

Geothermal Energy Use, Country Update for Italy (2015-2019)

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ABSTRACT

This paper presents an overview on the development of geothermal energy applications in Italy during the five-year period 2015-2019. In Italy, the geothermal resources are used for both electricity generation and direct uses.

Power plants are located in Tuscany, in the two “historical” areas of Larderello-Travale (in operation since 1904) and Mount Amiata. Direct uses are widespread over the whole Italian territory. To date, Enel Green Power is the only geo-electricity producer in Italy. In the year 2018, with an installed capacity of 915.5 MWe (807 MWe efficient capacity), 37 generating units and over 500 wells managed, the gross electricity generation reached about 6.1 billion kWh, (the record of electricity produced from geothermal resource in Italy was achieved in 2016 with about 6.3 billion kWh);

The paper deals with geo-electricity production, drilling activities and investments. Current status and future developments are illustrated with a particular focus on the first new geothermal lease from 1999 called “Milia”, directly emitted by Tuscany Region and the only geothermal lease that expires after 2024 (end 2044). The preliminary drilling activity for the construction of the new 20 MW Monterotondo 2 geothermal power plant (located within “Milia” lease) is underway. The surface exploration conducted in the four research permits was completed in 2018. The results of these investigations carried out made it possible to request the exploitation license for two of them (Murci and Boccheggiano).

1. INTRODUCTION

Geothermal resources are abundant in Italy, ranging from resources for shallow applications (mostly heat pump technology), through to medium (>90°C) to high (>150°C) temperature systems at depths accessible only by wells (usually within 3-4 km). High temperature systems tend to be in tectonically active regions either in volcanic and intrusive or fault-controlled systems (Santilano et al., 2015).

Electricity from geothermal resources nowadays is produced in the Tuscany region, central Italy by Enel Green Power. Many direct applications of geothermal heat are also located in Tuscany, however thermal uses are widespread in the national territory, with district heating systems (DHs) mostly localised in the north and other direct uses and ground source heat pumps (GSHPs) distributing on a much larger territory (Bargiacchi et al, 2020).

This paper deals with geo-electricity production, describing current status, the development during the five-years period 2015-2019 and future perspectives with a particular focus on new power plants and drilling activities.

2. THE ELECTRICITY MARKET IN ITALY AND ENEL GREEN POWER

In the year 2018 the electricity needs in Italy reached 321.4 billion kWh, with a domestic contribution of about 86,3%, while a relevant 13.7% was imported (Terna, 2018). The estimated electricity generation capacity and production data in Italy as of 2018 are summarized in Table 1. As regards the 279.8 TWh of net domestic electricity generation, 66.5% comes from thermal, 17.4% from hydro and 16.1% from geothermal, wind and solar (Figure 1). Although the contribution of geothermal electricity generation is only 2.1% of the whole Italian generation, it covers over 30% of the electricity needs in Tuscany, giving a substantial contribution to the green energy generation.

In 2018 the average market price of electricity was 6.191 Eurocent/kWh (GSE, 2019).

In 2018 the value of the GRIN tariff (Ex green certificates) for the plants that have access to this type of incentive was 9.9 Eurocent/kWh in addition to the average market price of electricity. To this value the specific reduction coefficients foreseen for the type of technology and the type of intervention carried out must be applied (GSE, 2018). The 2016 FER Decree defined the new “Base Incentive Fee” for geothermal plants reduced by a percentage due to the auction reduction: 13.4 Eurocent/kWh (under 1 MWe installed Capacity), 9.8 Eurocent/kWh (for plants between 1 MWe and 5 MWe) and 8.4 Eurocent/kWh (over 5 MWe installed Capacity). All these tariffs are already inclusive of the average market price of electricity (Ministerial Decree D.M. 23/06/2016).

All recent official documents forecasting energy production from RES in Italy envisage a small growth for geothermal energy applications. The Italian Energy Strategy released in 2017 (MISE, 2017) predicts a rather limited increase of production for electricity, and declares the wish to establish a support scheme for geothermal innovative technologies demonstrating electrical power production with zero emissions. While a support scheme for zero emission or other innovative technologies has not been established yet, on January 2019 geothermal power plants were excluded from the possibility to participate in the bids for incentive schemes offered to RES power plants.

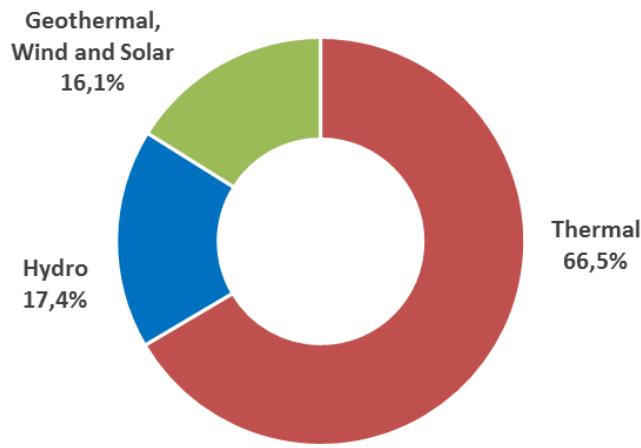


Figure 1: Electric domestic net generation in Italy (2018).

3. GEOTHERMAL POWER GENERATION: CURRENT STATUS AND DEVELOPMENT

The historical trend of electricity generation from geothermal resources in Italy is given in Figure 2, where two different increase phases are shown: the first one in the period from 1930s to the mid 1970s, related to the development of the shallow carbonate reservoir, with well depths up to about 1000 m. The second one from the beginning of the 1980s up to now, when the fluid production has been increased thanks to the positive results of the deep drilling activity and to the artificial recharge of the depleted shallow reservoirs by means of the reinjection of water and condensed steam.

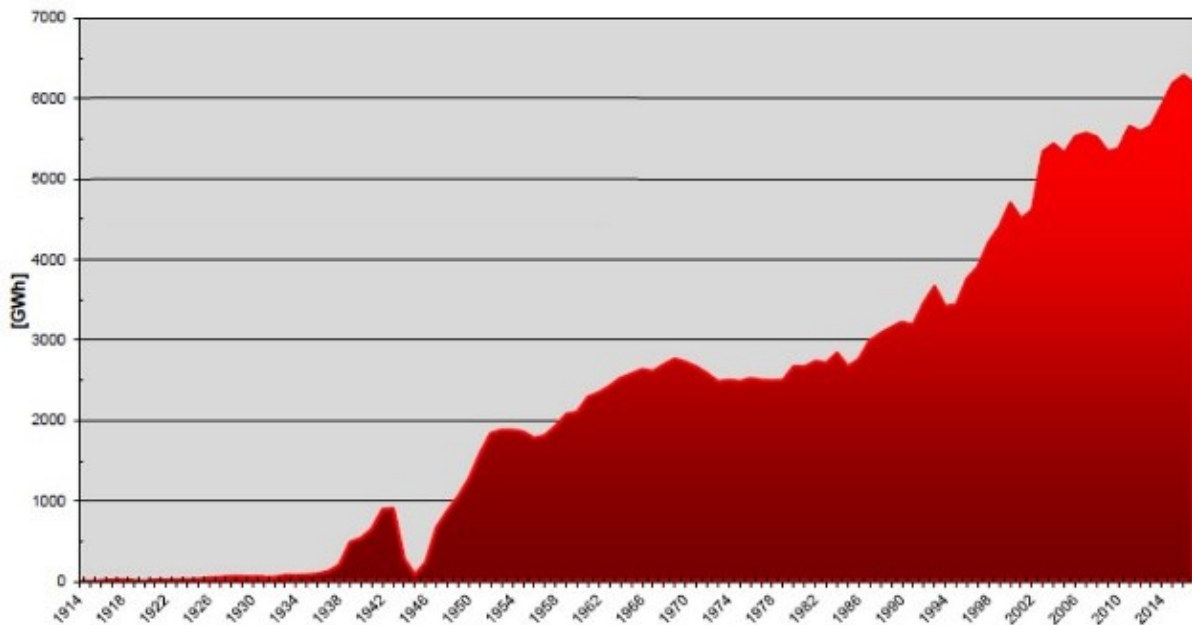


Figure 2: Historical trend of electricity generation from geothermal resources in Italy.

In 2016 EGP experience in geothermal fields management allowed the gross electricity generation to reach about 6.3 billion kWh, which represented the new record of electricity produced from geothermal resource in Italy within nearly a century of operations. During the year 2018, with an installed capacity of 915.5 MW_e, the electricity gross generation was 6105 GWh.

The complete list of the power plants in operation is given in Table 2; taking into account the real operating conditions of the plants in the different areas (pressure, temperature, non- condensable gas content in the steam), the total running capacity (Efficient Capacity) is 807 MW_e.

At present, all 34 of the country’s geothermal power plants are managed by Enel Green Power (EGP), the Enel Group company that develops and manages energy generation from renewable sources at a global level, present in all the continents. EGP is a major global operator in the field of energy generation from renewable sources, with an annual production of 82 TWh, mainly from water, sun, wind and geothermal, avoiding million tons of CO₂ emissions per year.

3.1 Plant for Hg and H₂S abatement (AMIS)

Enel developed and patented a proprietary technology, named “AMIS” (Abbattimento Mercurio e Idrogeno Solforato - mercury and hydrogen sulfide abatement). The AMIS system allows the removal of substances such as mercury and hydrogen sulfide present in the non-condensable gases of geothermal fluid. The process involves a stage of catalytic oxidation, by which the H₂S is selectively converted to SO₂. Thereafter, the SO₂ produced is absorbed in the water of the cooling circuit, through a packed column. Also, the mercury, which is present in the geothermal fluid can be removed by adsorption on fixed beds of sorbents with specific yields of over 95% (Sabatelli et al., 2009).

As 2018, 34 AMIS groups are in operation, providing each power plant with this technology. In 2018, the averaged availability of AMIS plants (hours of operation vs hours of operation of the associated power plant) exceeded 90%.

4. GEOTHERMAL FIELDS UPDATE

All of the Italian geothermal fields in exploitation for electricity generation are located in Tuscany (Figure 3) and managed by EGP: Larderello, Travale-Radicondoli, Bagnore and Piancastagnaio (the two latter being located in the Mount Amiata area).

All of the geothermal power plants are remotely controlled and operated from a Remote Control Station located in Larderello, where 12 people work in round the clock shifts (24/7), thus ensuring a continuous overseeing. In this way, every plant operating parameter can be monitored and analyzed and it is also possible to shut down and restart any unit from the Remote Station. This solution has allowed a better plant operation, at the same time dramatically reducing operating costs.

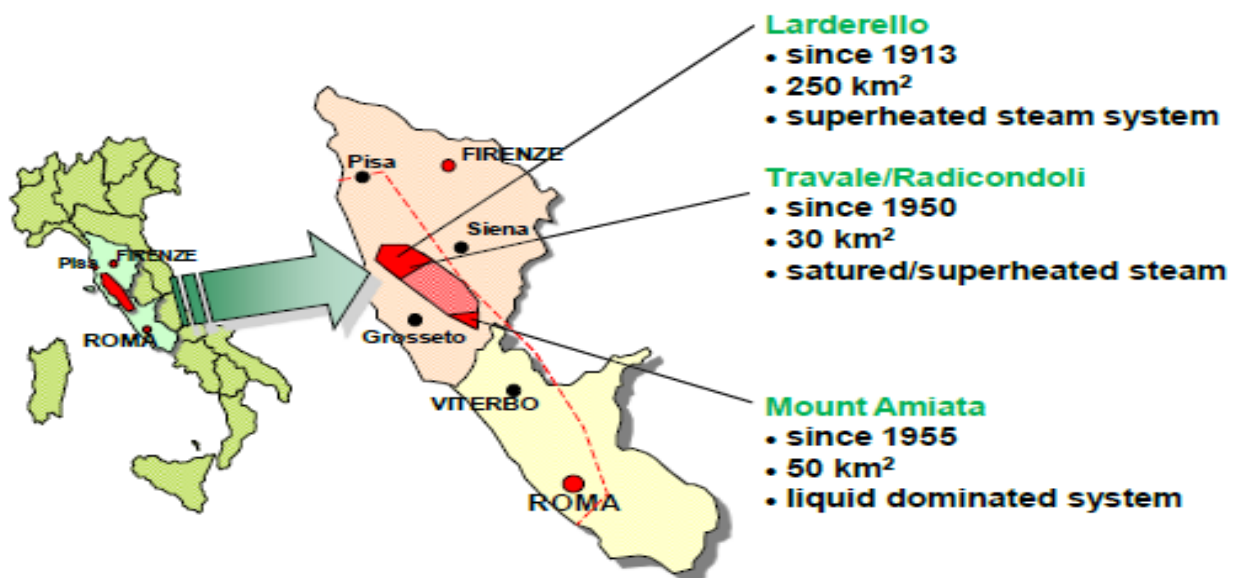


Figure 3: Location of the geothermal fields in Italy.

4.1 Enel Green Power activities in Tuscany

The activities carried out by EGP over the last five years have been concentrated mainly in Larderello and Travale-Radicondoli areas and were targeted at fields management optimization to reduce and contrast the natural decline. Serious acceptability problems from local communities have hindered further developments in the Mt. Amiata area, where the high potential deep reservoir could be further exploited.

4.1.1 Larderello

The explored area is about 250 km², where 200 wells produce superheated steam at pressure between 2 and 15 bars and temperature ranging from 150°C to 270°C. The non-condensable gas content ranges from 1 to 10% by weight. The installed capacity is 594.5 MW_e as of December 2018, with 22 units in operation. The area of Larderello has been exploited since the beginning of the 1900s and resource sustainability is ensured through two main strategies for the management of the reservoir: reinjection and deep drilling. Since the late 1970s, the reinjection of the steam condensate back into the shallow carbonate reservoir formation has been highly beneficial, especially in the most depleted area (Valle Secolo) and made it possible to increase the reservoir pressure and, accordingly, the steam production (Cappetti et al., 1995). The deep exploration program showed the presence of permeable layers within the Metamorphic Basement, up to 3,000 – 4,000 m depth, with reservoir pressure and temperature increasing with depth up to 7 MPa and 350°C, respectively (Barelli et al., 1995, 2000; Bertini et al., 1995; Cameli et al., 2000; Bertani et al., 2005).

In 2018 EGP started the construction of Monterotondo-2 geothermal power plant for additional 20 MW_e gross, on a new lease located SE of the traditional area, close to Lago Boracifero. The preliminary drilling activity is underway.

4.1.2 Travale-Radicondoli

The explored area covers approximately 50 km²; about 40 wells produce superheated steam at pressure ranging from 7 to 18 bars and temperature of 190-250°C. The non-condensable gas content is in the range of 5 – 6.5% by weight. The installed capacity is 200 MW_e with 8 units in operation. The deep exploration, performed in previous years, showed also in this area the presence of

permeable layers within the Metamorphic Basement, which resulted at the same depths and with the same reservoir temperature and pressure as in the Larderello area. Moreover, some of the deep wells (at depths of about 4000 m) showed the presence of productive layers also in the Granite underlying the Metamorphic Basement. It must be pointed out that the deep drilling activity proved that the two old and shallow fields of Larderello and Travale-Radicondoli represent the “outcropping” of a unique, wide and deep (3000-4000 m) geothermal system, with an extension of about 400 km². At a depth of about 3000 m, the same temperature and reservoir pressure was found (300-350°C and 6-7 MPa) both inside the field and in the marginal areas (Bertani et al., 2005).

The drilling activities have continued even in the last three years with 4 new production wells that have allowed to find new steam and reduce the natural decline of the field. To reduce the mining risk and to identify the main potential drilling targets, make-up wells are located based on a joint accurate interpretation of the well data and seismic 3D surveys.

The intensive exploitation of the Travale-Radicondoli geothermal field caused a change in the thermodynamic properties of the fluid; the lowering of the pressure induced by the extraction of fluid determined an increasing overheating by heat mining process. Therefore, there is an ongoing testing for reinjection into the deep reservoir to investigate the possibility to reduce the field natural decline through the evaporation of water injected.

4.1.3 Mount Amiata

Two geothermal fields are located in this area: Bagnore and Piancastagnaio. They were discovered between the late 1950s and the early 1960s, with wells producing steam from the shallow carbonate reservoir. In the late 1970s, a deep exploration program was begun and the results were very successful in both of these fields, revealing the presence of fractured layers at depths ranging from 2500 to 4000 m inside the Metamorphic Basement underlying the shallow carbonate reservoir. This deep reservoir is liquid-dominated, with a pressure of around 200 bars and a temperature of 300-350°C at 3000 m depth (Bertini et al., 1995). The produced fluid is a two-phase mixture that is separated at wellhead at 20 bars; the non-condensable gas content in the steam ranges from 5 to 8% by weight.

As of December 2018, the total installed capacity is 121 MW_e, with 6 power plant (7 units on line).

4.1.4 New development leases

In 2018, following a surface exploration started some 5 years before, EGP was granted two new development leases, one in Larderello and one in Mount Amiata: Boccheggiano and Roccalbegna (Figure 4).

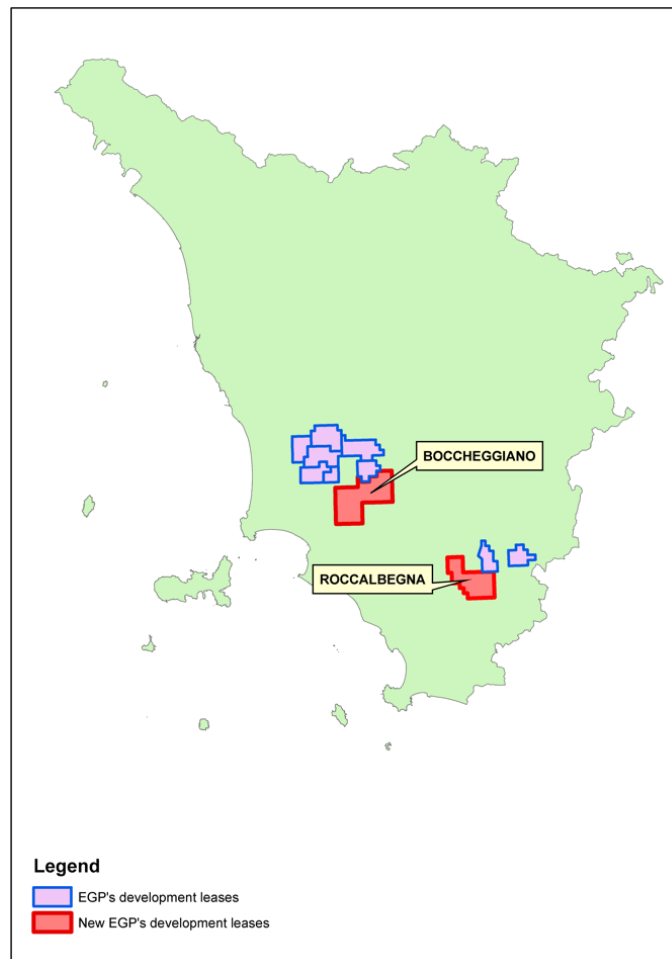


Figure 4: Location of the actual development leases of EGP (new leases in red).

The necessary EIA documentation for Roccalbegna is now submitted to the local authorities in order to start activities for future well drillings and power plants development. The planned additional installed capacity for this area is 20 MWe.

The necessary EIA documentation for Boccheggiano regarding the drilling of two deep wells is in progress.

4.1.5 Personnel and development

The number of professional personnel allocated to geothermal activities by EGP and the overall investments are shown in Table 7 and Table 8.

4.1.6 Drilling

In the period January 2015 – August 2019 a total of 28 geothermal wells were drilled in Italy, for a total drilled depth of 65,2 km. Fourteen are make-up wells drilled in Larderello (10) and Travale-Radicondoli (4) fields and they are relevant to the maintenance program to contrast natural decline of geothermal production. Two new wells were dedicated to the reinjection/injection program. In the same period, also sixteen existing wells were workovered to recover their productivity.

4.1.7 DESCRAMBLE project

Between 2015 and 2018 EGP coordinated and carried out the DESCRAMBLE project, an EU founded project under the H2020 framework aimed at drilling and testing new equipment in extremely high temperature and pressure conditions in continental-crust. Drilling was conducted in the Lago area, deepening an existing dry well: Venelle_2. The target was to reach the so called K-horizon in Larderello, where supercritical conditions ($T > 450^{\circ}\text{C}$ and $P > 450$ bar) were hypothesized. Before drilling new geophysical surveys (MT, VSP) and numerical modelling were conducted together with development of new drilling and measuring tools capable to resist such harsh predicted conditions. Final results and details on this project can be found in Baccarin et al. (2019).

5. CONCLUSIONS

This paper presents an overview on the development of the Enel Green Power activities carried out in the five-years period 2015-2019 in Italy. Over the last five years thanks to the public incentives for geothermal production it has been possible to get a development of the geothermal source. The significant incentive reduction penalized investments in new exploration and in fields characterized by a lower productivity per well.

The total installed capacity as of December 2018 was 915,5 MW and the gross electricity generation picked up to the value of 6,105 GWh/y, which represents about 30% of the electricity needs of Tuscany, the region where all geothermal fields in operation are located.

During 2015 the AMIS plant (abatement of mercury and hydrogen sulfide, designed by Enel) has been extended to all power plants in operation.

Table 1: Present and planned production of electricity.

| | Geothermal | | Fossil Fuels | | Hydro | | Nuclear | | Other Renewables (Wind & Solar) | | Total | |
|---|-----------------|--------------------------|-----------------|--------------------------|-----------------|--------------------------|-----------------|--------------------------|------------------------------------|--------------------------|-----------------|--------------------------|
| | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr |
| In operation in December 2018 | 915,5 | 6.105 | 65.031 | 192.730 | 24.669 | 50.503 | | | 30.372* | 40.370 | 120.987 | 289.708 |
| Under construction in December 2018 | 20 | | | | | | | | | | | |
| Funds committed, but not yet under construction in December 2019 | | | | | | | | | | | | |
| Estimated total projected use by 2020 | | | | | | | | | | | | |

* This value is the Efficient Capacity

Table 2: Utilization of geothermal energy for electric power generation as of 31 December 2018.

¹⁾ N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

²⁾ 1F = Single Flash
2F = Double Flash
3F = Triple Flash
D = Dry Steam
B = Binary (Rankine Cycle)
H = Hybrid (explain)
O = Other (please specify)

| Locality | Power Plant Name | Year Commissioned | No. of Units | Status ¹⁾ | Type of Unit ²⁾ | Total Installed Capacity Mwe* | Total Running Capacity Mwe* | Annual Gross Energy Produced 2018 GWh/yr | Total under Constr. or Planned MWe |
|----------------------------|-------------------------|-------------------|--------------|----------------------|----------------------------|-------------------------------|-----------------------------|--|------------------------------------|
| Larderello | Valle Secolo | 1991 | 2 | | D | 120 | 110,6 | 929,1 | |
| | Farinello | 1995 | 1 | | D | 60 | 52,4 | 488,6 | |
| | Nuova Larderello | 2005 | 1 | | D | 20 | 16,6 | 119,1 | |
| | Nuova Gabbro | 2002 | 1 | | D | 20 | 19,1 | 148,3 | |
| | Nuova Castelnuovo | 2000 | 1 | | D | 14,5 | 14,9 | 126,3 | |
| | Nuova Serrazzano | 2002 | 1 | | D | 60 | 47,5 | 320,9 | |
| | Nuova Sasso | 1996 | 1 | | D | 20 | 14,0 | 100,9 | |
| | Sasso 2 | 2009 | 1 | | D | 20 | 16,7 | 135,5 | |
| | Le Prata | 1996 | 1 | | D | 20 | 18,0 | 156,9 | |
| | Nuova Monterotondo | 2002 | 1 | | D | 10 | 8,0 | 52,0 | |
| | Nuova San Martino | 2005 | 1 | | D | 40 | 36,2 | 226,0 | |
| | Nuova Lago | 2002 | 1 | | D | 10 | 10,9 | 88,1 | |
| | Nuova Lagoni Rossi | 2009 | 1 | | D | 20 | 12,7 | 92,7 | |
| | Comia 2 | 1994 | 1 | | D | 20 | 12,0 | 150,7 | |
| | Nuova Molinetto | 2002 | 1 | | D | 20 | 14,5 | 95,1 | |
| | Carboli 1 | 1998 | 1 | | D | 20 | 15,4 | 135,8 | |
| | Carboli 2 | 1997 | 1 | | D | 20 | 15,4 | 122,5 | |
| | Selva | 1997 | 1 | | D | 20 | 18,3 | 68,8 | |
| | Monteverdi 1 | 1997 | 1 | | D | 20 | 17,8 | 110,6 | |
| | Monteverdi 2 | 1997 | 1 | | D | 20 | 15,6 | 117,1 | |
| | Sesta | 2002 | 1 | | D | 20 | 13,9 | 92,8 | |
| Subtotal | | | 22 | | | 594,5 | 500,5 | 3877,8 | 0 |
| Travale-Radicondoli | Nuova Radicondoli | 2002 | 2 | | D | 60 | 58,5 | 358,2 | |
| | Pianacce | 1987 | 1 | | D | 20 | 14,1 | 67,7 | |
| | Rancia | 1986 | 1 | | D | 20 | 19,1 | 143,6 | |
| | Rancia 2 | 1988 | 1 | | D | 20 | 19,1 | 130,2 | |
| | Travale 3 | 2000 | 1 | | D | 20 | 16,5 | 100,1 | |
| | Travale 4 | 2002 | 1 | | D | 40 | 38,9 | 196,5 | |
| | Chiusdino 1 | 2010 | 1 | | D | 20 | 19,4 | 159,9 | |
| | Subtotal | | | 8 | | 200 | 185,6 | 1156,3 | 0 |
| Mt. Amiata | Bagnore 3 | 1998 | 1 | | 1F | 20 | 19,9 | 175,3 | |
| | Gruppo Binario Bagnore3 | 2013 | 1 | | B-ORC | 1 | 1,0 | 6,7 | |
| | Bagnore 4 | 2014 | 2 | | 1F | 40 | 39,6 | 363,5 | |
| | Piancastagnaio 3 | 1990 | 1 | | 1F | 20 | 20,0 | 174,7 | |
| | Piancastagnaio 4 | 1991 | 1 | | 1F | 20 | 20,0 | 171,4 | |
| | Piancastagnaio 5 | 1994 | 1 | | 1F | 20 | 20,0 | 179,2 | |
| Subtotal | | | 7 | | | 120,99 | 120,5 | 1070,9 | 0 |
| Total | | | 37 | | | 915,5 | 806,6 | 6105 | 0 |

* Installed capacity is maximum gross output of the plant; running capacity is the Efficient Capacity

Table 6: Wells drilled for electrical, direct and combined use of geothermal resources from January 1, 2015 to August 31, 2019 (excluding heat pump wells).

¹⁾ Include thermal gradient wells, but not ones less than 100 m deep

| Purpose | Wellhead Temperature | Number of Wells Drilled | | | | Total Depth (km) |
|---------------------------|----------------------|-------------------------|------------|----------|-----------------|------------------|
| | | Electric Power | Direct Use | Combined | Other (specify) | |
| Exploration ¹⁾ | (all) | 1 | | | 4 | 1,8 |
| Production | >150° C | 20 | | | | 59,9 |
| | 150-100° C | | | | | |
| | <100° C | | | | | |
| Injection | (all) | 3 | | | | 3,5 |
| Total | | 24 | | | 4 | 65,2 |

Table 7: Allocation of professional personnel to geothermal activities (Restricted to personnel with University degrees).

- | | |
|----------------------|--|
| (1) Government | (4) Paid Foreign Consultants |
| (2) Public Utilities | (5) Contributed Through Foreign Aid Programs |
| (3) Universities | (6) Private Industry* |

| Year | Professional Person-Years of Effort | | | | | |
|-------|-------------------------------------|-----|-----|-----|-----|-----|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| 2015 | | | | | | 101 |
| 2016 | | | | | | 108 |
| 2017 | | | | | | 99 |
| 2018 | | | | | | 106 |
| Total | | | | | | |

*Perimeter referring to Enel Green Power S.p.a. personnel involved in geothermal activities

Table 8: Total investments in Geothermal in 2010-2018 period (US\$).

| Period | Research & Development Incl. Surface Explor. & Exploration Drilling | Field Development Including Production Drilling & Surface Equipment | Utilization | | Funding Type | |
|-----------|---|---|--------------|--------------|--------------|--------|
| | | | Direct | Electrical | Private | Public |
| | Million US\$ | Million US\$ | Million US\$ | Million US\$ | % | % |
| 2010-2014 | 56 | 420 | | 521 | 100 | |
| 2015-2018 | 47 | 216 | | 257 | 100 | |

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