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Geothermal Energy Use, Country Update for Italy

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ABSTRACT

This paper presents the development of geothermal applications in Italy in the 2017-2021 period for both the power and the heating & cooling sectors. Enel Green Power is the only geo-electricity producer in Italy. At the end of 2021, the installed geo-capacity was 915.8 MWe, supported by 34 power plants and 37 generation units. In 2021, the gross electricity production reached about 5.92 thousand GWh. All the geo-power plants are in Tuscany Region. During the 2017 – 2021 period, no additional generation units have been installed; 13 new wells have been drilled between 2018-2021 for a total depth of 33.8 km approx. Concerning the heating and cooling sector, the most recent data refer to 2020: the total installed capacity is about 1,300 MW_{th}, with the corresponding thermal energy use of about 9,700 TJ/yr (~2700 GWh/y). Compared with 2017 data, the H&C sector has experienced a reduction of about 11% in terms of geo-heat use. The reduction is mainly due to the temporary closure of spa facilities imposed by the COVID-19 pandemic (-15% in terms of heat delivery). On the contrary, the heating of buildings continues to grow at an average pace of 3% per year, thanks to the continuous expansion of GSHPs and DH networks. Therefore, the heating of buildings confirms its leading position among the other sectors of applications (49% of the total energy, 59% of the overall installed capacity). The effects of the pandemic are expected to vanish in the coming year, but the historical data show an unsatisfactory standing trend for geothermal energy in Italy: the main drawbacks and possible boosting actions for a new growth phase of geothermal energy in Italy are presented and discussed for both power and H&C sectors.

1. INTRODUCTION

Italy is one of the main countries for geothermal resources worldwide. Thanks to a favorable geological context, the use of geothermal energy in Italy dates back to prehistoric times and developed intensively during the Roman Ages (3rd B.C. - 5th A.D.). Historical applications included: thermal baths, cooking, heating spa facilities in localities with active manifestations, and the use of hydrothermal minerals. All these uses declined notably from the 6th to the 12th century A.D., but they started growing again from the 13th century onward, making a substantial jump ahead in the 19th and early 20th centuries with the production of boron compounds (Ciardi and Cataldi, 2005).

During the 20th century, geothermal energy continued to expand. Besides the famous experiment by Prince Ginori Conti, Italy is also the country of the first industrial power plant (250 kWe) in the world that entered into operation in September 1913 in Larderello. At the end of World War II, installed capacity started to grow unceasingly for both power and heating&cooling applications (H&C). The evolution of the Italian geothermal development is briefly reviewed in Figs. 1 and 2. Geo-power data have been constantly increasing both in terms of installed capacity and electricity production, reaching a maximum value of about 6.3 TWh/y in 2016 (Conti *et al.*, 2016). The heating and cooling sector has experienced notable growth in the 2000s thanks to a new expansion phase related to space heating applications, namely district heating (DH) and ground-source heat pumps (Bargiacchi *et al.*, 2020). The variation of H&C statistics is also ascribed to the different data collection, processing methodology, and estimations made by the various authors of the Country Updates over the years. Geo-heat statistics have always suffered from a lack of official and robust datasets, especially for low-capacity Ground Source Heat Pump systems (GSHPs), fish farming, and thermal balneology. Due to the absence of official and complete catalogs, data are often the result of an educated guess, based on indirect information (e.g., market information).

Since 2010, the Italian geothermal union (UGI), in collaboration with the main geothermal-related association (e.g., AIRU – District Heating Association and ANIGHP – National Association of Geothermal Heat Pump), has started a systematic survey aimed at creating a database of all Italian direct uses (Conti *et al.* 2015). Additionally, large-capacity thermal application of geothermal energy in Italy is now monitored by the Italian authorities (GSE), improving the statistics on heating applications; nonetheless much work still remains to be undertaken because only a few operators can provide quantitative data and it is important to complete the final H&C statistics with estimations by CU authors (Conti *et al.* 2015, Bargiacchi *et al.*, 2020).

To date, Italy is one of the top 10 countries for electricity generation (Hutter, 2020) and among the first 15 for heating and cooling applications (Lund and Toth, 2020). Despite its continuous development (see Figs. 1 and 2), the contribution of geothermal energy to the overall Italian energy scenario has still notable room for improvement. In 2020 the gross final energy consumption in Italy amounted to 107.6 MTOE (~4,500 PJ or ~1,250 TWh), with a share of Renewable Energy Sources (RES) of 21.96 % (GSE, 2022).

Due to the COVID-19 pandemic, final energy consumption in 2020 was lower than in previous years: for comparison, the same value in 2019 was 120.3 MTOE. However, the RES share is keeping up always around 21% – 22% since 2015.

In 2020, the share of the total electricity consumption covered by geothermal energy has been about 2% (~6 TWh on the total electricity consumption of about 311 TWh). The same share (2%) occurs in the thermal sector thanks to 81 kTOE provided by GSHPs, and 141 kTOE provided by other technologies, DH included (GSE, 2022).

This paper presents the geothermal development during the 2017 – 2021 period for both power and heating & cooling sectors. Section and data regarding electricity production were prepared by Enel Green Power (EGP), i.e., the Enel Group company that develops and manages energy generation from renewable sources at a global level, including all the 34 currently active geothermal power plants in Italy. Data regarding thermal applications are mainly derived from government statistics provided by Italian authorities (e.g., Italian Energy Services Manager (GSE), Ministry of Economic Development, and Ministry of Ecological Transition), together with datasets and information collected by UGI, AIRU, and ANIGHP.

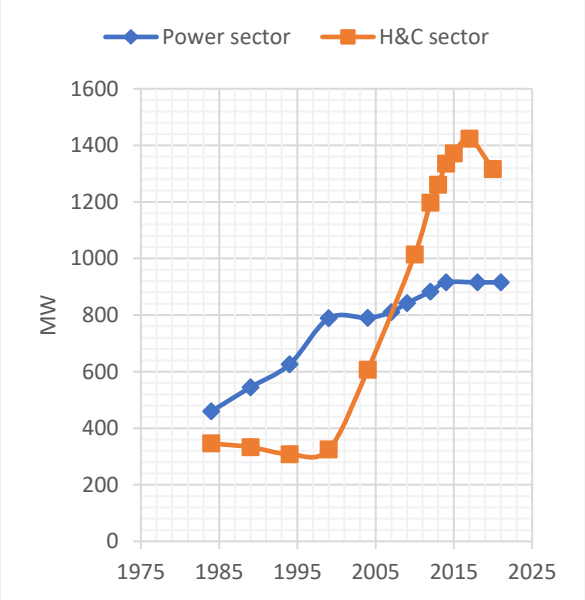


Figure 1: Evolution of geothermal capacity in Italy.

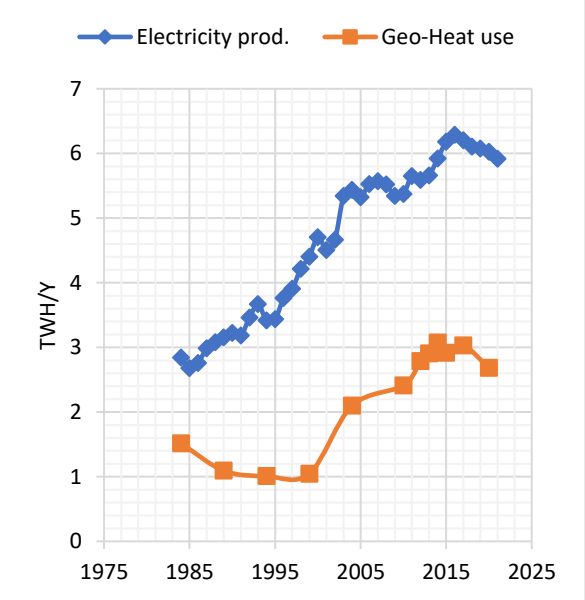


Figure 2: Evolution of geothermal energy use in Italy.

2. GEOTHERMAL ELECTRICITY GENERATION

In the year 2020, the electricity needs in Italy reached 312.73 billion kWh (including the energy needed for auxiliary services), with a reduction of more than 6% compared to 2018 due to the reduction in consumption linked to the COVID-19 pandemic. In 2020 the domestic contribution was about 89.7%, while a relevant 10.3% was imported (Terna, 2021). Of the 280.5 TWh of net domestic electricity generation, 65% comes from thermal and 35% from renewable sources (see Fig. 3). The latter percentage is almost equally distributed between hydro and wind plus solar and geothermal (Terna, 2021).

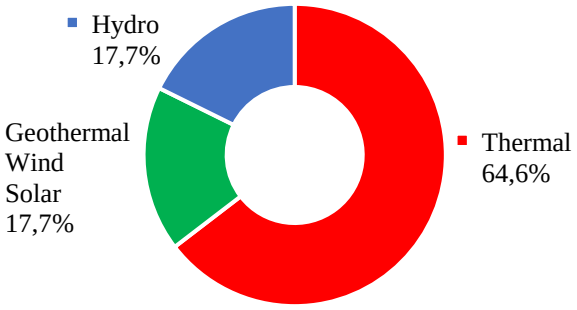


Figure 3: Electric domestic net generation in Italy (Terna, 2021).

The geothermal contribution only corresponds to 2.1% of the whole Italian electricity generation, however, it covers over 30% of the electricity needs in Tuscany, increasing the green energy share of the Region. In 2020 the average market price of electricity was 3.98 Eurocent/kWh showing a significant decrease compared to previous years (GSE, 2021). In 2021 the value of the GRIN tariff (Ex green certificates) for the plants that benefit from this type of incentive was 10.9 Eurocent/kWh in addition to the average market price of electricity. To this value, it must be applied the specific reduction coefficients foreseen for the type of technology and the type of intervention carried out (GSE, 2021). 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 inclusive of the average market price of electricity (D.M. 23/06/2016). A new FER2 Decree is expected before the end of 2022.

2.1 Geothermal power generation: current status and development

An updated historical trend of electricity generation from geothermal resources in Italy is given in Figs. 2 and 4, where two different increase phases are shown: the first one in the period from the 1930s to the mid-1970s, related to the development of shallow carbonatic reservoirs, with well depths up to about 1000 m. The second one from the beginning of the 1980s up to now, when the fluid production was increased thanks to the positive results of the deep drilling activity and the artificial recharge of the shallow reservoirs by means of the reinjection of water and condensed steam (Cei *et al.*, 2020a).

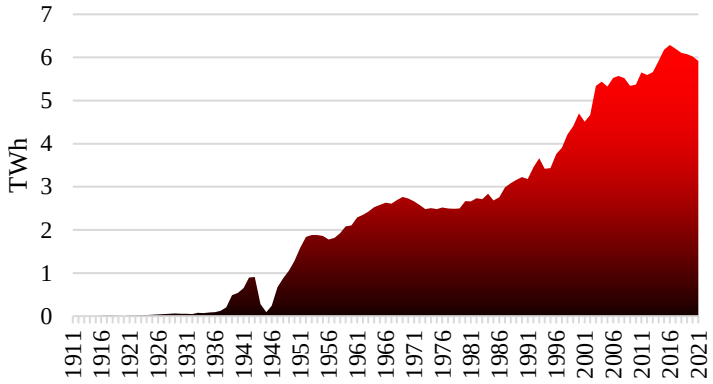


Figure 4: Historical trend of electricity generation from geothermal resources in Italy.

Despite the difficulties caused by the COVID-19 pandemic, EGP set up a new record in 2021 by building 5,120 MW of new renewable capacity with projects around the world, which includes 220 MW of batteries for the first time. In addition, EGP also set up a record in terms of energy from renewable sources produced in the year, with approximately 119 TWh, of which 55.4 TWh from wind and solar, 57 TWh from hydro, and 6 TWh from geothermal, avoiding million tons of CO2 emissions per year. EGP has cumulated an important multi-year experience in the management of geothermal fields that allowed the reaching of a record of electricity produced from the geothermal resource in Italy, with a gross electricity generation of about 6.3 GWh in 2016. During the year 2021, with an installed capacity of 915.8 MWe, the electricity gross generation has picked up to 5,917 GWh. The complete list of the power plants in operation is given in Table A; 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 (Reference Net Capacity) is 773.7 MWe. All 34 geothermal power plants in operation in Italy are equipped with AMIS (Abbattimento Mercurio e Idrogeno Solforato - mercury and hydrogen sulfide abatement) technology, with an averaged availability (hours of operation vs hours of operation of the associated power plant), in 2021, that exceeded 90% in the traditional area (Larderello and Travale-Radicondoli) and about 95% in the Mount Amiata area. AMIS technology removes mercury and hydrogen sulfide present in the non-condensable gases of the geothermal fluid through a stage of catalytic oxidation for H_2S and specific sorbents for mercury (Sabatelli *et al.*, 2009).

2.2 Geothermal fields

The four Italian geothermal fields under cultivation for electricity generation are all located in Tuscany (Fig. 5) and are the following: Larderello, Travale-Radicondoli, Bagnore, and Piancastagnaio (the two latter ones being located in Mount Amiata area). All 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) ensuring continuous monitoring. In the remote-control station, every operating parameter of each plant is monitored and analyzed and every unit could be shut down and restarted. This solution allowed a more efficient and optimized plant operation, reducing dramatically operating costs. The complex networks of steam pipelines, which often include many production wells with different thermodynamic and fluid-dynamic characteristics, are managed thanks to the use of innovative numerical modelling tools. This allows the optimization of production, evaluating in advance the best-operating conditions of the wells in order to manage the geothermal resource at its best performance during workovers or power plant shutdowns (Cei *et al.*, 2020b).

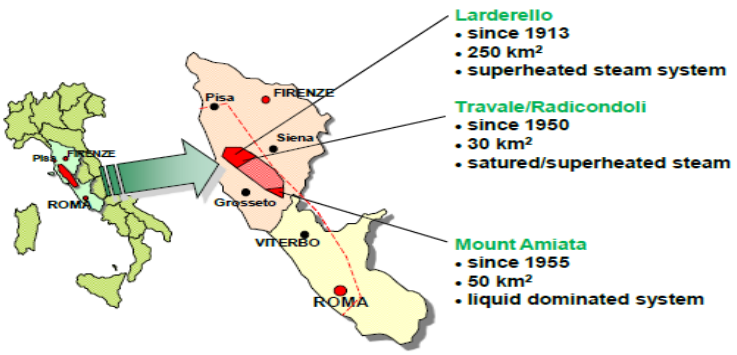


Figure 5: Location of the geothermal fields in Italy.

The activities carried out by EGP over the last three years were concentrated mainly in the Larderello and Travale-Radicondoli areas and targeted at fields management optimization to reduce and contrast the natural decline by drilling new deep production wells. In the Mt. Amiata area, where the high potential deep reservoir could be further cultivated, no new drilling activities were put in place due to the excess of available resource compared to the installed power capacity in the area.

2.2.1. Larderello

In the explored area of Larderello, extending approx. 250 km^2, 200 wells produce superheated steam at a pressure between 2 and 15 bar and temperature ranging from 150°C to 270°C. The non-condensable gas (NCG) content ranges from 1 to 10% by weight. The installed capacity is 594.8 MWe, as of December 2021, with 22 units in operation. The area has been cultivated since the beginning of the 1900s and reservoir sustainability is ensured through two main strategies for its management: reinjection and deep drilling. Since the late 1970s, the condensed steam reinjection 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 and Cei *et al.*, 2020a). The deep exploration program showed the presence of permeable layers within the Metamorphic Basement, down to 3,000 – 4,000 m depth, with increasing reservoir pressure and temperature 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 the period 2018 – 2021 the drilling activities in the Larderello area focused both on reinjection (especially in the central part of the geothermal field, where reservoir pressure is lower) and on new production wells in the peripheral area. In 2018, EGP started the construction of the Monterotondo-2 geothermal power plant for additional 20 MWe gross, on a new lease located SE of the traditional area, close to Lago Boracifero. Unfortunately, the drilling of the first commercial well did not confirm the expectations. Nevertheless, the Monterotondo-2 project was not abandoned, but its power capacity was reduced. The construction of a new 5 MW geothermal power plant is therefore expected by 2028.

2.2.2. Travale-Radicondoli

The explored area of Travale-Radicondoli extends for approx. 50 km^2. In this area, 42 wells produce superheated or saturated steam at a pressure ranging from 8 to 20 bars and a 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, located 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 4,000 m) show 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 shallow fields of Larderello and Travale-Radicondoli represent the "outcropping" of a unique, wider, and deeper (3000-4000 m) geothermal system, with an extension of about 400 km^2. At a depth of about 3000 m, the same temperatures and reservoir pressures were found (300-350°C and 6-7 MPa) both inside the fields and in the marginal areas (Bertani *et al.*, 2005). The drilling activities have continued during the last three years with 5 new production steam wells that reduced the natural decline of the field and with 7 workover activities on existing productive wells to recover their production. The new wells were located based on a joint accurate interpretation of the geophysical data, well data and 3D seismic surveys. No reinjection wells were drilled so far. The intensive cultivation of the Travale-Radicondoli geothermal field caused a change in the thermodynamic properties of the fluid; in particular, the pressure lowering induced by fluid production has increased the superheating status of the fluid. Experimental tests carried out in recent years confirmed the possibility of using the reinjection strategy also in the deep geothermal system of Travale-Radicondoli in order to reduce the natural decline in reservoir pressure. For this purpose, a new important project is planned in the next few years to start the reinjection strategy, but no new production plants are planned until 2028.

2.2.3. Mount Amiata

Bagnore and Piancastagnaio are the two geothermal fields located in this area. 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 deeper exploration program was initiated, with very successful results for both fields, revealing the presence of a fractured Metamorphic Basement, underlying the shallow carbonate reservoir, at depths ranging from 2500 to 4000 m. This deeper 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 the wellhead at a pressure of 20 bar; the non-condensable gas content in the steam ranges from 5 to 8% by weight. At the end of 2021, the total installed capacity was 121 MW_e, with 7 units in operation. In the period 2018 – 2021 the drilling activity was mainly dedicated to the recovery of existing damaged wells, most of them for re-injection purposes. The geothermal area of Mount Amiata is undoubtedly the most promising one for further development. EGP plans to build two new production units for a total of 60 MW by 2028 within the existing leases.

2.3 New development leases

The exploration activity carried out by EGP in previous years on the new research permits makes it possible to identify interesting new areas for the development of new projects for electric power production. In particular, EGP has acquired a new lease (called Roccalbegna), adjacent to the existing concessions in the Monte Amiata area. The construction of at least one new 20 MW production unit is planned in this new lease. Drilling activities will begin in the next 3 - 4 years, once the necessary environmental permits will be acquired.

2.4 Personnel and development

The number of professional personnel allocated to geothermal activities by EGP and the overall investments in 2021 are 695 individuals and 166.6 M€, respectively. The manpower estimate considers EGP personnel only and it does not take into consideration the contribution of ancillary personnel working in local companies to support the geothermal activities of EGP. This contribution is difficult to quantify, but in any case, it is very important for the local economy.

2.5 Drilling

In the period 2018 – 2021, a total of 13 geothermal wells were drilled in Tuscany, for a total drilled depth of 33.8 km. Eight are make-up wells drilled in the Larderello field, six for production, and two for reinjection. Another five production wells were drilled in the Travale-Radicondoli fields to contrast the natural decline of geothermal production. Heat mining activity also includes an important recovery and maintenance activity of the existing wells. A total of sixteen work-over jobs were carried out in the considered period, both on production and reinjection wells, and for plug and abandonment of old geothermal wells no longer exploitable.

GEOTHERMAL ENERGY USE FOR HEATING AND COOLING

While electricity from geothermal resources is produced only in Tuscany, heating and cooling applications are widespread all over the national territory. Among the main applications, we mention agriculture and food processing, industrial process heat, balneotherapy, recreation and tourism, space heating and cooling. H&C geothermal applications include individual ground-source heat pump systems (GSHPs), but also building blocks, DH networks, hot-water wells with direct use of the geothermal fluid, and cascade uses. Cooling applications are not considered in this report due to the lack of an established methodology for its quantification, though their development is expected to become significant in the next years.

Energy data are available only for large facilities, such as district heating systems (DHs), large greenhouses, and industrial applications. For those systems, the data source consists of the values declared by systems owners and analysed by AIRU (2021), UGI, and EGP. On the contrary, the data on small individual systems, thermal balneology, and aquaculture are based on the aggregated national data reported in GSE (2022). Finally, statistics on ground-source heat pumps (GSHPs) are based on the data reported in GSE (2022) and EurObserv'ER (2021).

All the collected data from different sources have been processed by the authors and presented in Tables 1 – 3. Tables and charts were produced using the same methodology presented and applied in previous Country Updates (Conti *et al.*, 2015, Conti *et al.*, 2016, Manzella *et al.*, 2019) to allow a coherent comparison framework for the analysis of the historical evolution.

When it was not possible to obtain the source data, the statistics were performed according to available information, energy engineering considerations, suitable capacity factors (CF), and/or equivalent full load hours of operation (EOHs). For instance, there is no data on the capacity installed in agriculture, aquaculture, balneology, and industrial sectors. Therefore, we used the same CF values of previous country reports and the global average values suggested by Lund and Boyd (2016). For GSHP, reference EOH and seasonal coefficient of performance are based on the values suggested in 2013/114/EU.

For this section, the following definitions apply:

- "Capacity" is the maximum instantaneous geothermal energy deliverable by the system under well-defined and declared operational conditions;
- "Energy" refers to the amount of geothermal energy delivered to the end-user systems (losses included) over the year of reference;
- "Capacity factor" (CF) is the ratio between the actual energy delivered by a system and the maximum theoretical output if operating at full capacity load were indefinitely possible.

3.1 Heating and cooling energy statistics

The reference year for all the statistics concerning the heating and cooling sector is 2020. At the end of the year, the geothermal energy thermal use installed capacity exceeds 1,300 MW_{th}, with the corresponding total energy use of 9,668 TJ/yr (Figs. 6 and 7, Tables 1 – 3). The main sector of utilization is space heating of the buildings, which accounts for 41% and 49% in terms of installed capacity and energy use, respectively. Health, recreation, and tourism is the second sector, representing 30% of both energy use and installed capacity; the sum of agriculture, fish farming, and food processing accounts for 20% of the total geo-heat utilization (1,908 TJ/yr), and about 10% of the overall installed capacity (133 MW_{th}). Heat utilization for industrial processes and minor uses amounts to less than 1% of the total, with a capacity of 18 MW_{th} employing about 107 TJ/yr. The average CF of all the H&C geothermal applications is 0.23 (see Section 3.3). This value is driven by the high equivalent working hours of fish farming (CF equal to 0.49) and agriculture (CF equal to 0.41), while the space heating CF is decreasing year by year, because of the globally increasing outdoor temperature and the increasingly restrictive Italian laws on building insulation.

3.1.1. Ground-source Heat Pumps

Regarding ground-source heat pumps, they account for 43% of the total installed capacity and some 36% in terms of energy. We recall that in this report we have referred to "Capacity" and "Energy" values as the power/energy delivered by the ground source, namely to the evaporator section, as it represents the actual geothermal contribution in heating mode. Other statistics on GSHPs in other reports might be referred to as the condenser output as the focus might also be the contribution of the technology to the heating service for the end-user system. In any case, attention shall be paid when different sources are used for GSHP aggregation (see Conti *et al.*, 2015 and Conti *et al.*, 2016 for further details on statistics processing methodology).

3.1.2. District heating systems

District heating systems represent about 9% of the total geothermal heat utilization (856 TJ/yr) with a total installed capacity of about 164 MW_{th}. The largest number of DH systems are in the Tuscany Region as cascade heat from the conventional geothermal power plants. The fluid used to feed the DH networks is indeed produced by the same deep wells and geothermal system feeding the power plants and is delivered to the heat exchanging sections depending on fluid characteristics. The other main Italian geothermal DH application is in Ferrara, where a 14 MW_{th} -capacity system with 2 production wells at about 2 km depth produces pressurized hot water at about 95 °C. The fluid is then totally reinjected in a third well. Other two systems worth to be mentioned are located in Milano, where two large GSHP units (18 MW_{th} and 15 MW_{th}) are used to deliver heat to two urban districts. Another district heating

system, which uses a geothermal source, is that of Vicenza. The "Vicenza" geothermal well was drilled by the Saipem company in 1983 in the northern part of the city and within the area of Vicenza DH plant. It reaches the production area between 1,500 m and 2,150 m deep from ground level with a wellhead temperature of 68°C at a flow rate of 100 m^3/h. The geothermal resource has been integrated into the DH system since 2013 The geothermal district heating system was realized in Grado (Gorizia) based on a producing well at 1200 m (up to 100 tons/h at 50 °C) and on a re-injection well of about 1000 m deep at one km distance) feeding 6 public buildings with a DH network of more than 3 km started in 2014, but it could not be completed. Now it is not working, and it requires completion and a workover on the production well.

Table 1: Summary of installed geothermal capacity in the H&C sector in Italy at the end of 2020 (values in MW_{th}).

	TOTAL	GSHP	DH
Aquaculture	**78**		
Heating for buildings	**779**	555	161
Agriculture and Food Processing:	**55**	13	
Industrial process heat	**18**	4	3
Health, Recreation & Tourism	**387**		
TOTAL	**1,317**	**572**	**164**

Table 2: Summary of geothermal energy use in 2020 in the H&C sector in Italy (values in TJ/y).

	TOTAL	GSHP	DH
Aquaculture	**1,208**		
Heating for buildings	**4725**	3,404	844
Agriculture and Food Processing:	**700**	75	
Industrial process heat	**107**	25	11
Health, Recreation & Tourism	**2,928**		
TOTAL	**9,668**	**3,504**	**856**

Table 3: Summary of the capacity factor in 2020 in the H&C sector in Italy.

	TOTAL	GSHP	DH
Aquaculture	**0.49**		
Heating for buildings	**0.19**	0.19	0.17
Agriculture and Food Processing:	**0.41**	0.18	
Industrial process heat	**0.19**	0.20	0.10
Health, Recreation & Tourism	**0.24**		
AVERAGE	**0.23**	0.19	0.17

3.3 Discussion on the evolution of the geothermal heating and cooling sector in the 2017-2020 period

Tables 3 – 5 and Figs. 8 and 9 show the evolution of the geothermal heating and cooling sector in the years 2017 – 2020.

- Installed capacity and heat use have both experienced a general reduction, i.e., -8% and – 11%, respectively;
- Heating for buildings is one notable exception to the general reducing trend. The whole sector of application has increased from 739 MW_{th} to 779 MW_{th} (+5%) in terms of installed capacity and from 4,566 TJ/y to 4,725 TH/y in terms of geo-heat used (+3%). During the considered 3-year period, the yearly average increase ratio has been about +1%/yr and +2%/yr for power and energy, respectively.
- The increase in the building sector has been led by the GSHP market (+ 40[1] MW of installed geo-capacity and + 239 TJ/yr of geo-heat use). Additionally, the DH sector has increased its contribution with 12 MW of additional thermal capacity.
- As shown in Fig. 9, in 2020, the GSHP and the DH sectors account for 9% and 36 % of the total geothermal energy in Italy. The same statistics in 2017 were 8% and 29%.
- Aquaculture variation is mainly ascribed to a different methodology and data source compared to the one used in the last CU. An estimation of the actual reduction between 2017 and 2020 is about – 20 % in terms of both installed capacity and energy use.
- Statistics on the agriculture sector are affected by a similar statistical uncertainty due to the different data sources used in this report compared to the previous one. However, a reasonable analysis of the numbers suggests that the sector of

[1] As explained in Section 3.1.1, in this report the GSHP capacity is referred to the ground-coupled section of the HP device (i.e., the evaporator). The same statistic referred to the building section (i.e., the condenser) would be +52.5 MWth.

application has not significantly changed its relevance in the 2017 – 2020 period, with a geo-heat use in the range of 650 – 700 TJ/yr.

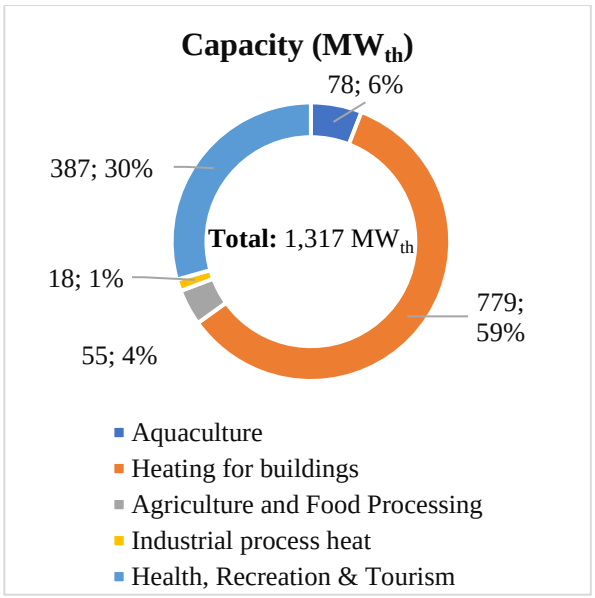


Figure 6: Share of geothermal installed capacity of H&C sector in Italy in 2020.

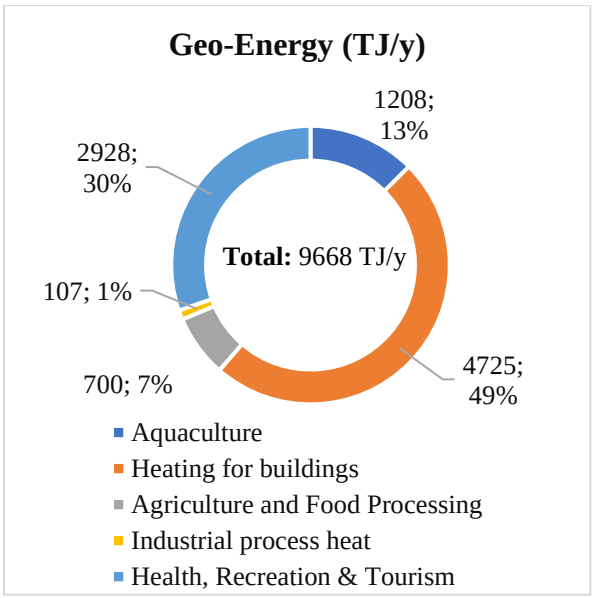


Figure 7: Share of geothermal geo-energy use of H&C sector in Italy in 2020.

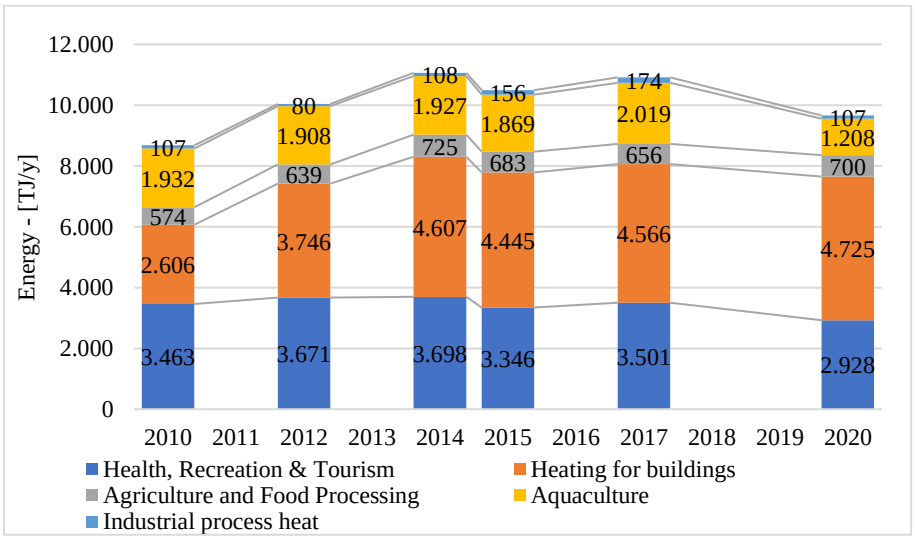


Figure 8: Development of the different sectors of direct uses in Italy (2010-2020).

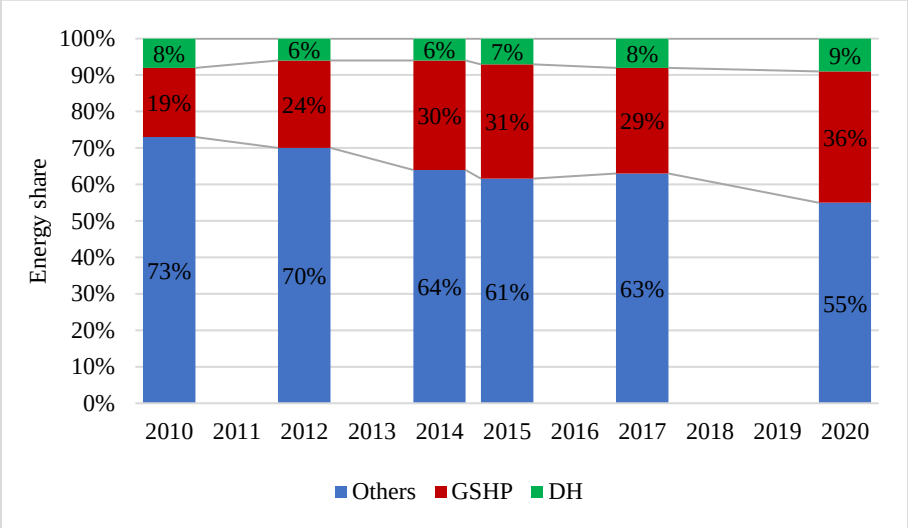


Figure 9: Development of geothermal DHs and GSHPs for space heating&cooling concerning the total geo-heat delivered in Italy (2010-2020).

Table 3: Development of geothermal direct uses in Italy during the period 2017-2020 (values in MW_{th}).

	TOTAL	GSHP	DH
Aquaculture*	**-52 (-40%)**		
Heating for buildings	**+40 (+5%)**	+40 (+8%)	12 (+8%)
Agriculture and Food Processing:	**-25 (-31%)**	-	
Industrial process heat	**- 2 (-10%)**	-	-
Health, Recreation & Tourism	**-69 (-15%)**		
TOTAL	**-109 (-8%)**	+40 (+8%)	+14 (+9%)
* Aquaculture variation is mainly due to a different methodology and data source compared to the one used in the last country update report.			

Table 4: Development of geothermal direct uses in Italy during the period 2017-2020 (values in TJ/y).

	TOTAL	GSHP	DH
Aquaculture*	**--811 (-40%)**		
Heating for buildings	**+159 (+3%)**	+239 (8%)	- 9 (-1%)
Agriculture and Food Processing:	**+44 (+7%)**	-	
Industrial process heat	**- 67 (-39%)**	-	1 (10 %)
Health, Recreation & Tourism	**-573 (-16%)**		
TOTAL	**-1248 (-11%)**	+239 (+7%)	-7 (-1%)
* Aquaculture variation is mainly due to a different methodology and data source compared to the one used in the last country update report.			

Table 5: Development of geothermal direct uses in Italy during the period 2017-2020 (values in TJ/y).

	TOTAL	GSHP	DH
Aquaculture*	-		
Heating for buildings	**-0.01 (-5%)**	-	- 0.02 (-11%)
Agriculture and Food Processing:	**+0.15 (+58%)**	-	
Industrial process heat	**- 0.09 (-32%)**	-	-0.22 (-69 %)
Health, Recreation & Tourism	-		
TOTAL	**-0.01 (-4%)**	-	-0.02 (-11%)

4. LEGISLATIVE FRAMEWORK AND SUPPORT MEASURES

Geothermal energy has been declared to be a strategic energy source for Italy (L. 134, 2012) having the potential to significantly accelerate the energy transition. The combined heat and power production and the great potential that Italy has for H&C, DH, and

electric power generation clarify the great role and perspectives that this energy source will play in the future of the country. There is a great expectation for a significant improvement of the legislative framework and support measures since a few years for the three main sectors of geothermal applications in Italy, particularly after the publication of the recent RePower EU communication. Law 34/2022 of the last end of April 2022, introduced urgent measures to control natural gas and energy costs, develop renewable energy sources, and relaunch industrial and energy policies. There is a clear endorsement for the development of the GSHP supported by both closed (BHE) and open loop heat exchangers. The corresponding national guideline and regulatory framework are due in two months following the publication of Law 34. The Italian Geothermal Platform (https://www.cngeologi.it/2022/06/24/convegno-webinar-gratuito-stati-generali-della-geotermia/) is contributing to the finalization of this process which could start a great development of GSHP for H&C in single houses, as well as in blocks and cities to contribute to the decarbonization, energy saving and reduction of greenhouse gas emissions in urban areas, according to the EU directives and policies.

On the DH side, the legislative framework is suffering because of the delay and lack of due legislative and regulatory instruments which are pending since a few years and prevent the development and deployment of DH systems fed by RES and waste heat locally available. The electric power production sector is stagnant since about two decades and it is waiting for an adequate legislative framework and support measures, following the Decree n.22/2010 on the re-organization of the legislative framework on research and cultivation of geothermal resources. The so-called "FER1 Decree" enacted in 2019 provides incentives to renewable energy plants in order to achieve the European targets by 2030 defined in the Integrated National Plan for Energy and Climate and to promote the effectiveness, efficiency, and sustainability of the sector, both in environmental and economic terms. Sources benefiting from the scheme include onshore wind, solar PV, hydroelectric, and sewage gases. The bad news was that geothermal was not included in this supportive scheme. The FER2 scheme, announced long ago, is now under discussion and it is due quite soon by next Fall. It includes traditional geothermal plants with innovation and innovative new "zero emission" geothermal plants.

UGI and AIRU, with the support of EGEC, settled the Tavolo Tecnico "Geotermia per la Transizione Energetica" (TTG) in February 2022. The agreed document has been signed by 10 operators of the heating sector and 14 of the geothermoelectric sector. UGI and AIRU will facilitate and coordinate the following sessions and activities. The target of this technical table is to underline and highlight the great potential contribution that geothermal energy can give to the energy transition in the country, identifying the barriers that still prevent full development. The TTG is supporting the decision makers in giving value to the extraordinary geothermal potential of the country for a quick, sustainable, secure, and low-impact energy transition. The TTG, in collaboration with the Italian Geothermal Platform, is contributing its expertise and entrepreneurship to policymakers for the improvement of the FER2 that should enable the development of innovative geothermal plants for the next five years.

5. R&D ACTIVITY IN GEOTHERMAL ENERGY TOPICS

Increasing accessibility of deep geothermal resources for low carbon heating and power generation is a fundamental requirement to accelerate the development of decarbonized and indigenous energy supplies in Europe. The achievement of the above-mentioned goal requires R&D activities in different, but complementary, Earth Sciences and Engineering topics. In this context, the advancement in drilling technology plays a key role in geothermal exploration and exploitation. The DeepU Project, founded by the European Union, seeks to achieve the deployment of geothermal anywhere and at providing a stable, uninterrupted, base load energy to meet global CO_2 emission reduction target. The overall aim of DeepU is to create a deep (> 4 km), closed-loop, vitrified, waterproof, non-cracked U-tube heat exchanger by combining laser and cryogenic gas into a single technological drilling solution. The technology envisioned in this project will revolutionize the deep geothermal energy sector, offering a complementary approach and an alternative solution to traditional drilling approaches. The innovative, fast and effective drilling technology is tested at the laboratory scale in different rock types to verify its capacity to liquefy and vitrify the rocks, leaving the borehole ready for heat exchange immediately after drilling. The demonstration at the laboratory scale produces the information required for assessing the technological, environmental, and economic sustainability and defining the potential and commercial attractiveness of the proposed solution.

Besides, lowering emissions from geothermal power generation by capturing them for either reuse or storage is an important aspect. The GECO Project is an innovative EU-funded project which aims to provide clean, safe, and cost-efficient non-carbon and sulfur-emitting geothermal energy across Europe and the World. It builds upon the success of the recently completed CARBFIX project. This past project advanced considerably the ability to clean the exhaust gases emitted by geothermal power plants based on a novel water dissolution method in a dedicated scrubbing tower. By an industrial-scale demonstration, this new method has been demonstrated 1) to offer considerable cost savings compared to other approaches to capture and dispose of acidic carbon and sulfur-bearing gases; 2) to be far more environmentally compared to other available technologies, and 3) to aid in the long-term viability of geothermal systems by enhancing the permeability of fluid injection wells. The goal of the GECO Innovation Action is to adopt this approach, together with emission gas reuse schemes, to become a standard in the geothermal power industry worldwide through its application to three new sites across Europe. Moreover, the detailed monitoring and chemical modeling of this injection have provided novel insights into the reactions that occur in the subsurface in response to flowing fluids in geothermal systems. By consistently monitoring the reactions that occur in the four GECO field sites, each having distinct geology, we will be able to generalize these findings to create a tool for predicting the chemical behavior of a large number of other systems before they are developed for geothermal energy. Such tools have the potential to decrease both the risk and the cost of future geothermal energy projects.

In addition to the above-mentioned projects, which focus on geothermal applications, the characterization, mapping, and understanding of the crustal thermal conditions need further improvements. The International Heat Flow Commission (IHFC) is developing and recommending standards and techniques for the determination of all parameters necessary for geothermal research, such as heat-flow density, thermal properties of geo-materials, underground temperatures, and quantification of geothermal energy resources. The IHFC oversees the Global Heat Flow database, which is under extensive review and quality assessment.

6. EXPECTED DEVELOPMENTS

RePower EU, New Green Deal, Europe for 55, and other European Projects and Missions are making a great deal toward a secure, sustainable, and affordable energy supply for the near future, through a structural change of the economic and social development to meet climate ambitions.

Geothermal, together with the other RES, the waste heat locally available and the huge heat storage represented by the surface and groundwater masses and the coastal marine areas, have the potential to accelerate this change starting from the demand of H&C and hot water supply. AIRU estimated that the present 400 networks for DH distribute about 9.3 TWh/y (about 2.3 % of the national heat demand), but the potential for the deployment of DH systems is about 38 TWh.

The TTG highlighted the main barriers to a fully accomplished development, briefly listed here for district geothermal heating: leak of coherence in the legislative framework at the National level, need for stable rules and regulations, and need for complete planning at the Country level. Electric power generation has a huge potential in Tuscany, Latium, Campania, and in parts of Sicily and Sardinia Island. Coastal areas and islands on the Tyrrhenian side are also excellent sites to consider for zero emission binary plants that could also be integrated with desalination infrastructures. The Geothermal Technical Table estimated that the realization of geothermal projects (by Enel GP and other operators of Rete Geotermica) presently under authorization, with permits in progress, or with lease just released, should be able to install about 240 new MW of electric capacity by 2030. The projects in pre-feasibility and feasibility phases could provide the installation of a further 120 MW capacity by 2035. Thus, a total of 360 MW (equivalent to about 3000 GWh) would represent an important contribution (3%) to the total RES production capacity, foreseen by the Italian Government in about 100 TWh, mainly supplied by 70 GW installed capacity provided by wind and PV. In addition, geothermal shall be beneficial to the stabilization of the electric networks. The main barriers identified by the TTG are the following: high initial capital costs, complex procedures and too long permitting timing for final authorization, leak of support, and incentives.

7. CONCLUSIONS

The paper has presented the development of geothermal applications in Italy during the 2017-2021 period, together with an updated status of R&D activities, and legislative framework and support measures (both ongoing and expected). The geo-power sector has maintained a good level with an installed capacity equal to 915.8 MW_e and an electricity production of 5.92 TWh without significant variations in the considered period. However, according to all the main industrial operators (EGP and Rete Geotermica), there is an unexploited potential in various Italian Regions (about 360 MW of electric capacity by 2035). The different operators are now working on several projects that are at different progress development (under authorization, permits in progress, permitting, pre-feasibility, and feasibility phases, and so on). Concerning the heating and cooling sector, the most recent data refer to 2020: the total installed capacity is about 1,300 MW_{th}, with the corresponding thermal energy use of about 9,700 TJ/yr (~2,700 GWh/y). Compared with 2017 data, the H&C sector has experienced a reduction of about 11% in terms of geo-heat use, mainly due to the temporary closure of spa facilities imposed by the COVID-19 pandemic (-15% in terms of heat delivery). On the contrary, the heating of buildings continues to grow at an average pace of 3% per year, thanks to the continuous expansion of GSHPs and DH networks. Space heating confirms its leading position (49% of the total geo-heat use) and the potential for the next years.

However, several actions must be undertaken, and several drawbacks must be overcome to support the geothermal development in Italy and the possible contribution to the ambitious targets of the energy transition, as declared by RePower EU, New Green Deal, Europe for 55, and other European Projects and Missions. Currently, the overall geothermal sector suffers from the lack of coherence in the legislative framework at the National and Regional levels, it needs stable laws and regulations, together with comprehensive energy planning at the country level. The current permitting phases are too complex and too long to be attractive for capital investments, and there is minor support and incentives for geothermal projects. UGI and AIRU, with the support of EGEC, settled the Tavolo Tecnico “Geotermia per la Transizione Energetica” (TTG) in February 2022 intending to coordinate and support all the geothermal stakeholders, investors, and decision-makers in giving value to the extraordinary geothermal potential of the country. In particular, TTG acts as a sound interface for policymakers, especially in the context of a new legislative and incentives framework (FER2) that should enable the development of innovative geothermal plants for the next five years.

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ANNEX

Table A: Existing geothermal power plants in Italy (2021).

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Larderello	Valle Secolo	1991	2 (RI)	O	D	**120.0**	108.9	**915.7**
Larderello	Farinello	1995	1 (RI)	O	D	**60.0**	52.8	**434.8**
Larderello	Nuova Larderello	2005	1 (RI)	O	D	**20.0**	16.0	**126.6**
Larderello	Nuova Gabbro	2002	1 (RI)	O	D	**20.0**	18.2	**153.9**
Larderello	Nuova Castelnuovo	2000	1 (RI)	O	D	**14.8**	14.1	**127.5**
Larderello	Nuova Serrazzano	2002	1 (RI)	O	D	**60.0**	43.4	**342.6**
Larderello	Nuova Sasso	1996	1 (RI)	O	D	**20.0**	13.1	**112.5**
Larderello	Sasso 2	2009	1 (RI)	O	D	**20.0**	16.0	**112.5**
Larderello	Le Prata	1996	1 (RI)	O	D	**20.0**	18.4	**122.8**

Larderello	Nuova Monterotondo	2002	1 (RI)	O	D	**10.0**	7.5	**53.3**
Larderello	Nuova San Martino	2005	1 (RI)	O	D	**40.0**	34.3	**225.5**
Larderello	Nuova Lago	2002	1 (RI)	O	D	**10.0**	10.1	**64.8**
Larderello	Nuova Lagoni Rossi	2009	1 (RI)	O	D	**20.0**	11.8	**89.7**
Larderello	Cornia 2	1994	1 (RI)	O	D	**20.0**	11.1	**156.4**
Larderello	Nuova Molinetto	2002	1 (RI)	O	D	**20.0**	13.4	**118.6**
Larderello	Carboli 1	1998	1 (RI)	O	D	**20.0**	15.3	**131.3**
Larderello	Carboli 2	1997	1 (RI)	O	D	**20.0**	15.3	**136.4**
Larderello	Selva	1997	1 (RI)	O	D	**20.0**	17.4	**97.7**
Larderello	Monteverdi 1	1997	1 (RI)	O	D	**20.0**	17.5	**98.1**
Larderello	Monteverdi 2	1997	1 (RI)	O	D	**20.0**	15.3	**121.2**
Larderello	Sesta	2002	1 (RI)	O	D	**20.0**	13.0	**101.2**
Travale-Radicondoli	Nuova Radicondoli Gr.1	2002	1 (RI)	O	D	**40.0**	36.4	**222.1**
Travale-Radicondoli	Nuova Radicondoli Gr.2	2010	1 (RI)	O	D	**20.0**	18.5	**117.7**
Travale-Radicondoli	Pianacce	1987	1 (RI)	O	D	**20.0**	13.0	**72.2**
Travale-Radicondoli	Rancia	1986	1 (RI)	O	D	**20.0**	18.2	**124.7**
Travale-Radicondoli	Rancia 2	1988	1 (RI)	O	D	**20.0**	18.2	**117.1**
Travale-Radicondoli	Travale 3	2000	1 (RI)	O	D	**20.0**	15.3	**23.2**
Travale-Radicondoli	Travale 4	2002	1 (RI)	O	D	**40.0**	36.6	**212.1**
Travale-Radicondoli	Chiusdino 1	2010	1 (RI)	O	D	**20.0**	18.5	**141.9**
Mount Amiata	Bagnore 3	1998	1 (RI)	O	1F	**20.0**	19.4	**171.0**
Mount Amiata	Gruppo Binario Bagnore3	2013	1 (RI)	O	B-OCR	**1.0**	1.0	**4.3**
Mount Amiata	Bagnore 4	2014	2 (RI)	O	1F	**40.0**	38.0	**354.9**
Mount Amiata	Piancastagnaio 3	1990	1 (RI)	O	1F	**20.0**	19.2	**171.5**
Mount Amiata	Piancastagnaio 4	1991	1 (RI)	O	1F	**20.0**	19.2	**169.7**
Mount Amiata	Piancastagnaio 5	1994	1 (RI)	O	1F	**20.0**	19.2	**171.5**
TOTAL						**915.8**	**773.7**	**5917**

* O: Operating; N: Not operating (temporarily); R: Retired / Decommissioned; D: Dry-Steam; 1F: Single Flash; B-ORC: Binary (ORC); RI: re-injection applied