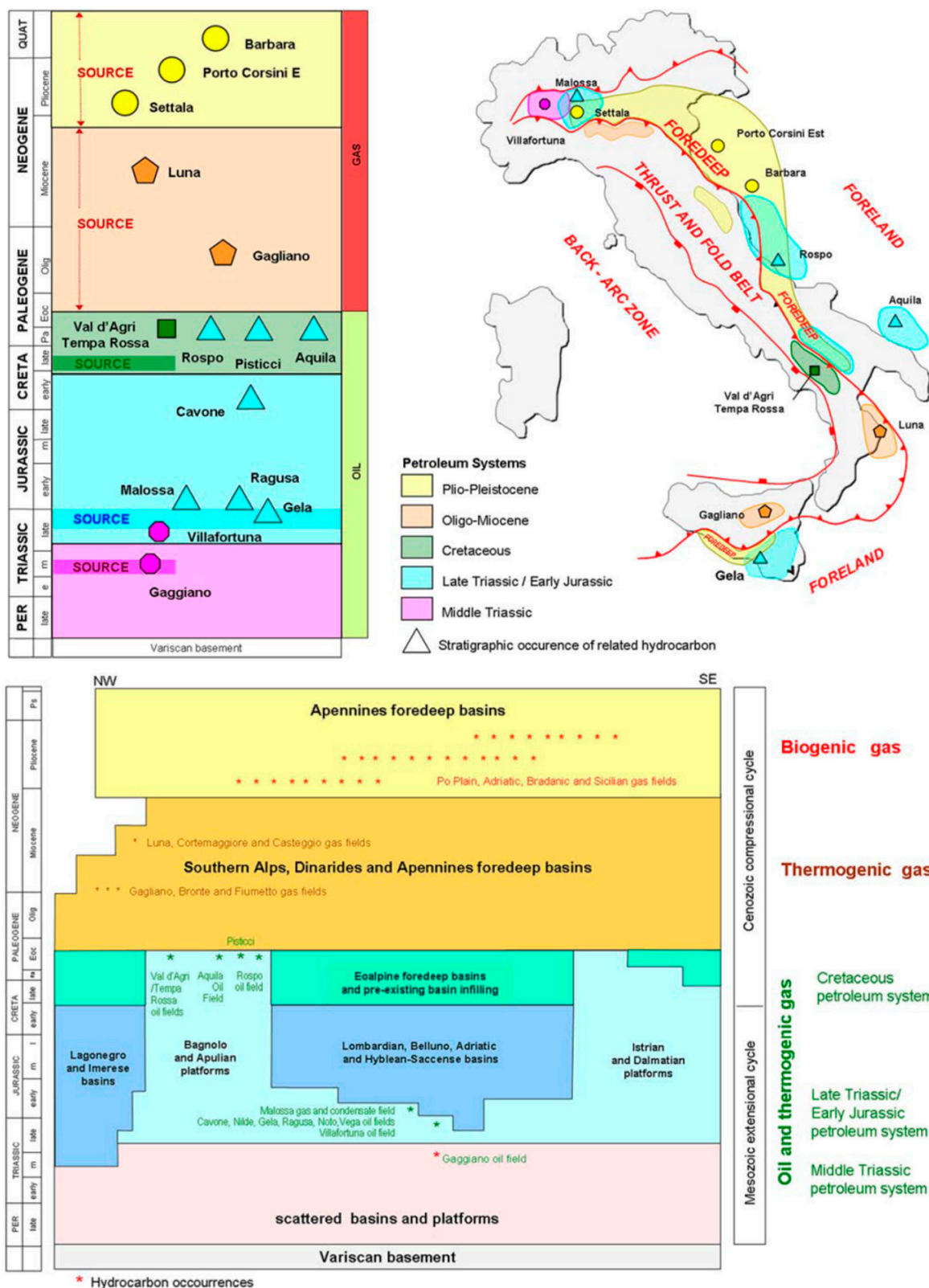


Figure 1. The geographic location of the five petroleum systems recognised in Italy (above, right), stratigraphic distribution of the related source rocks and hydrocarbon occurrences (above, left), and relationships between hydrocarbon occurrences and the tectono-stratigraphic setting (below; after [34]).

Table 1. Italian petroleum system and typical associated fields.

Petroleum System	Reservoir Source Rock	Representative Fields
Middle Triassic	Fractured and dolomitized shelf carbonates, hosted in trust-related folds and sealed by marly and volcanoclastic units, are charged by the Besano Shales (Anisian/Ladinian) and Meride Limestone (Ladinian) source rocks.	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.
Late Triassic–Early Jurassic	Oil accumulations in a variety of stratigraphic intervals of the Mesozoic–Early Cenozoic sedimentary cover overlying Late Triassic–Early Jurassic source rocks in traps generally represented by reactivated structures occurring along the foreland margin.	Gela oil field in Sicily discovered in 1956 with reserves of 130–150 Mbo.
Cretaceous	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. 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.	Val d’Agri oil field, discovered in 1988 with estimated reserves of about 480 Mbo of 26°–42° API oil.
Thermogenic gas in Oligo–Miocene foredeep	This system is associated with 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 with some light oil and condensate.	Typical examples are the Gagliano and Luna gas fields.
Biogenic gas in Plio–Pleistocene foredeep	The sand-rich turbidite reservoir is charged with biogenic gas by the interbedded clay levels, characterised by an organic matter of terrestrial origin, which also provides the seal. Traps are usually structural although several stratigraphic traps have been also recognised.	Porto Corsini East and Barbara gas fields.

3. Materials and Methods

The National Mining Office of the Italian Ministry for Economic Development (MISE) provides information and data regarding productive oil and gas wells, and hydrocarbon and gas storage licences in Italy [40]. Data are also provided by the website of the project “Visibility of petroleum exploration data in Italy” [41] promoted by the MISE-DGRME (Direzione Generale Risorse Minerarie ed Energetiche), 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., [27,28,30,32–34,42–44]).

The MISE reported, at the end of November 2019, 93 research permits and 193 production concessions, while the active hydrocarbon wells (as of February 2019) numbered 2166 in total, of which 898 were located onshore with a productive or potentially productive operational status (Figure 2).

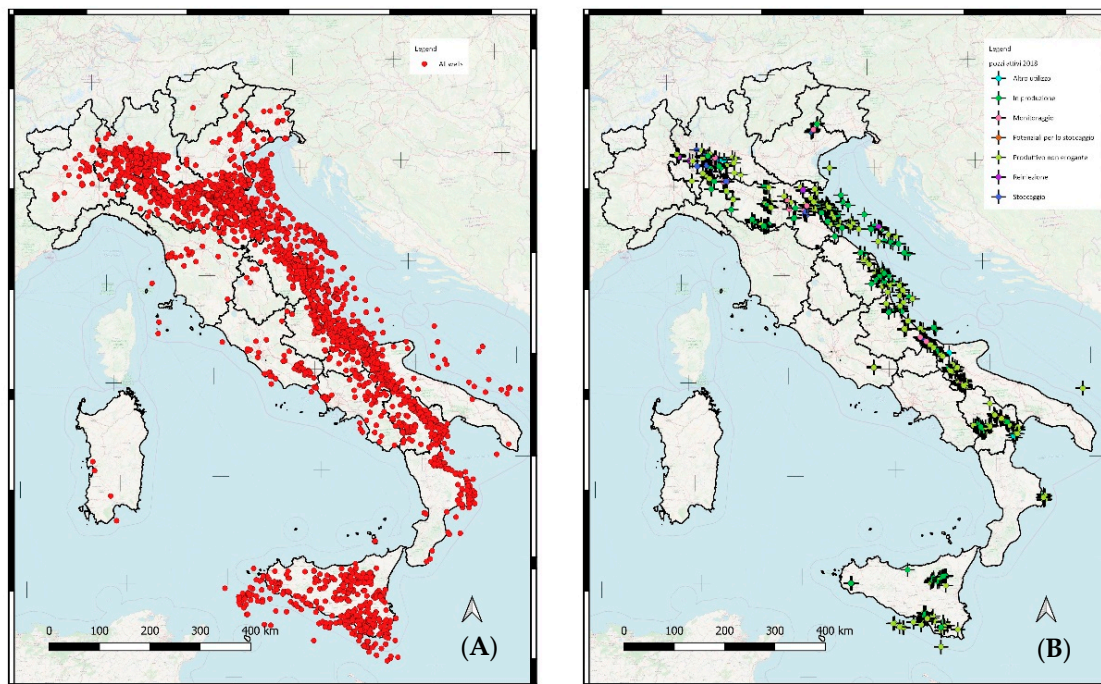


Figure 2. Oil and gas wells in Italy. (A) The complete collection, (B) Only active wells in 2019.

For this contribution, we selected only the onshore fields that had productive (or potentially productive) wells. We then cross-checked the position of these fields with the available information on the temperature at depth. To get the results, and taking into consideration that this was a first-pass national screening, we adopted a simple approach using the temperature maps at depths -1000 , -2000 , and -3000 m below ground level published by [45], also available in the Italian National Geothermal Database [26].

The selection criterion to identify the promising fields was based on the lower temperature for possible applications. The chosen temperature was $70\text{ }^{\circ}\text{C}$, interesting for direct uses, and the temperature maps used in the selection were limited to -2000 and -3000 m. The selected fields are located in areas where the temperature estimated at -3000 m and -2000 m was higher than $70\text{ }^{\circ}\text{C}$ according to the total depth of the existing wells. Moreover, in the Bradano foredeep, the selection also includes fields that overlap areas with a temperature higher than $60\text{ }^{\circ}\text{C}$ at -2000 m. With the approach described above, 42 fields were identified. Among those fields, 23 fields were deeper than 3000 m with a temperature higher than $70\text{ }^{\circ}\text{C}$ while, at a depth between 2000 and 3000 m, 9 fields had a temperature higher than $70\text{ }^{\circ}\text{C}$ and 10 fields had a temperature higher than $60\text{ }^{\circ}\text{C}$ (Figure 3).

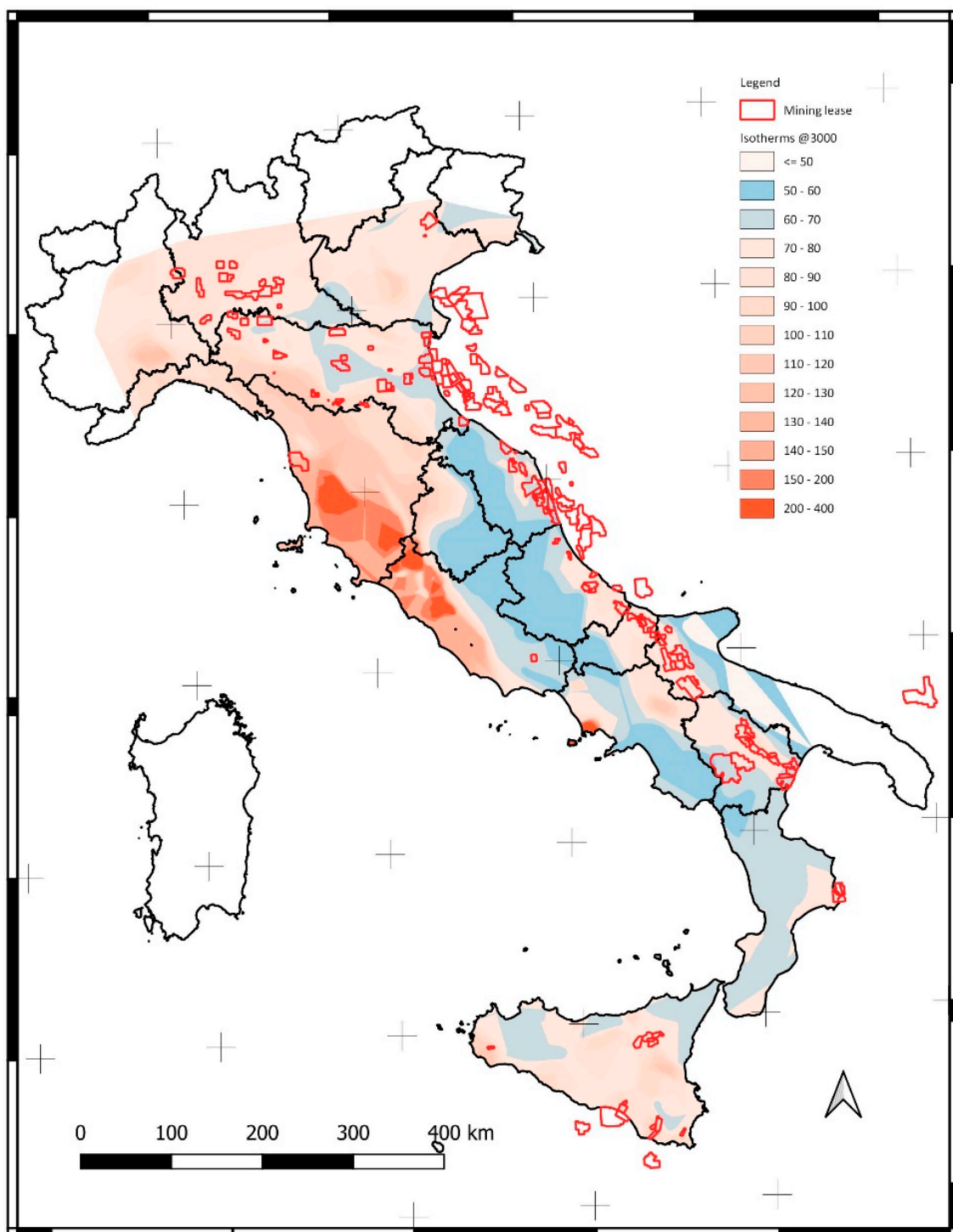


Figure 3. Production concessions with productive or potentially productive wells overlaid on the map with the estimated temperature at −3000 m below ground level (after [45]).

4. Case Studies

A few representative case studies have been selected for which the available data allow a more detailed analysis. These case studies are the Villafortuna-Trecate and Gaggiano fields in Northern Italy (Middle Triassic petroleum system in the thrust belt in Northern Italy) and the Irminio field (Late Triassic–Early Jurassic petroleum system in the Hyblean foreland domain in Sicily).

4.1. Villafortuna-Trecale

Villafortuna-Trecale is a field located in the Piemonte region, between the municipalities of Trecale, Romentino, and Galliate (Figure 4). The larger part of the wells is near Galliate and Romentino. A cascade plant system composed of an Organic Rankine Cycle (ORC) power plant, a district heating plant, and an aquaculture plant is proposed. One system will serve the municipality of Galliate and a second one the Romentino. For the municipalities of Galliate and Romentino, there are, respectively, six wells and three wells available. The produced water, after use, will be sent to existing reinjection wells.

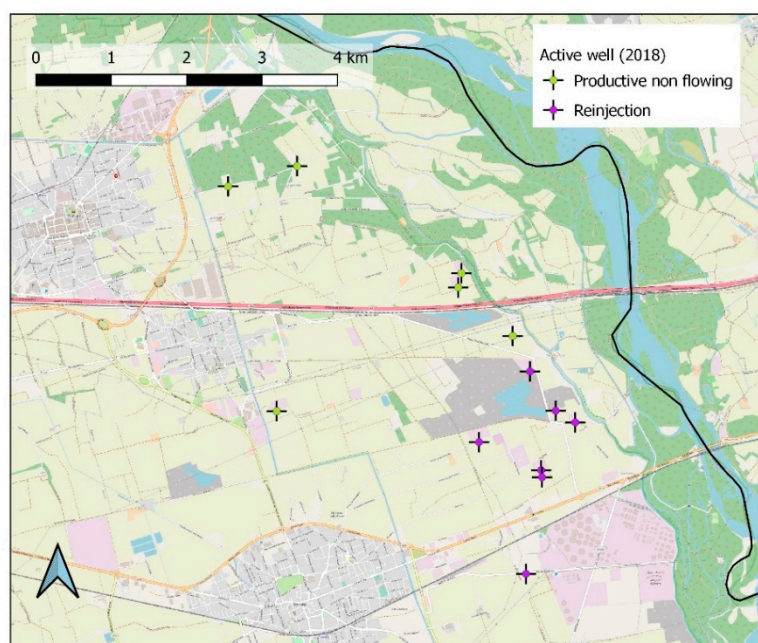


Figure 4. The Villafortuna-Trecale field. Wells and Municipalities.

From literature data and based on a previous analysis of productive well potential [14], the single well can produce a flow rate of 100 kg/s of hot water having a wellhead brine temperature of 130 °C.

The geothermal fluid is supplied first to the ORC plant. A thermodynamic analysis of the binary plant, the working fluid selection (isobutane), the sizing of the condenser, and the cooling tower is included. To evaluate the number of supplied consumers, a precautionary consumption per capita of 1400 kWh per year was assumed.

From the preheater of the ORC plant, the geothermal fluid at a temperature of 84 °C is fed to the district heating (DH) plant. Assuming a heating request of 2 kW per person, the number of inhabitants served was evaluated. The geothermal brine exits from the heat exchanger of the DH plant at the temperature of 50 °C, suitable for aquaculture applications.

For the aquaculture plant, the selected species is shrimp, which need a constant water temperature of 35 °C. Indoor ponds constitute the plant. The annual heat requirement supplied by the geothermal energy includes the heat loss from convection, radiation, and evaporation. The evaluation assumes the following mean values for air properties: air temperature of 20 °C, relative humidity of 30%, and saturation pressure of 0.007 bar.

Tables 2 and 3 illustrate the basic data of plants and economic pre-feasibility.

The results indicate that the proposed power plants, whose size guarantees a surplus of energy to be sold, can supply the yearly electrical demand of Galliate and Romentino municipalities. The cost of the power plants was obtained considering a mean value of 2000 €/kW. An energy price of 0.06 €/kWh and a working time of 7500 h were used to evaluate the annual revenues. 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.

Table 2. Galliate cascade plant system.

	Power Plant	DH Plant	Aquaculture Plant
Inhabitants/Pond area	15,700		4500 m ²
Power (MW)	6	22.5	-
Energy produced (MWh)	45,000		-
Supplied consumers	32,143	11,268	-
Plant cost (M€)	12	40.5	0.697
Revenues per year (M€)	1.7	5.25	0.14
Payback time (year)	4.5	7.7	4.9

Table 3. Romentino power plant.

	Power Plant	DH Plant	Aquaculture Plant
Inhabitants/Pond area	5635		2800 m ²
Power (MW)	3	11.2	-
Energy produced (MWh)	22,500		-
Supplied consumers	16,071	5635	-
Plant cost (M€)	6.6	21	0.456
Revenues per year (M€)	1.35	2.7	0.088
Payback time (year)	5	7.75	5.2

The DH plants may guarantee the cover of the thermal need of 71% of inhabitants of Galliate and 100% of inhabitants of Romentino. To estimate the DH plant cost, a value of 1800 €/kW was used. Considering 3110 working hours per year and a price of thermal energy equal to 0.075 €/kWh, the investment cost would be recovered in about eight years for both of the municipalities.

For the economic evaluation of the aquaculture plants, two values were used for the installation cost, 155 €/m² for the plant of Galliate and 163 €/m² for the plant of Romentino. Considering a price of 7 €/kg for the shrimp and a shrimp production of 4.5 kg/m², the payback period would be about five years for both of the plants.

4.2. Gaggiano

The oil field of Gaggiano is located in the southwestern portion of the Province of Milan and belongs to Middle Triassic petroleum system in the thrust belt in Northern Italy. The selected wells are located near the municipalities of Tainate and Noviglio (Figure 5). The production performance, based on the analogy with the Trecate field, is more conservative with a flow rate of 50 m³/h, and the wellhead temperature of the water is estimated to be 125 °C. Considering the availability of two production wells and one injection well, and the agricultural vocation of the territory, the proposed cascade scheme is composed of a DH plant, a greenhouse, and an aquaculture plant.

From the two wells, it 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 DH plant. 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 to supply the thermal request of an aquaculture system.

Assuming a heating request of 2 kW per person, the plant may guarantee the cover of the thermal need of 40% of inhabitants of Gaggiano. Using the same hypotheses of the Trecate case study for the plant cost, energy price, and the total number of working hours, the recovery time of investment cost is 7.4 years.



Figure 5. The Gaggiano field. Wells and Municipalities.

For the 6000 m² of greenhouses in Gaggiano, the total installation cost is 0.33 M€. Considering as reference cultivation tomatoes, the selling price was assumed equal to 1.0 €/kg. The annual revenue 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 5.1 years. Table 4 illustrates the basic data of plants and economic pre-feasibility.

Table 4. Gaggiano power plant.

	DH Plant	Greenhouse Plant	Aquaculture Plant
Inhabitants/Pond area	4584	6000 m ²	3200 m ²
Power (MW)	3.92	-	-
Supplied consumers	1960	-	-
Plant cost (M€)	7	0.33	0.515
Revenues per year (M€)	0.95	0.09	0.10
Payback time (year)	7.4	3.7	5.1

4.3. Irminio

The Irminio oil field (Figure 6) is located near the Irminio River between the municipalities of Ragusa and Scicli. The Irminio field belongs to the Late Triassic–Early Jurassic petroleum system in the Hyblean foreland domain in Sicily. There are currently four production wells and an oil centre, where oil is separated from natural gas and water and stored before marketing.

An evaluation of possible use in a greener way of the wells was studied. As a result, the oil company installed a cogeneration unit (CHP) with thermal power of 570 kW and electrical production of 360 kW. The proposed solution was to design a roadmap for the conversion of the plant into a green plant, based on the use of produced heat both from wells and CHPs, 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 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 was designed based on the population in Scicli (262,000 people) and assumed to have an organic waste production of 130 kg per capita. The residence time chosen was 30 days for

the digester and 60 days for the storage tank to obtain good digestion of the biomass. The daily production is 4038 m³ 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 CO₂ 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 CO₂ from power plants into clean-burning biodiesel. Practically, all the CO₂ produced by the cogenerator will be introduced in the indoor pond to feed the algae. In this way, it is possible to feed 1800 m² of ponds for algae cultivation.

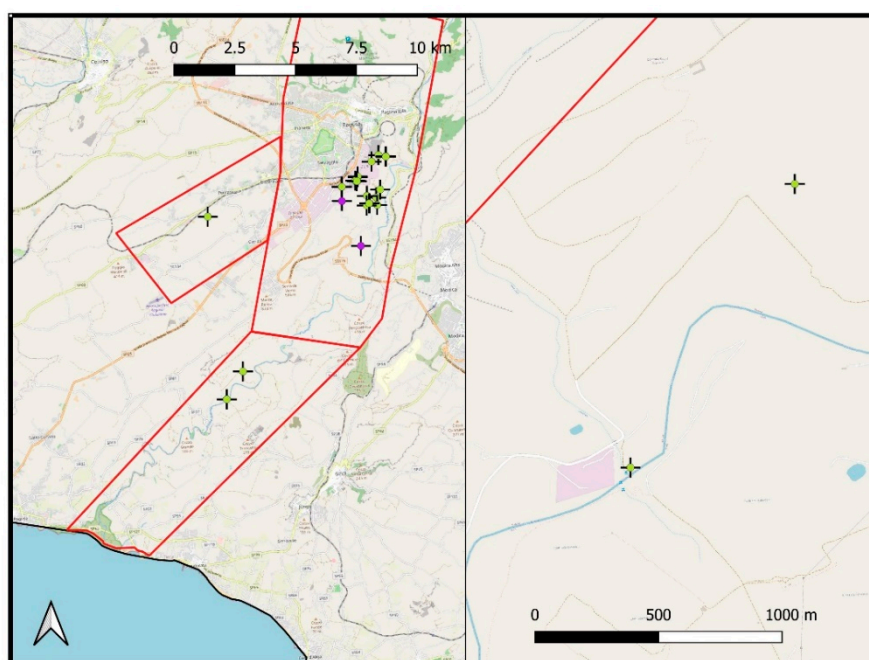


Figure 6. The Irminio field. Wells and Municipalities.

The biogas power plant (Table 5) has a total installation cost of 2.05 M€. Considering the price of electricity equal to 0.06 €/kWh, the annual revenue from electricity is 151,200 €. Taking into account that almost 1000 m³ of biogas per day are consumed to supply the CHP, the remaining 1.1 Mm³ 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 5. Irminio Biogas plant.

Installation cost	2.05 M€
Installed electrical power	360 kW
Installed thermal power	568 kW
Revenue from electricity	151.200 €/y
Gas produced	1,108,761 m ³
Revenue from gas	243,927 €
Annual revenue	395,127 €
Payback time	5.2 years

In Gela, on the refinery site is going to build a plant to distillate algae and produce biodiesel. This opportunity can be assumed to reduce the investment cost to build only the cultivation part to 170 €/m². The total installation cost (Table 6) concerning the 1800 m² of indoor ponds is 306,000 €. The annually produced biodiesel is 155,000 L and, considering a price of biodiesel equal to 0.452 €/L, the annual income is 70,000 €. A simple payback period of 4.37 years is found. Of course, the cost for transporting algae must be taken into account for a more detailed analysis.

Table 6. Irminio Biodiesel plant.

Area of the indoor pond	1800 m ²
Installation plant cost	306,000 €
Biodiesel produced	155,000 L/y
Annual revenue from biodiesel	70,060 €
Payback time	4.3 years

5. Discussion and Conclusions

The adopted selection method identified 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; and 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 may be slightly different where the actual temperature measurements are taken into consideration. One of the main issues in developing a systematic and detailed analysis was the lack of data, which are often covered by industrial secrets.

Three case studies were investigated in detail to identify a second life for the hydrocarbon wells: Villafortuna-Treccate, Gaggiano, and Irminio having in total 18 wells, 13 of which were production wells and the remaining 5 of which were injection wells. Below are listed the achievable results of the proposed reuse solutions:

- the generation of 9 MW of electrical power.
- heating supply for 18,862 people thanks to DH.
- heating supply of 10,500 m² of enclosed ponds.
- heating supply for 6000 m² of greenhouses.
- the disposal of 47,160 tons of organic waste to produce 4037.7 m³/day of biogas.
- the cultivation of algae for the production of 150,000 L/year biodiesel in 1800 m² of indoor ponds.

These results confirm the relevant benefits resulting from the repurposing of existing hydrocarbon wells for geothermal applications. It is necessary to emphasize that all these results are achieved without any emission of CO₂ into the atmosphere. The same results also highlight the advantages for the local communities to produce a renewable energy source from the existing infrastructures, and the possibility for the companies to reduce abandonment costs. This last point can be a driving force to make available the basic data required to carry out a more detailed analysis of the Italian countryside.

Indeed, considering that in Italy 898 onshore wells with a productive or potentially productive operational status are present, a national project to assess the potential repurposing of oil and gas wells may be a great opportunity for the energy transition to renewables and the recovery of waste heat.

Conflicts of Interest: The authors declare no conflict of interest.

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