Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Direct Uses in Italy: Country Update for WGC2015

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Keywords: Country update, direct uses, Italy

ABSTRACT

This paper deals with the application of geothermal energy for direct uses in Italy during the period 2010-2014. After a brief overview of the national geothermal potential, we present the figures in accordance with the framework requested by the WGC2015 organizing committee; we also include additional charts and tables that follow a new format proposed by UGI for reporting direct uses data. The latter splits 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 specified within each final sector. The paper describes 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. Consequently, we encourage the setting-up by IGA of an *ad-hoc* working group aimed at establishing a globally accepted methodology to assess the direct applications of the geothermal energy, so improving the quality of future reports, and making the comparison among data from different countries more meaningful. UGI is available to give its contribution to this aim.

1. INTRODUCTION

The use of hot geothermal waters in Italy dates back to prehistoric times and developed intensively during the Roman Antiquity (3^{rd} B.C. - 5^{th} A.D.). Applications included: thermal baths, cooking food, heating spa facilities in localities with active manifestations, and use of hydrothermal minerals. All these uses declined notably from the 6^{th} to the 12^{th} centuries A.D., but started to grow again from the 13^{th} century onward, reaching a peak in the early 20^{th} century with the production of boron compounds. In that long lapse of time (over 3,000 years), two phases of most intensive development of direct uses occurred: the first during the imperial period of Rome (1^{st} B.C. - 4^{th} cent. A.D.) with widespread use of thermal balneology, and the second between 1850-1920 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), especially in chapters 1.4, 2.3, 3.3, 3.4, 3.10 and 3.11.

Almost 325 MW_t capacity of direct uses was installed in Italy towards the end of the 20^{th} century (Cappetti et al. 2000). In that period Italy was one of the first five countries of the world (the first in Europe) in terms of annual spa users; as a consequence, thermal balneology has been the main sector of direct uses for a long time. After 2000, other direct uses (especially ground-source heat pumps) started to grow: initially (2000-2005) at small annual rates, and afterwards with moderate or relatively sustained paces.

Concerning geothermal electricity production, we shall limit ourselves here to recall that, following studies, lab experiments and the installation of two demonstration units (20 kW_e each), the first industrial power plant in the world (250 kW_e) entered into operation in September 1913 at Larderello. Since then, two main periods of development occurred: the first until July 1944 when, due to events related to the 2^{nd} World War, the capacity installed (127 MW_e) was totally destroyed; and the second from late 1944 onward, when the installed capacity started to grow unceasingly till reaching 875 MW_e at Dec. 2013, with a gross production of 5.66 TWh. For geothermal power generation a specific country report has been prepared by Enel authors for this Congress (Razzano and Cei, 2015).

Direct uses are undergoing continuous growth in Italy and in over 80 other countries in the world. Their importance within the global energy scenario is increasing continuously, especially thanks to the huge development of ground-source heat pump applications. The renewable share of the heat delivered by direct uses is counted within the energy balance of each European country and contributes to reach the EU energy targets mandated by the Directive 2009/28/EC for European Union and by the law Decree 2011/28 for Italy.

In general, we should say that, despite their relevance, several issues have always affected direct uses statistics. To date, at least in Italy, but probably also in many other countries, only a few geothermal operators monitor and declare actual operation data; therefore, it is practically impossible to identify and list all existing systems, especially those with a small capacity (e.g. domestic heating, geothermal heat pumps, fish farming pools, and others). Moreover, even when direct use systems are known, not always the energy data are available, and consequently the final figures of most countries must be estimated. On the other hand, a globally established methodology to assess the final statistics on direct uses does not exist. For these reasons, current values are often an aggregation of fragmentary and incomplete figures, mainly based on simplifying assumptions and personal evaluations by the papers' author(s).

In addition, it is worth recalling that direct applications often combine the geothermal source with other forms of energy, e.g. natural gas, electricity, solar technologies and others; therefore, the use of too simple equations, without a proper energy fluxes analysis, may result in wrong evaluations (for thermal balneology see, for instance, Cataldi and Conti, 2013). Furthermore, regarding terminology, many reports and papers on direct uses show a variety of acronyms and concepts without providing an adequate definition of the terms used. Finally, we must point out that, to date, an established methodology to evaluate the geothermal contribution in "cooling applications" has still not been defined.

In short, the above-mentioned issues make assessment and comparison of direct uses statistics a very hard task. Therefore, in our opinion, three urgent measures are necessary to improve the current situation:

a) to the set-up of an *ad-hoc* IGA working group entrusted with establishing a standard methodology and terminology on data collection and figures assessment of geothermal direct uses;
b) to promote and implement awareness campaigns addressed to international and national institutions involved in energy matters, and through them to all geothermal operators in each country, for the timely application of the above-said methodology. IGA Regional Branches and affiliated country organizations might contribute to this goal;
c) to include the new methodology in the author guidelines for the next WGC2020.

Improved statistics on direct uses will be useful to better understand the actual situation and to formulate truthful development scenarios. UGI, from its side, is already working to set up a new methodology to gather and process the Italian data on direct uses, together with a new format for their presentation. They will be shortly described in section 3 and Appendix A of this paper.

2. GEOLOGICAL AND GEOTHERMAL BACKGROUND

The Italian territory formed as a result of the collision between the African and European plates, which started in the Upper Cretaceous (80 My ago) and ended in the Upper Miocene (10 My ago). During this long period, a compression regime predominated in the south-western Mediterranean area, with mantle arching, rising of igneous material from deep magma chambers, thinning of the crust, formation of anatectic bodies at shallow depth, and development of large thermal anomalies with high heat flow values (80 - 450 mW/m^2, see Figure 1). A tensional regime followed in the Pliocene and Quaternary, with formation of prevailingly NW-SE horst-graben structures and thick faulting, accentuation of thermal anomalies in areas of up-lifted features, and extrusion of deep and anatectic magmas. These phenomena occurred especially in the pre-Apennines belt from Tuscany to Campania, in the southern Tyrrhenian Sea, in central Sardinia, and in eastern Sicily (Figure 2).

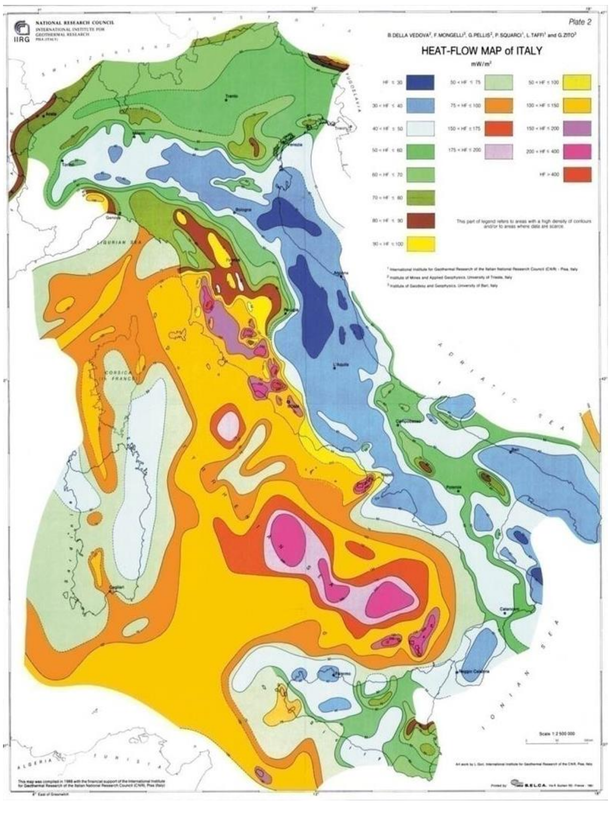

Figure1: Conductive heat flow of Italian territory (after Buonasorte et al., 2010).

Where permeable complexes overlain by impermeable covers exist at relatively short distance from absorption outcrops through which meteoric water can percolate, confined aquifers formed, with water temperature depending on the depth of the aquifer and the intensity of the local thermal regime. Thus, temperature in such aquifers may range between many tens and few hundreds degrees °C at depths, say, of between several hundreds and few thousands metres. In the latter cases, provided that favorable hydrogeological conditions exist as a result of combined structural and lithostratigraphic situations, a convective circulation may have been triggered inside confined aquifers, with local escapes of hot water along fractures and faults and formation of hot springs in many areas. In particular, where thermal anomaly is strong enough and confined aquifers are found at relatively shallow depths, the water temperature may reach values well above 100°C; therefore, steam caps may have formed at the top of the reservoir with fumarole vents at surface. This type of manifestations, however, occur in few places only, characterized by recent intrusive processes or young and present volcanic activity.

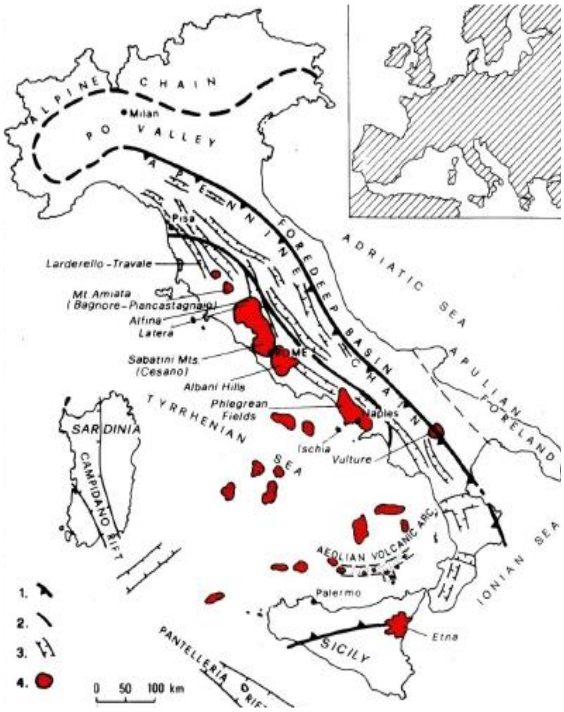

Figure 2: Main deodynamic domains and recent volcanism (after Buonasorte et al., 2010).

On the contrary, where permeable formations of notable thickness (several hundreds metres, or more) outcrop and overlay impermeable complexes, unconfined aquifers exist, whose water temperature exceptionally exceeds 50 C within 2 km depth. In these situations too, owing to peculiar hydrogeological conditions (heteropies of facies, fault contacts, lateral barriers with impermeable formations, differential porosity, belts of thick fractures, etc.), the water may escape upwards from unconfined aquifers to form superficial springs with temperature in most cases below 50°C. In particular cases only, where structural situation occur of the “range and basin” type, and the water can rise fastly through faults from depths above 3 km, its surface temperature may reach 70-80°C. However, the sizeable quantity of thermal energy associated to such unconfined aquifers can be harnessed in few cases only, for low-temperature applications.

In addition to the factors mentioned above (heteropies of facies, fault contacts, etc.), inversions of litho-stratigraphic sequences with doubling of series in many areas of Italy also played an important role on the formation of geothermal fields and manifestations. Such inversions are the result of the compression tectonics (with main north- and eastwards components) occurred during the final orogenetic stage of the Alps and Apennines, characterized by overturned anticlinals, detachments of rock complexes from their basement, and overthrusts of thick nappes over younger terrains. This compression tectonics, preceded the occurrence in the Pliocene and Quaternary of the tensional tectonics cited before, with formation of horst-graben structures and thick faulting.

The tensional tectonics, in turn, affected and modeled the piedmont belt of the southern Alps and of the western Apennines, where the recent igneous processes highlighted in Figure 2 were concurrently happening during the late Pliocene and the Quaternary. And in fact, as result of all the above, the areas with the thickest concentration of thermal anomalies and hot springs in Italy are found in the Euganean district near Padua, in the pre-Apennines belt of Tuscany-Latium-Campania, and in the Ischia island in the southern Tyrrhenian Sea.

In short, a wide variety of geological and geodynamic situations can be found in Italy, both at the regional and local scale, in each of which different types of geothermal resources could form. Therefore, Italy is endowed with all types of geothermal resources and systems: high-, moderate-, and low-temperature resources associated with hydrothermal and *unconventional geothermal systems*.

Concerning high-temperature hydrothermal systems at depths $\leq$ 5 km, however, we should point out that the aggregate surface extension of their occurrence areas is 1,500 km^2 at most; thus, the resources harnessable from them for power generation are intrinsically limited by the slightness of their existence areas. The high-temperature *unconventional systems*, on the contrary, are found in much larger areas (see Cataldi et al., 2015; Proceedings of this WGC2015). To sum up, the long-term future of geothermal energy in Italy should be envisioned in the light of a much more sustained development of moderate-to-low temperature resources for direct applications, and on the possibility to harness high-temperature *unconventional systems* for power generation.

More detailed information on the geological background of the Italian geothermal resources and manifestations are given in Buonasorte et al. (2011), Cataldi et al. (2013), and Carlino et al. (2013). For thermal springs, in particular, reference can be made to the papers by Cataldi et al. (2010), and Ceccarelli A. and Ceccarelli E. (2010).

3. GATHERING DATA AND PROCESSING METHODOLOGY

We have already outlined in the introduction the main issues that currently affect Italian and other direct uses reports. Additional remarks on this matter, concerning Italy in particular, can be found in the first section of the paper by Grassi et al. (2013).

Therefore, in this paragraph, we describe the main features of the data gathering, the processing methodology, and the terminology used in this report. For better details on evaluation formulas, the reader can refer to Appendix A.

3.1 Gathering and availability of input data

With the term "*input data*" we mean all the information helpful to assess the energy balance of the direct applications of the geothermal heat. Two kinds of input data have been considered:

a) *Monitoring data*, when sufficient numerical information is made available by operators and/or authorities;
b) *Estimated data*, in all other cases, when the aforesaid information is not available and a number of considerations must be made by the authors to evaluate the required figures.

The final statistics of any national or regional report on direct uses are always affected by the accuracy of the data used. As to Italy, in particular, the geothermal value of the low-temperature applications (fish farming, heat pumps, thermal balneology, etc.) is still unfamiliar at the government level; therefore, an official database of the direct uses does not exist.

This is why, since 2010, UGI has started a systematic survey aimed at creating a database of all Italian direct uses, and every two years sends a questionnaire to the main geothermal operators and authorities in order to collect any sure information available in this field. As a result, the statistics on heating applications (i.e. individual system and DHs) could already be improved notably; but a lot of time-taking work still remains to be done because, as said above, few operators only have and can provide quantitative data. Therefore, to now, it is always necessary to complete final statistics with a number of figures estimated by the authors. In particular, fish farming and balneology figures are based on estimations of temperature and volume of water used yearly, while the geothermal share of the heat delivered by heat pumps has been evaluated on the basis of the installed capacity declared by the trade associations to the national authorities.

3.2 Sectors of utilization

Most country reports and published papers usually consider together final sectors of application (e.g. fish farming, industrial processes, greenhouse heating, etc.) and equipment used to exploit the resource or deliver the geothermal heat. This happens, in particular, for district heating networks and geothermal heat pumps; but, this way of processing data is intrinsically ambiguous as the same type of equipment can be used in different applications. Consequently, UGI has decided to organize its reports on direct uses according to five main application sectors: *space heating* (including all HVAC systems), *thermal balneology*, *agricultural uses*, *fish farming*, and *industrial processes* plus *minor uses*. Space cooling systems have not been considered in this paper because criteria to define and evaluate the geothermal share in this kind of applications have not been established yet.

The contributions of heat pumps and DHs are shown as a share of each specific sector, in the same way made in the papers by Buonasorte et al. (2011) and Grassi et al. (2013), according to the methodology established by UGI. In this paper, however, we have followed both ways of presenting the data: that indicated in the prescriptions given by the WGC2015 organizing committee, and the one elaborated by UGI in its methodology of processing data on direct uses, as described in the papers quoted above and in the Appendix to this paper.

3.3. Processing methodology and terminology

As known, every sector of application has very different characteristics, resulting in the need to have a specific calculation methodology. Moreover, the use of general terms like "*capacity*", "*energy*", and "*capacity factor*" may raise ambiguities, if made with no accurate description of the energy fluxes considered. Besides, it is worth recalling that the energy balance of any energy system depends on its technical layout, which may or may not to be directly related to its final sector of use. For example, buildings can be heated in different ways (by district heating networks, heat pump systems, gas boilers, or others): in all these cases, we have the same final sector (i.e. space heating), nonetheless, each of those cases requires a different method to calculate its energy balance.

Regarding terminology, the following definitions have been followed in this work:

- *Capacity*
  In thermal applications, the term "*capacity*" is generally associated with the nominal gross power of heat generation unit(s). Therefore, by analogy we define the "*geothermal capacity*" the maximum instantaneous geothermal power deliverable by the concerned system under well-defined operational conditions.
- *Energy*
  We use the generic term "*energy*" to indicate the amount of geothermal energy delivered to user systems, losses included. Whenever possible, we have reported the values declared by the system owners; otherwise, energy has been estimated by using appropriate capacity factors and/or equivalent full load hours of operation (EOHs). In particular, for the balneology sector we have applied the methodology described by Cataldi and Conti (2013), whereas for the seasonal COPs and EOHs we have followed the prescriptions given by the European Decision 2013/114/EU for GSHP applications.
- *Capacity factor*
  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. We estimated CF values only when the capacity of the analyzed system was available. For example, in heating applications, the thermal load depends mainly on local climate and building characteristics; so that, we have assumed that CF values are proportional to the installed capacity and to the local "*degree-days*". When no other information was available, typical CF values from Lund et al. (2010) have been used.

3.4 Year of reference

In Italy, geothermal operators usually release operational data from many months to two years after the end of the year concerned; moreover, the preparation of a country report requires several months to search and obtain all available information necessary to complete the work. Thus, consolidated data can be reported not less than two years after the year of reference. This is why in this work, we have been able to give confirmed figures for 2010 and 2012 whereas, for 2014, we can provide estimated figures only.

4. REVISED SITUATION AT DECEMBER 2010

In this paragraph, we present the statistics 2010 revised according to the processing methodology illustrated in the previous paragraph and in Appendix A. Table 1 shows data split into the details required by the WGC2015 organizing committee, while Table 2 and Figure 3 present figures grouped according to the final sectors of application established by UGI, with the contribution of GSHP and DH systems shown separately.

Table 2 shows that the total installed capacity amounted in 2010 to a little more than 1,000 MW_t, with an energy utilization of about 8,700 TJ/yr. In terms of energy, thermal balneology was the main sector (~40 % of the total), space heating the second (~30% of the total), and fish farming the third (~22% of the total). Ground-source heat pumps installed were about 250 MW_t with a corresponding geothermal energy use of 1,500 TJ/yr: thus, 24% of the total in terms of capacity, but some 16 % in terms of energy. In Figure 3 the shares of ground-source heat pumps are included in the application sectors concerned.

Table 1: Summary table of geothermal direct heat uses as of 31 December 2010 in Italy (WGC2015 format).

Use	Installed Capacity[1)] (MW_t)	Annual Energy Use[1)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[2)]
Individual Space Heating[3)]	67	517	0.25
District Heating [3)]	68	589	0.27
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	69	574	0.32
Fish Farming	121	1,932	0.50
Animal Farming	-	-	-
Agricultural Drying[4)]	-	-	-
Industrial Process Heat[5)]	14	107	0.19
Snow Melting	-	-	-
Bathing and Swimming[6)]	418	3,463	0.26
Other Uses (specify)	-	-	-
Subtotal	**758**	**7,182**	**0.30**
Geothermal Heat Pumps	257	1,500	0.19
TOTAL	**1,015**	**8,682**	**0.27**

Note: [1)] See Appendix A for formulas, [2)] CF= Energy (TJ) / Capacity (MW_t) x 0.03171, [3)] Other than heat pumps; [4)] Includes drying or dehydration of grains, fruits and vegetables; [5)] Excludes agricultural drying and dehydration; [6)] Includes all uses of thermal balneology (cures of any type, rehabilitation, sport and relax).

Table 2: Summary table of geothermal direct heat uses as of 31 December 2010 in Italy (UGI format).

Sector of application	Capacity[1)] (MW_t)			Energy[1)] (TJ/yr)		
	Total	**GSHPs**	**DHs**	**Total**	**GSHPs**	**DHs**
Space heating	393	240	68	2,606	1,400	589
Thermal balneology	418	-	-	3,463	-	-
Agriculture uses	69	13	-	574	75	-
Fish farming	121	-	-	1,932	-	-
Industrial process heat + minor uses	14	4	-	107	25	-
TOTAL	**1,015**	**257**	**68**	**8,682**	**1,500**	**589**

Note: [1)] See Appendix A for formulas.

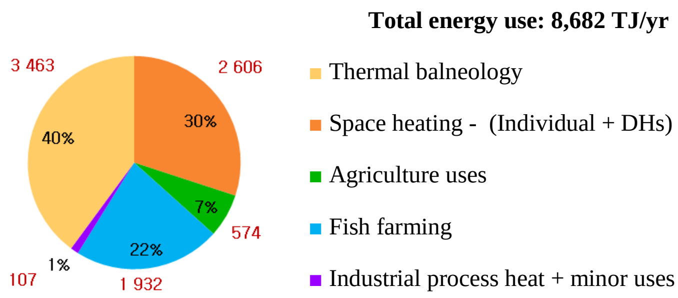

Figure 3: Share of geothermal energy utilization of direct uses in 2010 in Italy.

5. EXPECTED SITUATION AT DECEMBER 2014

The situation at the end of 2014 (with the details required by the WGC-2015 organizing committee) are presented in Table 3 with figures estimated from the confirmed statistics in 2010 and 2012. The estimated totals 2014, broken down into the 5 application sectors established by the UGI methodology, are also shown in Table 4 and Figure 4.

We see in Table 4 that, by Dec. 2014, the total installed capacity is expected to exceed 1,350 MW_t, with an energy utilization of over 11,000 TJ/yr. Out of this total, space heating accounts for almost 42%, thermal balneology for over 33%, fish farming for about 17%, and the rest (less than 10 %) shared between agricultural and subordinate industrial process uses. Therefore, thermal balneology, which had ranked by far the first till 2010, dropped soon after that year to the second place. Heat pump applications, on the contrary, have further increased in recent years; therefore, by Dec. 2014, they are expected to reach a relevant position in terms of geothermal energy delivered (~3,300 TJ/yr), soon after thermal balneology (~3,700 TJ/yr).

Table 3: Summary table of geothermal direct heat uses as of 31 December 2014 in Italy (WGC2015 format).

Use	Installed Capacity[1] (MW_t)	Annual Energy Use[1] (TJ/yr = 10^{12} J/yr)	Capacity Factor[2]
Individual Space Heating[4]	78	606	0.25
District Heating [3]	79	683	0.27
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	69	725	0.33
Fish Farming	122	1,927	0.50
Animal Farming	-	-	-
Agricultural Drying[4]	-	-	-
Industrial Process Heat[5]	18	108	0.19
Snow Melting	-	-	-
Bathing and Swimming[6]	421	3,698	0.28
Other Uses (specify)	-	-	-
Subtotal	**787**	**7,747**	**0.31**
Geothermal Heat Pumps	568	3,318	0.19
TOTAL	**1,355**	**11,065**	**0.26**

Note: [1] See Appendix A for formulas; [2] CF= Energy (TJ) / Capacity (MW_t) x 0.03171;[3] Other than heat pumps; [4] Includes drying or dehydration of grains, fruits and vegetables; [5] Excludes agricultural drying and dehydration; [6] Includes all uses of thermal balneology (cures of any type, rehabilitation, sport and relax).

Table 4: Summary table of geothermal direct heat uses as of 31 December 2014 in Italy (UGI format).

Sector of application	Capacity[1] (MW_t)			Energy[1] (TJ/yr)		
	Total	**GSHPs**	**DHs**	**Total**	**GSHPs**	**DHs**
Space heating	725	550	78	4 607	3 211	683
Thermal balneology	421	-	-	3 698	-	-
Agriculture uses	69	14	-	725	82	-
Fish farming	122	-	-	1 927	-	-
Industrial process heat + minor uses	18	4	-	108	25	-
TOTAL	**1,355**	**568**	**92**	**11,065**	**3,318**	**683**

Note: [1] See Appendix A for formulas.

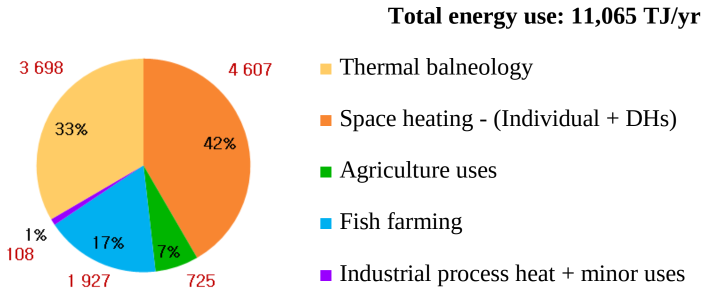

Figure 4: Share of geothermal energy utilization of direct uses in 2014 in Italy.

6. COMPARATIVE DEVELOPMENT 2010-2014

The evolution of direct uses in Italy in the 4 years period 2010-2014 can be drawn from Tables 2 and 4, and are graphically shown in Figure 5. On their base the following main remarks can be made:

- installed capacity has increased from ~1,000 MW_t to ~1,350 MW_t, with an average annual growth rate of over 7%. The increase is mostly attributable to ground-source heat pump installations that have more than doubled their capacity: from ~250 MW_t to over 550 MW_t: an average annual growth rate of some 22%/yr;
- energy use has increased from about 8,700 TJ/yr to ~11,000 TJ/yr, with an annual growth rate of ~ 7 %;
- space heating has become the first utilization sector, growing in terms of energy use from ~2,600 TJ/yr (30 %) in 2010 to ~4,600 TJ/yr (42%) at the end of 2014. As above said, this is mainly due to the notable increase of GSHP applications;
- ground-source heat pumps have more than doubled both in terms of installed capacity (from ~250 to over 550 MW_t), and geothermal energy utilization (from 1,500 TJ/yr to over 3,300 TJ/yr), with average annual growth rates of about 30%.

Table 5: Development of geothermal direct uses in Italy during the 4-years period 2010-2014.

Sector of application	Capacity (MW_t)			Energy (TJ/yr)		
	Total	GSHPs	DHs	Total	GSHPs	DHs
Space heating	+85%	+129%	+16%	+77%	+130%	+16%
Thermal balneology	+1%	-	-	+7%	-	-
Agriculture uses	-	+7%	-	+26%	+9%	-
Fish farming	-	-	-	-	-	-
Industrial process heat + minor uses	+24%	-	-	+1%	-	-
TOTAL	**+34%**	**+121%**	**+16%**	**+27%**	**+121%**	**+16%**

7. CONCLUDING REMARKS AND FUTURE DEVELOPMENT

In presenting the development of geothermal direct uses for 2010-2014 we have felt opportune to mention here the intrinsic difficulties existing in Italy to gather the input data (see section 3.1), and to describe shortly the methodology followed to process data and calculate final figures (see Appendix A). Moreover, we have felt useful stressing that the definition of an agreed-upon standard methodology aimed at assessing the direct uses of the terrestrial heat would result in an improvement of the statistics and would ensure the correct comparison of data and results from different countries. To this aim, UGI would firmly encourage the setting-up by IGA of an ad-hoc working group.

Regarding the final results, both installed capacity and energy use have increased remarkably in the last years. The installed capacity, by the end 2014, will attain values around 1,350 MW_t (+34% with respect to 2010), with the energy rising to some 11,000 TJ/yr (+27% with respect to 2010). The main contribution to the growth is expected to come from GSHP systems through a doubling of both their capacity and energy.

Geothermal district heating networks, in particular, are expanding thanks to the heat pumps technology. Very important instances in this regard are the two DH networks of Canavese and Famagosta districts in Milan (15 MW_t each) that use the water of a shallow phreatic aquifer at ~15°C as heat source (details on these two systems can be found in Grassi et al., 2013).

Other application sectors are also expanding in recent years; in particular, the industrial applications are starting to grow again after a decrease period due to economic reasons. Moreover, several other direct-uses projects are currently under development; among them, the new district heating project of Grado (touristic town near Trieste) and the expansion of the DH system in Ferrara are worthy of mention. In addition, other systems have started operation during 2014, including the DH of the town of Montieri and a brewery in the Boraciferous region of Tuscany that uses geothermal steam to feed its industrial equipment. To sum up, jointly with the hoped recovery of the Italian economy, we expect that direct uses of geothermal energy will also increase in the next years, especially in space heating applications.

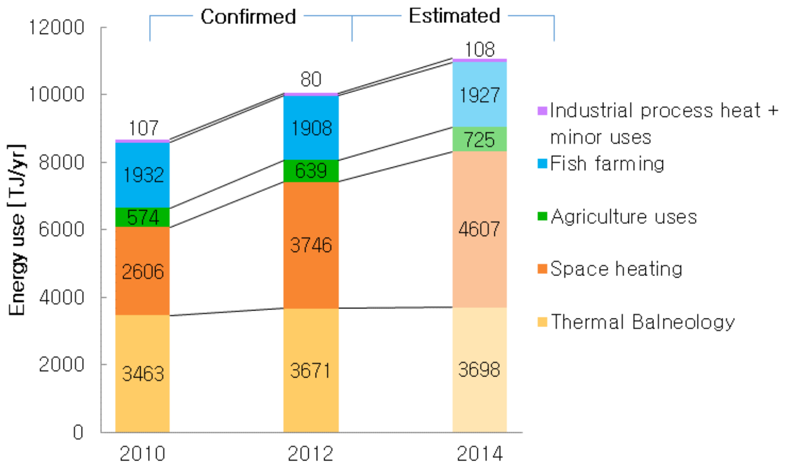

Figure 5: Development of the different sectors of direct uses in Italy (2010-2014).

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APPENDIX A: METHODOLOGY FOR ENERGY ASSESSMENT OF DIRECT USE SYSTEMS.

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 3, 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:

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

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.

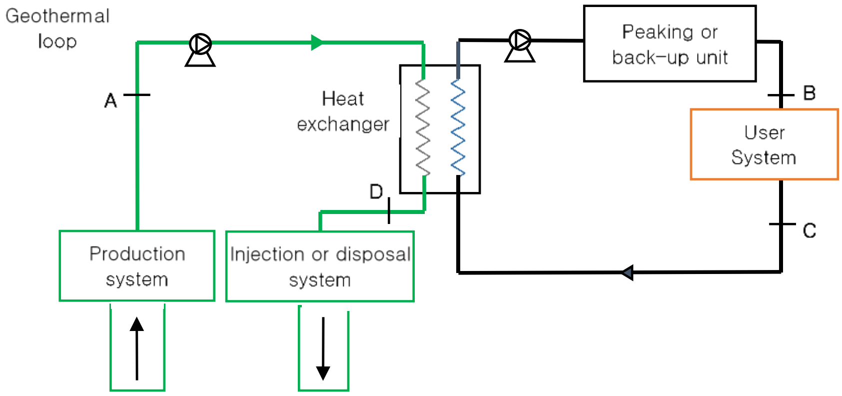

Figure A.1: Direct-use system with heat exchanger (after Lund, 1982). The green path indicates the geothermal fluid.

A.2. Direct use of geothermal fluid

This configuration is typically used in thermal balneology and fish farming applications (Fig. 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.

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

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);
- $\bar{T}_A$ 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.

$$E_{th} = E_{TOT} \cdot \alpha = E_{TOT} \frac{T_A - T_0}{T_B - T_0} \quad \text{(A.5)}$$

This methodology for the evaluation of the geothermal share of total energy used has already been followed for thermal balneology systems by Cataldi and Conti 2013.

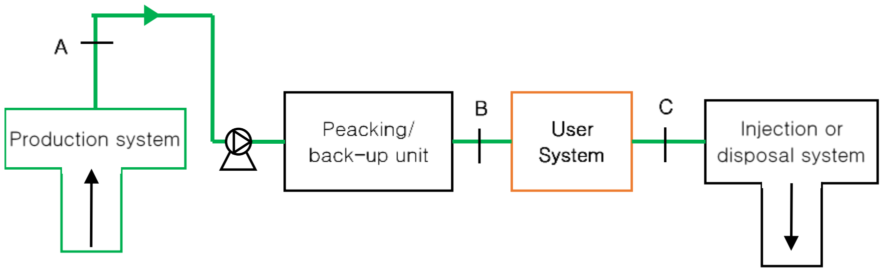

Figure A.2. Direct use system without heat exchanger (after Lund, 1982). The green path indicates the geothermal fluid.

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).

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

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 have used a precautionary value of COP_{DC} equal to 4. The energy delivered by GSHPs has been calculated according to the EOHs suggested by the European decision 2013/114/EU.

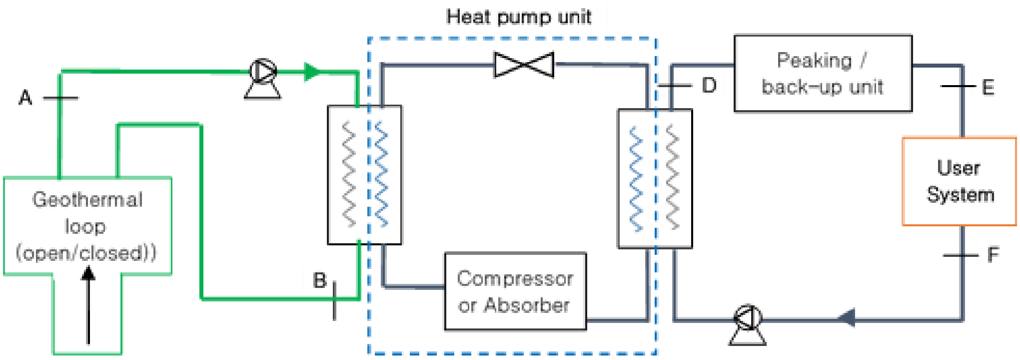

Figure A.3. Direct use system with geothermal heat pumps. The green path indicates the geothermal fluid.