Geothermal Energy Use, Country Update for Italy (2010-2015)

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ABSTRACT

This paper presents an overview on the development of geothermal energy applications in Italy during the six-years period 2010-2015. 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 and Mount Amiata. Direct used are widespread over the whole Italian territory.

To date, Enel Green Power is the only geo-electricity producer in Italy. In the year 2014, with an installed capacity of 915.5 MWe (807 MWe efficient capacity), the gross electricity generation reached 5.9 billion kWh, which represents the new record of electricity produced from geothermal resource in Italy; in 2014 one additional unit (Bagnore 4) was realized, increasing the capacity from 875.5 to 914.5 MWe.

Regarding direct uses, the installed capacity reaches the value of around 1,300 MWt (+33% with respect to 2010), with an energy use of some 10,300 TJ/yr (+19% with respect to 2010). The main sectors of application are space heating (42% of the total energy) and thermal balneology (32% of the total energy), though numerous remarkable systems occur also in the industrial and agricultural sectors. Ground-source heat pumps (GSHPs) constitute the main technology to exploit and deliver geothermal heat, but important developments have been observed also in the district heating (DH) sector.

The first part of this paper deals with geo-electricity production (sections 1-5). Current status and future developments are illustrated with a particular focus on new power plants, drilling activities, personnel and investments.

The second part (sections 6-9) describes the evolution of direct uses in Italy: the values into five main final sectors of application: space heating (including all HVAC systems), thermal balneology, agricultural uses, fish farming, and industrial processes plus minor uses. The contribution of geothermal-source heat pumps (GSHPs) and district heating networks (DHs) are broken down in each final sector. Besides, for direct uses, we provide a detailed exploitation of the terminology, assumptions, and methodology used to obtain the final statistics, pointing out the main issues that currently affect most reports on direct uses in terms of data collection and processing methods.

PART 1: GEOTHERMAL ELECTRICITY GENERATION

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1. THE ELECTRICITY MARKET IN ITALY AND ENEL GREEN POWER

In the year 2014 the electricity needs in Italy reached 323.5 billion kWh, with a domestic contribution of 86.5%, while a relevant 13.5% was imported.

The electricity generation capacity and production data in Italy as of 2014 are summarized in Table 1. As regards the 280 TWh of domestic electricity generation, 63.0% comes from fossil fuels, 21.5% from hydro and 15.5% from geothermal, biomass, wind and solar (Figure 1). Even if 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.

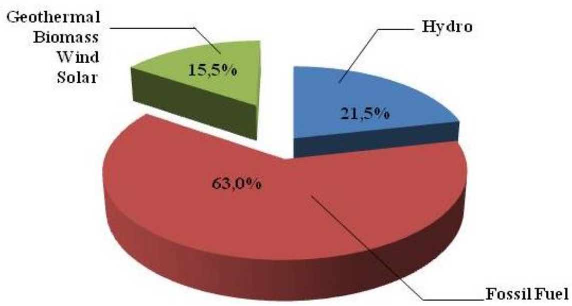

Figure 1: Electric domestic generation in Italy (2014).

According to the Bill Law issued on July 2012, starting from January 1st 2013 new power plants with a capacity exceeding 1MWe, will no longer be granted with “Green Certificates” but with an “Incentive Fee” similar to an all-inclusive fee decreased by zonal price of energy to which additional premiums can be added.

In 2015 the average market price of electricity was approximately 4.7 Eurocent/kWh. The value of the net kWh generated from new or recent geothermal power plants awarded with “Green Certificates” is around 13.7 Eurocent/kWh, while with a new “Incentive Fee” was 9.9 Eurocent/kWh (under 20 MWe installed capacity) or 8.5 Eurocent/kWh (over 20 MWe installed capacity).

1.1 Enel Green Power

Enel Green Power Spa (EGP), established in December 2008, is the Enel Group company that develops and manages energy generation from renewable sources at a global level, with a presence in Europe, the Americas and Africa. Enel Green Power is a major global operator in the field of energy generation from renewable sources, with an annual production of 32 TW/h, mainly from water, the Sun, wind and the Earth’s heat, meeting the energy consumption of over 11 million families and avoiding 17 million tonnes of CO2 emissions per year. At present, Enel Green Power has an installed capacity of 10.468 MWe, produced by 708 plants in 16 countries and with a generation mix that includes wind, solar, hydro, geothermal and biomass.

2. 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.

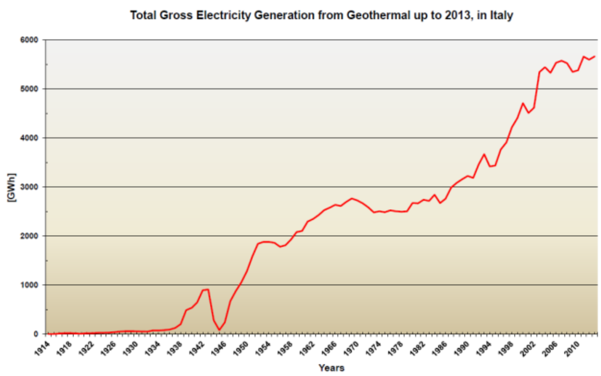

Figure 2: Historical trend of electricity generation from geothermal resources in Italy.

During the year 2014, with an installed capacity of 915.5 MWe, the electricity gross generation has picked up to 5.916 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 is 807.4 MWe.

In 2010 two new 20 MWe units in Travale/Radicondoli area (Nuova Radicondoli GR2 e Chiusdino 1 – Figure 3) were built. Between 2012-2013 six units have been renovated because of their outdated technology: one in Larderello area (Le Prata – Figure 4), two in Travale /Radicondoli area (Rancia and Rancia 2 – Figure 5) and, all the three Piancastagnaio area power plants (Piancastagnaio 3, Piancastagnaio 4 e Piancastagnaio 5).

This upgrading and two new 20MWe units (Bagnore 4 power plant) have led to an increase in performance that, together with the geothermal field maintenance, allowed to achieve a new record for electricity production from geothermal sources in the year 2014.

Figure 3: Chiusdino 1 (20MWe) power plant.

Figure 4: Le Prata (20MWe) power plant.

Figure 5: Rancia (20MWe) and Rancia 2 (20MWe) power plants.

Figure 6: Bagnore 4 (40MWe) power plant.

In 2013 also a the first geothermal binary power plant (Gruppo Binario Bagnore3) (Figure 7) in Italy was installed as an upgrade to Bagnore 3 power plant; this has led to an increase of 1 MWe installed capacity on this group.

Figure 7: Gruppo Binario Bagnore (1MWe) power plant.

In 2015 was built the first Geothermal - Biomass combined power plant in Italy at Cornia 2 power plant with an increase of the output power from 12 MWe to 17.2 MWe, with an overall plant efficiency improvement.

Figure 8: Cornia superheater.

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.

2.1 Plant for Hg and H_2S 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 H_2S is selectively converted to SO_2. Thereafter, the SO_2 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).

In May 2010 the Resolution of Country Council 344/2010 provides that, in order to obtain the renewal of the emissions permits, all the geothermal power plants are equipped with the latest technologies, including AMIS plants and high efficiency demister. As May 2015, 34 AMIS groups are in operation, providing each power plant with this technology.

In 2014, the averaged availability of AMIS plants (hours of operation vs hours of operation of the associated power plant) exceeded 90%, with only 1-2 outages per thousand of operating hours.

3. GEOTHERMAL FIELDS UPDATE

All of the Italian geothermal fields in exploitation for electricity generation are located in Tuscany (Figure 9): Larderello, Travale/Radicondoli, Bagnore and Piancastagnaio (the two latter being located in the Mt. Amiata area).

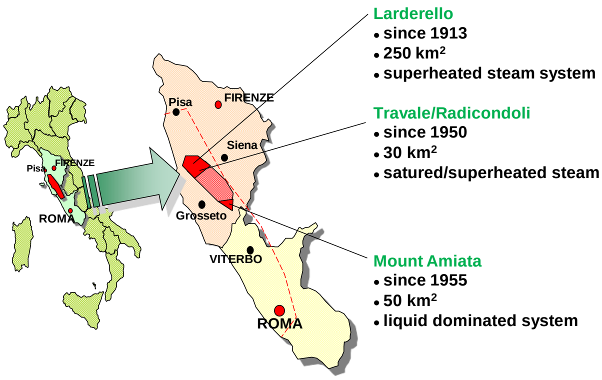

Figure 9: Location of the geothermal fields in Italy.

The activities carried out over the last five years have been concentrated both in Larderello-Travale and in Mount Amiata areas. Each area is characterized by a different type of mining activity depending on the geothermal reservoir characteristics and the level of exploitation. Therefore, while the activity in the Larderello-Travale areas are being targeted at field management optimization to reduce and contrast the natural decline, in the area of Monte Amiata development activities was carried out to increase electricity generation.

Since 1980, in order to increase the productivity of individual wells after drilling and to preserve it during their production life, some stimulation techniques have been developed and are currently being implemented. The aim of these techniques is to improve the permeability of fractured zones and to reduce or eliminate the formation damage (skin factor) by means of acid stimulation (Scali et al., 2013). With the experience gained during the operation and maintenance of the wells, different causes of well damage (formation or wellbore) have been identified and different techniques aimed to the recovery of the original productivity have been studied and implemented. Only in this way Enel Green Power experience in geothermal fields management, gained over decades, allowed obtaining positive results in a continuously increasing number of cases.

3.1 Larderello

The explored area is about 250 km2, where 200 wells produce superheated steam at pressure between 2 and 18 bars and temperature ranging from 150°C to 270°C. The non-condensible gas content ranges from 1 to 15% by weight. The installed capacity is 594.5 MWe as of December 2014, with 23 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 (Barelli et al., 1995, 2000; Bertani et al., 1995; Cameli et al., 2000).

An important activity on in this area was the empowerment of existing geothermal power plant named Cornia-2 by using biomass; the existing geothermal power plant (rated 19 MWe) was running at reduced capacity (12 MWe) and steam parameters and original thermal cycle were suitable for biomass firing integration using local biomass. The project consists of a Geothermal integrated Biomass power plant composed by superheater boiler for geothermal steam with combustion grate supplied by local forest woodchip, agricultural residues and powercrops. This example represents First innovative geothermal integrated biomass power plant in the world and allow an increase of about 5 MWe electric.

3.2 Travale/Radicondoli

The explored area covers approximately 50 km2; 29 wells produce superheated steam at pressure ranging from 8 to 20 bars and temperature of 190-250°C. The non-condensible gas content is in the range of 4 - 8% by weight. The installed capacity is 200 MWe 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 4,000 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 (3,000-4,000 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.

On the basis of the positive results of the deep exploration program, the drilling activities have continued even in the last five years with 10 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 on the basis of a joint accurate interpretation of the well data and seismic 3D surveys. In order to better understand the correlation between steam production and granite, in-depth analysis of petrography, geochemistry and geophysical log is currently under development (Casini et al., 2015)

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.

3.3 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 2,500 to 4,000 m inside the Metamorphic Basement underlying the shallow carbonate reservoir (Bertini et al., 1995). This deep reservoir is liquid-dominated, with a pressure of around 200 bars and a temperature of 300-350°C at 3,000 m depth (Bertini et al., 1995).

The produced fluid is a two-phase mixture that is separated at wellhead at 20 bars; the non-condensible gas content in the steam ranges from 6 to 8% by weight. Higher values occur in the steam produced from the shallow carbonate reservoir that feeds a back-pressure unit and is condensed downstream to supply heat for a large greenhouse complex in Piancastagnaio.

Between 2012-2013 all the three units in the Piancastagnaio area (Piancastagnaio 3, Piancastagnaio 4 e Piancastagnaio 5) have been renovated because of their outdated technology. At the same time several mining operations (both workover of existing well and new drillings) were conducted with the aim to find new geothermal fluid to ensure the full load on the power plants. A total of more than 120t/h was retrieved equal to an increase of 50% compared to the total steam extracted from the Piancastagnaio area .

In 2013 it was installed the first geothermal binary power plant (Gruppo Binario Bagnore3) in Italy as upgrade of Bagnore 3 power plant; this has led to an increase of 1 MWe installed capacity on this group. This new unit is based on an ORC cycle using the normal pentane as the secondary fluid. This unit is fed by a secondary flash steam at low pressure which is obtained from the partial evaporation for expansion of the liquid phase output from the primary flash (20bar). The operating conditions of temperature and pressure of the secondary flash are monitored in such a way as to avoid phenomena of scaling due to the possible deposition of the salts contained in geothermal fluid. Two new 20 MWe units (Bagnore 4) were commissioned at the end of 2014; the steam flow rate needed to feed the two new units (about 260t/h) was obtained from the drilling of two new deep wells (4,000m) and the workover of two existing wells currently non-productive because damaged. As of December 2014, the total installed capacity is 121 MWe, with 7 units on line.

3.4 New exploration leases

Since 2011, Enel Green Power has begun an exploration activity in areas adjacent to the existing exploitation leases. In particular EGP acquired 4 different exploration leases (Figure 10) for a total of approximately 1000km^2, two in the north-western part of Larderello (Montebamboli and Montegemoli), one in the southern part of Travale/Radicondoli (Boccheggiano) and the last one on the south-west edge of the geothermal field of Piancastagnaio (Murci).

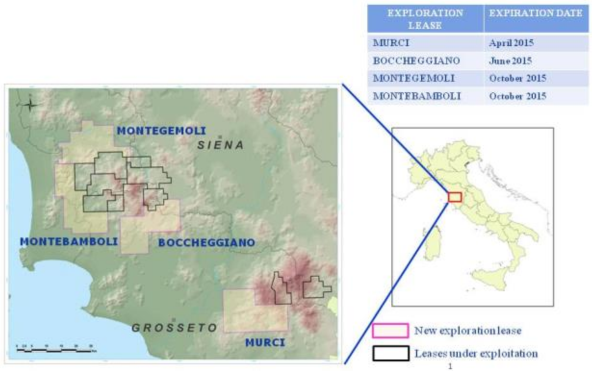

Figure 10: New exploration leases.

All these leases are considered as brown fields with the main purpose to improve the knowledge of the area to understand the possibility of finding a medium-high enthalpy fluid suitable for the production of electricity (temperature higher than 150°C). Until today a surface exploration (2D Seismic and MagnetoTelluric surveys) has been conducted whose interpretation has been used to locate some slim holes and wells for the next phase of deep exploration. In 2015 three slim holes have been drilled in the exploration lease of Boccheggiano, with good results that confirmed the possibility of future developments in the area. In next years 2 deep wells and some slim holes will be drilled in the other three areas to complete the exploration phase.

4. DRILLING

In the period 2010 - 2015 a total of 36 wells were drilled in Italy, for a total drilled depth of 112.2 km. Twenty of these wells are make-up wells drilled in Larderello (7) and Travale/Radicondoli (10) fields and they are relevant to the maintenance programs to contrast natural decline of geothermal production. In Mount Amiata area, the four production wells of development program are drilled. Other three drilled wells are relevant to the reinjection/injection program. Also three wells for monitoring the shallow aquifers (piezometers) are drilled in Mount Amiata area, as a prescription for the construction of the new production Bagnore-4 (under construction).

In 2015 the first two examples of multilateral wells for the production of geothermal steam were drilled with success; this new technology provides the opportunity to drill two or more production branches starting from the same well, allowing a considerable saving both in terms of cost and environmental impact.

5. PERSONNEL AND INVESTEMENTS

The number of professional personnel allocated to geothermal activities is given in Table F. The overall investments are shown in Table F; the values are lower than in previous five-year period due to the delay of development projects caused by the already mentioned environmental and acceptability problems.

PART 2: GEOTHERMAL DIRECT USES

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6. DIRECT USES: INTRODUCTION AND METHODOLOGICAL ISSUES

With regard to direct uses in Italy, we recall that hot geothermal waters have been used since prehistoric times for over 3,000 years. In particular, we cite two main development periods of direct applications: the first one during the imperial period of Rome (1st B.C. - 4th cent. A.D.) with a widespread use of thermal balneology, and the second one between 1850 and 1920 with the intensive exploitation of hydrothermal minerals. References on direct applications of geothermal energy in Italy from Prehistory to the end of the second millennium can be found in Ciardi and Cataldi (2005).

Today, geothermal direct uses are continuously growing in both Italy and worldwide (Lund and Boyd, 2015). Globally, the main sectors of application are space heating and thermal balneology, though many remarkable systems occur also in the industrial and agricultural sectors. Ground-source heat pumps constitute the main technology to exploit and deliver geothermal heat, but important developments have been observed also in the DH sector, thermal cascade uses, and integrated multi-source systems (EGEC, 2014). As we will point out in this work, the Italian situation in terms of application categories is in line with the one of the rest of the World.

As described in the last country updates (Conti *et al.* 2013, Conti *et al.* 2015), during the last five-year period, direct uses in Italy are experiencing an average annual growth rate of over 7%, both in terms of installed capacity and geo-heat utilization. As above-mentioned, the overall growth is due to the development of district heating networks and GSHPs (i.e. space heating).

The relevance of the direct uses in the overall Italian energy scenario has increased also at the political level. Indeed, it is worth recalling that the geothermal contribution to the national final energy consumption is counted within the energy balance of each European country and contributes to fulfill the EU energy targets mandated by the Directive 2009/28/EC for European Union and by the law Decree 2011/28 for Italy.

According to GSE (2015), the final thermal energy consumption from renewable sources was over 9.9 MTOE in 2014. Despite the predominant role of bioenergy, during the last two years, the geothermal share in the thermal sector has been increasing at an average rate of about 2% per year. At the end of 2014, it constituted the third thermal renewable energy source (behind bioenergy and air-source in heat pump systems), suppling about 2% of the total renewable heat consumption.

In this context, the use of a single global-accepted methodology to calculate and present statistics seems to be a basic condition to understand and compare the actual situation in different countries. However, as we already pointed out in previous papers (Conti *et al.* 2013, Conti *et al.* 2015), we should say that several issues are still affecting the reports on direct uses with respect to the ones concerning electricity production. In the above-cited works, we dealt with the analysis of current issues, together with some methodological proposals to increase the accuracy, the coherence and the comparability of provided figures.

Here, we recall four of the main outstanding points that should be addressed by the international geothermal community to improve current situation:

- *Availability of input data.* Not all of geothermal operators are required by law to monitor and declare quantitative figures on direct uses, especially those at low and very low temperature. Where no monitoring data are available, country reports are necessary affected by authors’ personal evaluations and estimations.

- *Ambiguity between the sectors of utilization and the technology employed in direct use systems*. Many papers mix up the final sectors of application (e.g. space heating, fish farming, industrial processes, greenhouse heating, etc.) and the equipment used to exploit the resource or to deliver the useful heat (e.g. geothermal district heating and geothermal heat pumps).

- *Cooling service*. Geothermal community still lacks of an established definition and a proper methodology to evaluate and present data on geo-assisted cooling systems.

- *Calculation methodology and terminology*. Any geothermal energy system has very different characteristics and engineering layouts, resulting in the need of a specific calculation methodology. Moreover, without an accurate description of the considered energy fluxes, the use of general terms like “capacity”, “energy”, and “capacity factor” may raise ambiguities.

- *Year of reference.* As a matter of facts, it is hard to obtain consolidated figures by less than two years after the year of reference of the statistics. This is due to the delay of the operators in realising data and to the time needed to collect and process the available information.

The above-mentioned issues do not occur only in Italy, but also in many other countries of the World. Consequently, to date, it is neither easy to compare statistics among different countries, nor to sum values to obtain continental or global reports. Conversely, a proper and established methodology is more than necessary for a better understanding of the current situation, to formulate sound development scenarios, investment plans, and energy politics.

To overcome those issues, UGI started in Italy a clarification work in collaboration with the Italian Authorities, aiming at developing an established and comprehensive methodology to collect and process statistics on direct uses. Besides, since 2010, UGI has started a systematic survey aimed at creating a database of all Italian direct uses: every two years a questionnaire is submitted to the main geothermal operators and authorities in order to collect any available information on geothermal energy use. However, a lot of work has still to be done because only a few operators are able to provide data.

In this work, we used the same method already introduced and successfully applied in Conti *et al.* (2015). For the sake of clearness, in section 7 we will shortly recall the main definitions and the evaluation formulas we used to calculate the hereby-presented statistics.

7. TERMINOLOGY, EVALUATION METHODOLOGY, AND DATA ACCURACY

As above-mentioned in section 6, in this work we employed the same methodology introduced and successfully used in Conti *et al.* (2015). The following definitions are applied:

- *"Geothermal capacity"* is the maximum instantaneous geothermal power deliverable by the system under well-defined and declared operational conditions;

- *"Energy or production"* refer to the amount of geothermal energy delivered to the end-user systems (losses included) over a declared period;

- *"Capacity factor"* (CF) is the ratio between the actual energy delivered by a system and the maximum theoretical output if operation at full capacity load were indefinitely possible. Standard values of CF iare generally used to estimate "Energy" when only the "geothermal capacity" is known.

The evaluation of the numbers is based on the energy balance of each considered system, according to its specific equipment layout. In direct-use geothermal systems, three main engineering solutions apply: the first one uses one or more heat exchangers to deliver the geo-heat to the end-user system, the second one uses the geothermal fluid directly, and the third one refers to heat pumps systems. The evaluation formulas and the three reference layouts are described in Appendix A.

With regard to the accuracy of presented statistics, it is worth specifying that, whenever possible, we reported the numbers declared by systems owners. Otherwise, we have been committed to estimate the numbers according to available information, some personal considerations, suitable capacity factors (CF), and/or equivalent full load hours of operation (EOHs). The use of a reference mean CF is particularly needed to analyse low-temperature applications. For instance, in the aquaculture sector, we used the global mean value of CF (i.e. 0.5) suggested by Lund *et al.* (2010).

For thermal balneology sector, the total energy use and the corresponding geothermal share were evaluated through the methodology presented in Cataldi and Conti (2013).

The statistics on GSHPs are based on the data reported in GSE (2015) and EurObserv'ER (2015), according to the methodology proposed in the European Decision 2013/114/EU. The adopted methodology refers to the prescriptions given by the European Decision 2013/114/EU that considers both electrically and thermal driven heat pumps. Only the heating service is taken into account.

8. EXPECTED SITUATION AT DECEMBER 2015

As above-mentioned, statistics on 2015 are still under development. Only partial information have been collected so far, therefore we are able to provide only the best estimation at this time. The expected situation of direct uses in Italy at the end of 2015 is presented in Tables C, D1, D2, E, according to scheme required by the EGC-2016 organizing committee, and in Table 1 and Figure 11 according to the established UGI methodology.

At the end of 2015, the total installed capacity exceeds 1,300 MWt, with a corresponding heat utilization of 10,500 TJ/yr. Space heating (DHs and individual systems) is the main sector of utilization in terms of both installed capacity (~ 52%) and energy use (~ 42%). Thermal balneology is the second sector (~32%), fish farming is the third one (~18%), and the rest (less than 10 %) is shared between agricultural applications, industrial processes, and minor uses.

Ground-source heat pump systems exceed 500 MWt in terms of installed capacity, with a corresponding geothermal energy exploitation of more than 3,200 TJ/yr. GSHPs account for 40% of the total installed capacity and some 31% in terms of energy. DHs deliver about 8% of the total geothermal heat. Further details on Italian Geo-DHs are shown in Table D1.

It is worth stressing that, according to the UGI methodology, GSHP statistics refer to the evaporator of the HP units as it is considered as the reference point to evaluate the actual geothermal contribution in heating mode (see Appendix A for further details). The values at the condenser (i.e. the useful power/heat delivered to the end-user system) are reported in Table E. Moreover, as already-mentioned, cooling operation is not accounted.

Finally, we inform that, according to the scheme required by the EGC 2016 organizing committee, the three large groundwater heat pumps connected to Milan DH (2 x 15 MWt) and Bango di Romagna DH (1.6 MWt) are accounted within the DH sector.

7. COMPARATIVE DEVELOPMENT 2010-2015

The revised situation at the end of 2010 has been presented in Conti *et al.* (2015). The evolution of direct uses in Italy in the five-year period 2010-2015 is shown in Tables 2 and Figure 12. We do specify that data on 2014 have been updated and confirmed with respect to the numbers presented in Conti *et al.* (2015). According to the available information to this time, the following main remarks can be made:

- Installed capacity has increased from ~1,000 MWt to more than 1,300 MWt, with an average annual growth rate of about 6%/yr. The increase is mainly due to ground-source heat pump installations that have more than doubled their capacity: from ~250 MWt to over 500 MWt. The corresponding average annual growth rate is more than 15%/yr. Also the DH sector has experienced a significant increase, with an annual growth rate of almost 15%/yr in terms of additional capacity;

- Geothermal energy use has increased from about 8,700 TJ/yr to more than 10,300 TJ/yr, with an annual growth rate of ~ 4%/yr. Again, the higher increase has occurred in space heating sector, i.e. GSHP (+ 16.8%/yr) and DH networks (+ 6.77 %/yr). It is also worth mentioning the notable development of industrial applications in the traditional geothermal areas of Tuscany, with a corresponding increase of the geo-heat utilization from ~100 TJ/y to more than 150 TJ/y (+7.9%/yr);

- As already pointed out in the previous two points and paragraph 6, space heating has become the first utilization sector. It grew from ~2,600 TJ/yr in 2010 (corresponding to the 30 % of the total geo-heat utilization) to ~4,450 TJ/yr at the end of 2015 (42% of the total geo-heat utilization). As above-mentioned, this is mainly due to the notable increase of GSHP applications and DH networks (see Figure 13). Thermal balneology (the previous first sector of utilization) has slightly reduced its relevance because of the economic crisis that has reduced the number of customers and the overall wellness market (Becheri and Quirino 2012);

- ground-source heat pumps have more than doubled both in terms of installed capacity (from ~250 to over 530 MWt), and geothermal energy utilization (from 1,500 TJ/yr to 3,260 TJ/yr), with average annual growth rates of about 17%/yr.

Table 1: Summary table of geothermal direct heat uses as of 31 December 2015 in Italy.

Sector of application	Capacity (MW_t)			Energy (TJ/yr)		
	Total	GSHPs	DHs	Total	GSHPs	DHs
Space heating	716	514	137	4,445	3160	807
Thermal balneology	435	-	-	3,346	-	-
Agriculture uses	83	13	-	683	75	-
Fish farming	120	-	-	1,869	-	-
Industrial process heat + minor uses	18	4	1	156	25	10
TOTAL	**1,372**	**531**	**138**	**10,500**	**3,260**	**818**

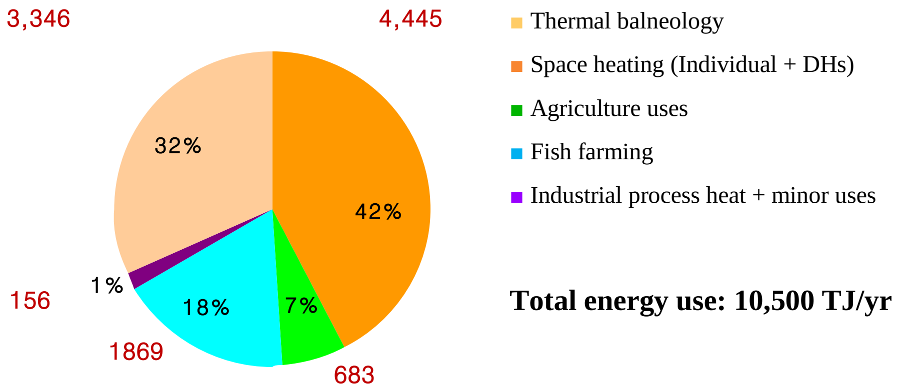

Figure 11: Share of geothermal energy utilization of direct uses in 2015 in Italy.

Table 2: Development of geothermal direct uses in Italy during the 5-year period 2010-2015.

Sector of application	Capacity (MW_t)			Energy (TJ/yr)		
	Total	GSHPs	DHs	Total	GSHPs	DHs
Space heating	+82%	+114%	+101%	+71%	+126%	+37%
Thermal balneology	+4%			-3%		
Agriculture uses	+21%	-		+19%	-	
Fish farming	-1%			-3%		
Industrial process heat + minor uses	+26%	-		+46%	-	
TOTAL	**+35%**	**+107%**	**+104%**	**+28%**	**+117%**	**+39%**

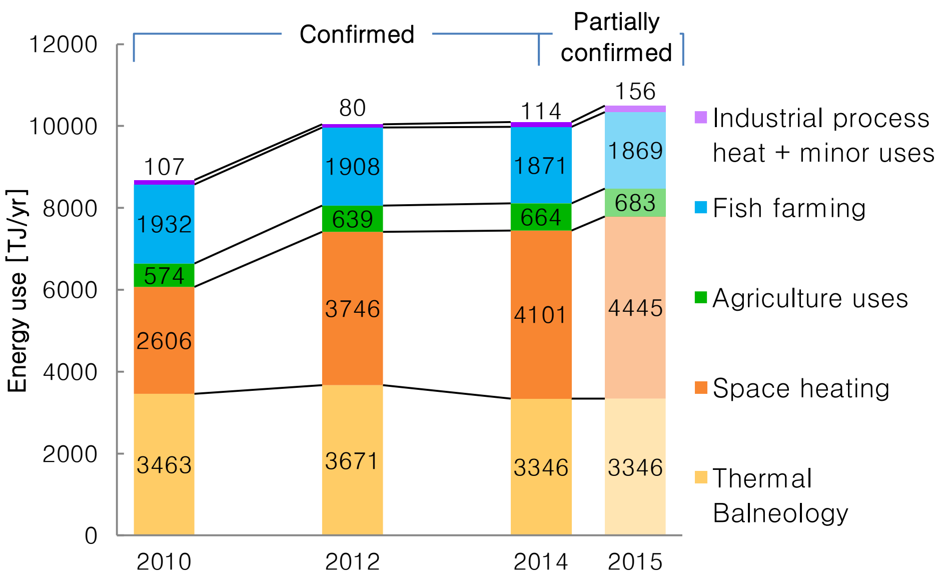

Figure 12: Development of the different sectors of direct uses in Italy (2010-2015).

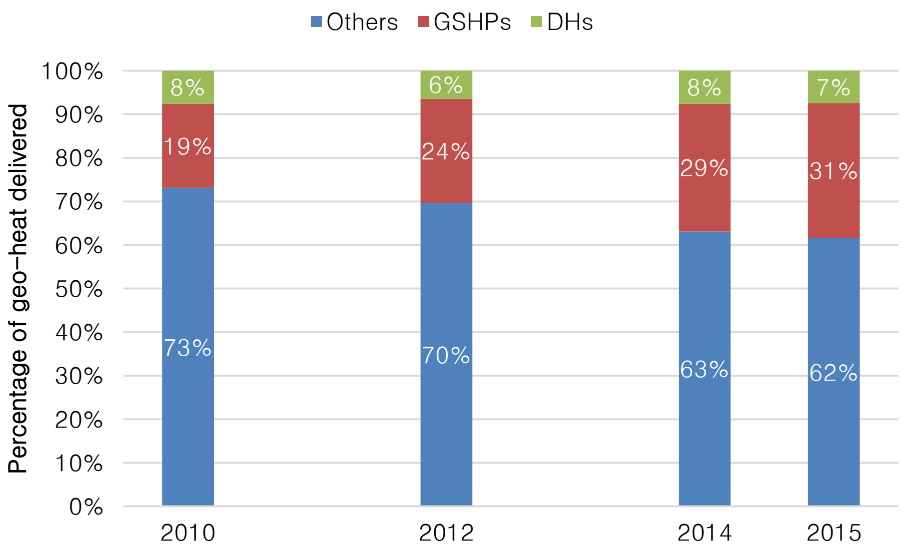

Figure 13: Development of geothermal DHs and GSHPs with respect to the total geo-heat delivered in Italy (2010-2015).

9. CONCLUSIONS

The paper presented the development of the geothermal energy in Italy from 2010 to 2015.

With regard to geo-electricity production, this paper presented an overview on the development of the Enel Green Power activities carried out in the five-years period 2011-2015 in Italy. We dealt also with direct uses evolution, with a particular focus on district heating networks, ground-source heat pumps, and current methodological issues.

Enel Green Power is a new company, fully owned by Enel Group. It was established in December 2008 with the aim to develop and manage the energy generation from renewable resources both in Italy and abroad. At present, this company is the world leader in this sector, with 32 TWh per year produced in sixteen countries of Europe and American continent.

Over the last five years thanks to the Green Certificates it has been possible to get a development of the geothermal source. Now with the new bill the incoming from the energy sale will be reduced. This significant incentive reduction is likely to penalize investments in new exploration and in fields characterized by a lower productivity per well.

Despite this, in addition to six units that have been renovated because of their outdated technology, two new units were installed in 2010 (Nuova Radicondoli GR2 20MWe and Chiusdino 20MWe), one in the year 2014 (Bagnore 4 40MWe) and in 2015 Cornia 2 power plant was upgraded by a biomass fired boiler allowing superheating of geo steam, with a total capacity of 85.2 MWe.

The total installed capacity as of December 2014 was 915.5 MWe and the gross electricity generation picked up to the value of 5,916 GWh/y, which represents about 30% of the electricity needs of Tuscany, the region where all geothermal fields in operation are located.

A deep exploration program including 3D seismic surveys and eleven exploratory wells 3,000-4,000 m deep was completed in the Larderello-Travale/Radicondoli area with positive results, but the strong interaction occurring between geothermal activities and territory, taking into account that we operate in Tuscany, has placed serious hindrance to the development of new projects.

In the shallow and most depleted areas of the geothermal field, different strategies for the optimization of resource management have been put in place (reinjection, chemical stimulation) to increase in steam production and reduce natural decline.

Aiming at the retrieval of a constructive and mutually beneficial relation with the territory, Enel Green Power has set going a number of initiatives with the intent of achieving a reduction of environmental drawbacks and an increase of acceptability. New design solutions have been envisaged to reduce the noise and visual impact of drilling pads, gathering systems and power plants. An innovative plant for the abatement of mercury and hydrogen sulfide (called AMIS) was designed by Enel and 34 abatement plants were installed and are now in operation.

On the basis of the scheduled activities, an increase of 85.2 MWe of the installed capacity for the period 2010-2015 can be regarded as a reasonable target.

Italian direct uses have experienced a remarkable growth during last five years; both in terms of installed capacity and energy use. The installed capacity reaches the value of around 1,300 MWt (+33% with respect to 2010), with a energy use of 10,500 TJ/yr (+21% with respect to 2010).

The main contribution to the growth of direct uses comes from GSHP systems that doubled their installed capacity and geothermal energy exploitation. Geothermal district heating networks are also notably expanding. Two DH networks have started operation during 2014 in Montieri and Monteverdi Marittimo. In addition, the new district heating project of Grado (touristic town near Trieste) has started operation during last winter, though data are still unavailable. In the next years, two other networks will be completed in the traditional geothermal area of Tuscany, i.e. Radicondoli and Chiusdino. Finally, two other DH projects have been planned in the same area (i.e. Belforte and Travale).

Other application sectors are also expanding in recent years; in particular, the industrial uses are starting to grow again after a decrease period due to the economic crisis. We cite a new brewery in the Boraciferous region that uses geothermal steam to feed its industrial equipment and a leather industry in the Amiata region. As above-mentioned, thermal balneology is the sector that has greatly suffered from the effects of the crisis with a reduction of the users number of about 5%. However, jointly with the hoped recovery of the Italian economy, we expect that all the sectors of the direct uses of geothermal energy will increase during the next years.

In presenting the development of geothermal direct uses in the 2010-2015 period, we feel necessary to stress again the achievable benefits of a single and universal methodology to process data and calculate final statistics. In fact, all the above-mentioned considerations derives from a continuous five-year period of data collection, together with the development of a novel methodology to evaluate the presented numbers. However, additional work is still necessary to increase the accuracy of the figures and, above all, the comparability of statistics among different countries and authors.

To this aim, UGI would firmly encourage the setting-up of an IGA ad-hoc working group aimed at defining an agreed-upon global standard methodology to produce and present statistics on direct uses.

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APPENDIX A

Details are given here on the methodology followed to calculate the *capacity* and *energy* values shown in the tables of this report. As said in paragraph 6, the energy balance of any energy system depends on its equipment layout. In direct-use geothermal systems, three main technologies may be applied: the first one base on one or more heat exchangers, the second where the geothermal fluid is used directly, and the third where heat pump(s) are employed.

A.1. Heat exchanger configuration

Heat exchangers are employed when the geothermal fluid cannot be directly used (Figure A.1). This is the typical design solution for space heating applications, district heating networks, agricultural uses, and industrial processes. A back-up unit may be used to match the thermal load of the user system without oversizing the geothermal section.

The geothermal *capacity* of the system is equal to the nominal capacity of the heat exchanger declared by manufacturer. It reads:

$$P_{th} = \dot{m}_A \cdot \left(h_A - h_D\right) \tag{A.1}$$

where:

- P_{th} is the nominal capacity of the geothermal system, MW_t;
- $\dot{m}_A$ is the nominal flow rate coming out from the production system, kg/s;
- h_A is the specific enthalpy of the geothermal fluid at the inlet section of the heat exchanger, MJ/kg;
- h_D is the specific enthalpy of the geothermal fluid at the outlet section of the heat exchanger, MJ/kg;

The energy value is given by the integral of the exchanged thermal power over the operation time (Equation A.2). It corresponds to the product of the *capacity* and equivalent full load hours of operation (EOH).

$$E_{th} = \int_0^{\tau} P_{th}(t)dt = P_{th} \cdot EOH \tag{A.2}$$

where:

- E_{th} is the geothermal energy utilization during the operative period, TJ/yr;
- $P_{th}(t)$ is the instantaneous thermal power transferred in the heat exchanger, MW_t;
- P_{th} is the nominal capacity of the geothermal system, MW_t;
- EOH is the equivalent full load hours of operation, h.

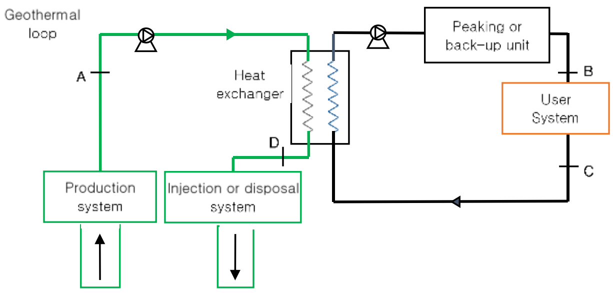

Figure A.1: Direct-use system with heat exchanger (after Lund, 1982). The green path indicates the geothermal fluid.

A.2. Direct use of geothermal fluid

This configuration is typically used in thermal balneology and fish farming applications (Figure A.2). The original temperature of the geothermal fluid may be modified by means of a back-up unit to reach the optimal value required by the user system (Cataldi and Conti, 2013; Lund, 1996). In these cases, we need to set a criteria to split the geothermal share of the total heat delivered to the user system. In this work, we decided to evaluate geothermal capacity as in Equation A.3.

$$P_{th} = \dot{m}_A \cdot c \cdot \left(\overline{T}_A - T_0\right) \tag{A.3}$$

where:

- P_{th} is the nominal capacity of the system, MW_t;
- $\dot{m}_A$ is the nominal flow rate from the production systems (wells or springs), kg/s;
- c is the specific heat of the geothermal fluid, MJ/(kgK);
- $\overline{T}_A$ is the average temperature of the fluid from the production systems (wells or springs), °C;
- T_0 is the reference temperature to evaluate the geothermal content of supply fluid, °C.

In this work, T_0 is conventionally set equal to 15°C that corresponds to the annual average temperature of outdoor air in Italy. No geothermal contribution is assumed to exist when the fluid temperature is below 15°C.

The Total energy delivered to the user system is evaluated through the Equation A.4:

$$E_{TOT} = V \cdot \rho \cdot c \cdot \left(T_B - T_C\right) \tag{A.4}$$

where:

- E_{TOT} is the thermal energy utilization during the year of reference, TJ/yr;
- V is the total volume of geothermal fluid used during the year of reference, m^3;
- ρ is density of the geothermal fluid, kg/m^3;
- T_B is the nominal inlet temperature of the user system, °C;
- T_C is the nominal outlet temperature of the user system, °C;

The geothermal share of E_{TOT} is evaluated by means of a dimensionless coefficient (α), as defined in Equation A.5.

$$E_{th} = E_{TOT} \cdot \alpha = E_{TOT} \frac{T_A - T_0}{T_B - T_0} \tag{A.5}$$

This methodology for the evaluation of the geothermal share of total energy used was already used in Cataldi and Conti (2013) and Conti *et al.* (2015).

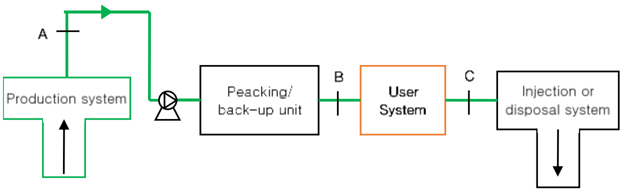

Figure A.2. Direct use system without heat exchanger (after Lund, 1982). The green path indicates the geothermal fluid.

A.3. GEOTHERMAL HEAT PUMPS

Usually, heat pumps manufacturers indicate to the so-called "*declared capacity*" (P_{DC}) to specify the heating capacity of a given unit at standard rating conditions (EN 14511-2:2013 for the European Union countries). This value does not correspond to the geothermal contribution, as it includes also the input power at the compressor or absorber. Equation A.5 shows the relation between declared capacity and geothermal capacity. The latter correspond to the nominal heat exchange in the evaporator (Figure A.3).

$$P_{th} = P_{DC} \cdot \left(1 - 1/COP_{DC}\right) = \dot{m}_A \cdot c \cdot \left(T_A - T_B\right) \tag{A.6}$$

where:

- P_{th} is the geothermal capacity of the system, MW_t;
- P_{DC} is the declared capacity of the unit, MW_t;
- COP_{DC} is the declared coefficient of performance resulting from manufacturer's data.

Only P_{DC} value is currently available in Italy; therefore, in this work, we evaluated the energy delivered by GSHPs by using the COP and the EOHs suggested by the European decision 2013/114/EU.

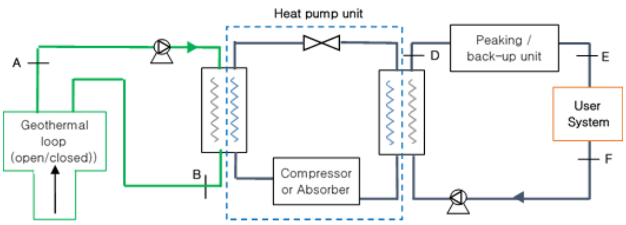

Figure A.3. Direct use system with geothermal heat pumps. The green path indicates the ground-coupled loop.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MWe$_e$)	Production (GWh$_e$/yr)	Capacity* (MWe$_e$)	Production (GWh$_e$/yr)	Capacity (%)	Production (%)
In operation end of 2014	915.5	5,916	121,277	279,828	0.75	2.1
Under construction end of 2015						
Total projected by 2018						
Total expected by 2020						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2015 (indicate exploration/exploitation, if applicable):						

* This value is the Efficient Capacity

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units	Status	Type	Total capacity installed (MWe$_e$)	Total capacity running (MWe$_e$)	2014 pro-duction (GWh$_e$/y)
Larderello	Valle Secolo	1991	2 (RI)	O	D	120	104,8	891
Larderello	Farinello	1995	1 (RI)	O	D	60	53,1	431
Larderello	Nuova Larderello	2005	1 (RI)	O	D	20	15,0	130
Larderello	Nuova Gabbro	2002	1 (RI)	O	D	20	17,3	150
Larderello	Nuova Castelnuovo	2000	1 (RI)	O	D	14,5	15,1	132
Larderello	Nuova Serrazzano	2002	1 (RI)	O	D	60	42,5	371
Larderello	Nuova Sasso	1996	1 (RI)	O	D	20	8,8	70
Larderello	Sasso 2	2009	1 (RI)	O	D	20	15,1	129
Larderello	Le Prata	1996	1 (RI)	O	D	20	17,0	144
Larderello	Nuova Monterotondo	2002	1 (RI)	O	D	10	6,1	53
Larderello	Nuova San Martino	2005	1 (RI)	O	D	40	37,5	325
Larderello	Nuova Lago	2002	1 (RI)	O	D	10	10,6	88
Larderello	Nuova Lagoni Rossi	2009	1 (RI)	O	D	20	8,9	75
Larderello	Cornia 2	1994	1 (RI)	O	D	20	11,5	100
Larderello	Nuova Molinetto	2002	1 (RI)	O	D	20	12,3	102
Larderello	Carboli 1	1998	1 (RI)	O	D	20	11,2	97
Larderello	Carboli 2	1997	1 (RI)	O	D	20	13,1	109

Larderello	Selva	1997	1 (RI)	O	D	20	12,9	112
Larderello	Monteverdi 1	1997	1 (RI)	O	D	20	17,2	149
Larderello	Monteverdi 2	1997	1 (RI)	O	D	20	15,4	134
Larderello	Sesta	2002	1 (RI)	O	D	20	9,5	83
Travle-Radicondoli	Nuova Radicondoli	2002	1 (RI)	O	D	40	33,2	275
Travle-Radicondoli	Nuova Radicondoli GR 2	2010	1 (RI)	O	D	20	18,1	151
Travle-Radicondoli	Pianacce	1987	1 (RI)	N	D	20	17,2	7
Travle-Radicondoli	Rancia	1986	1 (RI)	O	D	20	19,8	172
Travle-Radicondoli	Rancia 2	1988	1 (RI)	O	D	20	18,8	163
Travle-Radicondoli	Travale 3	2000	1 (RI)	O	D	20	14,0	121
Travle-Radicondoli	Travale 4	2002	1 (RI)	O	D	40	33,1	287
Travle-Radicondoli	Chiusdino 1	2010	1 (RI)	O	D	20	18,4	161
Mt. Amiata	Bagnore 3	1998	1 (RI)	O	1F	20	19,2	161
Mt. Amiata	GruppoBinario Bagnore3	2013	1 (RI)	O	B-OCR	1,0	0,8	6
Mt. Amiata	Bagnore 4	2014	2 (RI)	O	1F	40	29,7	21
Mt. Amiata	Piancastagnaio 3	1990	1 (RI)	O	D*	20	20,3	176
Mt. Amiata	Piancastagnaio 4	1991	1 (RI)	O	D*	20	19,5	169
Mt. Amiata	Piancastagnaio 5	1994	1 (RI)	O	D*	20	19,5	169
					total	**915,5**	**736,5**	**5916**

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
		2F	Double Flash	O	Other
R	Retired				

Table F: Investment and Employment in geothermal energy

	in 2015 *		Expected in 2018	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	126	676	-	-
Geothermal direct uses				
Shallow geothermal				
total				

* If 2014 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for individual buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2015 *	138	227	221	752	577	1008	435	929
Under constru-ction end 2015								
Total projected by 2018								
Total expected by 2020								

* If 2014 numbers need to be used, please identify such numbers using an asterisk

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion * (GW_{th}/y)	Geoth. share in total prod. (%)
Bagno di Romagna (FC) [3]		1983			1.38/1.6	7.58	2.50/2.80	28 % / 32 %
Castelnuovo V.C. (PI) [1]		1986			11.63		24.32	100 %
Sasso Pisano (Castelnuovo V.C. ,PI) [1]		1996			2.33		5.22	100 %
Montecastelli Pisano (Castelnuovo V.C. ,PI) [1]		2010			2.91		2.94	100 %
Ferrara[1,2]		1987		Y	14.00	154.5*	73.28*	52 %*
Vicenza[2]	Centrale Viale Cricoli	1990			0.70	29.2	4.37*	12 %
Milan[2,4]	Canavese + Famagosta	2010		Y	20/30	202	10.38/28.88*	1.2% / 3 %
Monterotondo M.mo (GR) [1]		1994			5.15		8.71	100 %
Larderello (Pomarance, PI) [1]		1988			5.00		1.34	100 %
Lustignano (Pomarance, PI) [1]		1996			1.00		3.80	100 %
Montecerboli (Pomarance, PI) [1]		1995			5.00		6.50	100 %
Pomarance (PI) [1]		2003			37.00		33.35	100 %
San Dalmazio (Pomarance, PI) [1]		1999			1.00		1.72	100 %

Serrazzano (Pomarance,PI) [1]		1996			2.50		1.48	100 %
S. Ippolito (Pomarance, PI) [1]		2003			0.50		0.43	100 %
Monteverdi Marittimo (PI) [1]		2014			5.00		6.66	100 %
Montieri (GR) [1]		2014			6.16		4.79	100 %
Larderello, (Castelnuovo VC) [1]							4.10	100 %
Sasso Pisano, (Castelnuovo V.C.) [1]							1.30	100 %
Santa Fiora (GR) [1]		2005			15.12		29.85	100 %
Grado (GO)					2.00		n.a.	
Total					**138 / 149**		**227 / 246**	

Note: When one or more GSHPs are used as heat generator for the DH network, two values of the installed capacity and thermal energy are presented: the first one refers to the evaporator and the second one refers to the condenser of the HP unit(s).

Data courtesy of: [1]Enel Green Power, [2]AIRU, [3]Soggetel, [4]A2A Calore & Servizi

* If 2014 numbers need to be used, please identify such numbers using an asterisk

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015 *	13 200[a]*	531 / 744	906 / 1268	800*	48 / 68	
Projected total by 2018						

* If 2014 numbers need to be used, please identify such numbers using an asterisk

Note: Two values of the installed capacity and thermal energy are presented: the first one refers to the evaporator and the second one refers to the condenser of the HP unit(s).