European Geothermal Congress 2016
Strasbourg, France, 19-24 Sept 2016

Geothermal Energy Use, Country Update for Greece

Maria Papachristou[1], Dimitrios Mendrinos[2], Paschalis Dalampakis[3] Apostolos Arvanitis[4], Constantine Karytsas[2], Nikos Andritsos[5]

[1] Department of Geology, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

[2] Centre for Renewable Energy Sources and Saving, 19th km Marathon Avenue, 19009, Pikermi, Greece

[3]Institute for Soil and Water Resources, Greek Agricultural Organization "DEMETER", 57400, Sindos, Greece

[4]Institute for Geology and Mineral Exploration, 1 Sp. Louis str., 13677 Acharnae, Greece

[5]Department of Mechanical Engineering University of Thessaly, Leoforos Athinon, 38334, Volos, Greece

mariap@geo.auth.gr

Keywords: geothermal activities, exploration, energy production, direct uses

ABSTRACT

Geothermal energy in Greece is still being utilized only for direct uses, mainly in the agricultural, healing and recreation sectors (spa facilities, greenhouses, soil heating, aquaculture, and fish farming). The most important investment in geothermal energy during the recent years, regards the operation (since 2014) of a new hydroponic geothermal greenhouse unit in Neo Erasmio (Xanthi, Northern Greece), currently covering 8.2ha. Further exploitation of the low enthalpy geothermal potential is under way in the geothermal fields of Eratino-Chrysoupolis and Aristino (Northern Greece). The production of geothermal electricity still remains a desideratum, despite the proven high enthalpy potential in Milos and Nisyros islands (>30 MWe confirmed through drilling, >200 MWe estimated) and the strong indications for the existence of medium enthalpy reservoirs in Northern Greece and certain Aegean islands (e.g. Chios, Lesvos, Samothrace). The projected geothermal power production pertains, at the moment, to the construction of small units (5-8 MWe) in six allocated concessions. The most significant growth of the Greek geothermal market comes from the considerable increase of installed GSHP systems (~3000 units). The exploration for low enthalpy geothermal resources is still on-going in some areas, e.g. Sidirokastro, Eastern Thessaly, Lemnos and Lesvos islands.

1. INTRODUCTION

The energy mix of Greece is somewhat different compared to the EU28 average; the use of petroleum and solid fuels is much higher, whereas no nuclear power is produced and the gas use is relatively low. On the other hand, there has been considerable progress during the recent years in new photovoltaic (PV) and wind power installations totaling approximately 2.4 GWe wind and 2.0 GWe PV of installed capacity in operation by the end of 2016, resulting in national fuel to electricity generation ratio of ~2. Even so, the penetration of Renewable Energy Sources (RES) in the national energy balance still does not reflect the country's enormous potential.

Figure 1: The most important geothermal exploration and exploitation sites in Greece

The geothermal conditions in Greece are favourable, or even ideal in some cases, due to the country's geotectonic regime. So far, the geothermal exploration has confirmed the existence of high enthalpy resources only in Milos and Nisyros islands (Figure 1). In addition, medium enthalpy resources most probably exist along the Aegean volcanic arc, in Northern Greece and in some Aegean islands. Nevertheless, in spite of the urgent necessity for reducing the energy import dependency, Greece still imports oil to provide power to many of the "geothermal" non-interconnected islands.

Numerous low enthalpy reservoirs in economic depths (<500m) have been discovered all around the country. Their potential is estimated to approximately 1000MWt (Andritsos et al., 2015), however only about 9% of the corresponding resources are currently under exploitation.

The total installed geothermal capacity has been increased by 22% since 2013, which, however, is mostly attributable to the GSHP installations. The GSHP market is expected to develop even more in the coming years, due to the European legislation requirements for total coverage of the primary energy consumption through energy supplied from RES, CHP, district heating and heat pumps for all new public and private buildings after 31.12.2019.

2. ENERGY USE IN GREECE

As a result of the crushing economic crisis that has hit Greece since 2008, and the consequent severe austerity and recession, the gross energy consumption in Greece has been decreased by 23% in the last 7 years (Eurostat-2014 Energy Balance, January 2016 edition). Yet, the situation was stabilized after 2013, with the consumption presenting a very slight increase of 0.05% (24.4 Mtoe) in 2014.

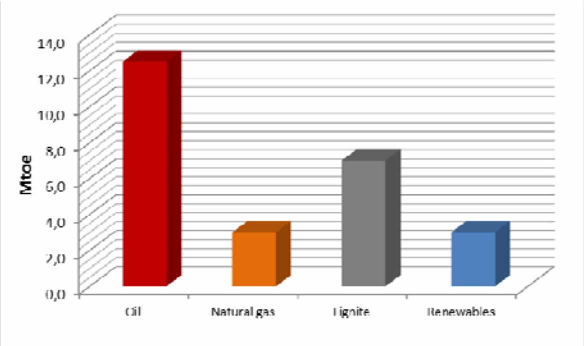

Figure 2: Gross energy consumption in Greece for the year 2014 (source: Eurostat, 2016)

Oil continues to dominate the energy balance in the country (Figure 2), representing more than half of the gross energy consumption (12.03 Mtn). The Renewable Energy Sources (including hydropower, wind, geothermal, solar, biomass and waste energy) made up almost 10% (2.45 Mtoe) of the energy demand, exhibiting a 6% drop compared to 2013.

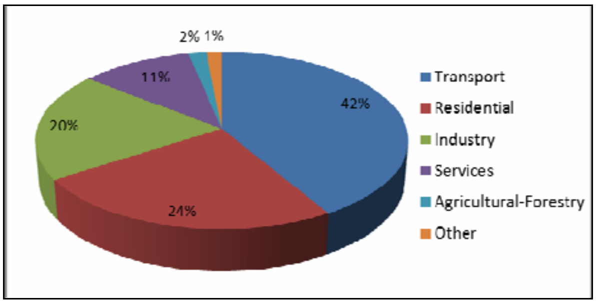

Figure 3: Final energy consumption by sector for 2014 (source: Eurostat, 2016)

Transport remains the most energy-consuming sector, followed by residential use, industry, services, and agricultural-forestry activities. The breakdown of the *final* energy consumption in Greece is illustrated in Figure 3.

The primary energy production in 2014 was 8.8Mtoe (Eurostat, 2016). Lignite holds the largest share (72.4%) of the domestic production, whereas the renewables the 26.7% (2.35Mtoe), with a small contribution (1.35%) of geothermal energy (Table 1).

Table 1: Primary energy production of Renewable Energy Sources by type, for 2014 (Eurostat, 2016)

Energy Source	Energy Production (ktoe)	Share (%)
Solid Biomass	869	36.98
Biogas	87	3.70
Biodiesel	142	6.04
Solar	518	22.05
Wind power	317	13.49
Hydropower	385	16.39
Geothermal*	31.7	1.35
TOTAL	2349.7	100

* *GSHP included (source: CRES)*

Renewable electricity accounted for 22% (1.12 Mtoe) of the total electricity generation in Greece (5.1Mtoe) at the end of 2014 (Eurostat, 2016). As mentioned above, no electricity is produced from geothermal energy. Hydro (413.3ktoe), wind (357ktoe) and solar energy (326ktoe) cover the 98% of the total domestic renewable power production.

3. GEOTHERMAL POTENTIAL & EXPLORATION

The confirmed high enthalpy potential in Milos and Nisyros islands exceeds 30MWe; however it is estimated to outreach 200MWe. Medium enthalpy resources with temperatures up to 120°C are probably present in the continental extension of the Aegean volcanic arc, in Northern Greece and in certain Aegean islands, such as Chios, Samothrace and Lesvos.

The thermal energy contained in the low enthalpy reservoirs that have been discovered up to depth of 500m, is estimated to roughly 1000MWt. Such resources can be found almost everywhere in Greece, but they are mostly located in the tectonic basins of Northern Greece basins and in several Aegean islands.

Limited geothermal exploration was carried out during the period 2013-2016. No progress was made for the exploration of the medium enthalpy reservoirs in Northern Greece (Chios island, Samothrace island, Evros River Delta and Nestos River Delta), after the withdrawal of the contractor from the project. Similarly, the exploration has not started yet in Sperchios Basin (Central Greece), Akropotamos (Eastern Macedonia), Soussaki (Central Greece) and

Ikaria Island (Figure 1). The exploration rights for the above areas have been awarded to the Public Power Corporation (PPC) Renewables S.A., after an international open tender in 2011.

The exploration for low enthalpy geothermal resources is still on-going by the Institute of Geology and Mineral Exploration (IGME) in the following areas:

Sidirokastro (Strymonas Basin, Northern Greece): An area of extensive hydrothermal alteration has been recognized and mapped in the northern part of the probable low temperature geothermal field of Sidirokastro. Previous studies were reviewed and evaluated in order to determine the location of four (4) new production geothermal wells. Geothermal fluids of approximately 75°C are expected to be found at depths of 100-300m. The Environmental Impact Study (EIS) for the proposed drilling project has been completed and submitted to the competent authority (Arvanitis et al., 2016).

Lemnos Island (NE Aegean Sea): A preliminary study was conducted in Lemnos Island, including geological and structural field observations, water temperature measurements at existing wells and natural springs, water sampling and analyses. This reconnaissance research has resulted in the identification of a new area of geothermal interest in the south-eastern part of the island (Moudros area), wellhead temperatures of 24-29.6°C have been measured at existing 70-105m deep wells (Arvanitis et al., 2016).

Lesvos Island (NE Aegean Sea): A promising geothermal area was identified in the area of Mytilene, where shallow (up to 150 m) existing wells produce waters at temperatures of 30-33°C. The preliminary study regarded geological and structural field observations, geophysical survey, water temperature measurements at existing relatively shallow wells and natural springs, as well as water sampling and analyses in the eastern part of Lesvos Island (Xenakis et al., 2016).

Eastern Thessaly (Central Greece): Preliminary reconnaissance study was conducted in certain areas of eastern Thessaly. In the Faros-Paliourio area, the temperature of 39.9°C was measured at the head of a 270m deep well. In the Chalki-Kileler and Mikrothives-Almyros areas, irrigation and water supply wells (depths up to 280m) produce waters of 16.6-19.6 and 17.9-30.2°C, respectively. North of Farsala town, in the Krini - Zoodochos Pigi - Aghios Georgios area, the wellhead temperatures vary between 20.3 and 26.3°C. The survey was focused in the area of Ampelia-Farsala, where existing 235-410m deep irrigation wells produce low salinity waters (0.3 g/l) at 35.1-41.3°C. According to the geological and structural field observations, the evaluation of temperature measurements, the results of water analyses and the interpretation of the geophysical survey, the location and the probable depth of four (4) new large diameter geothermal wells was determined. The Environmental Impact Study for the proposed drilling project has been completed and submitted to the competent authority (Vakalopoulos et al., 2016).

Edipsos (Euboea Island, Central Greece): The exploration work regarded mapping of the existing thermal springs (onshore and submarine) for providing a more complete understanding of the hydrothermal system in this area. Water temperatures of 30-82°C have been recorded (Vakalopoulos et al., 2016).

Lithotopos-Iraklia (Serres, Northern Greece): The location of four (4) new geothermal wells has been determined, after the performance of extensive exploration works, such as: water temperature measurements, sampling and chemical analyses, soil gas measurements (CO_2 and radon concentrations, CO_2 flux) and geophysical surveys (Time Domain Electromagnetic Method) (Arvanitis et al., 2015).

The exploration in Sidirokastro, Lemnos, Lesvos, Eastern Thessaly and Edipsos was funded by the NSRF (National Strategic Reference Framework) 2007-2013. The works in Lithotopos-Iraklia area were conducted under a contract made between I.G.M.E and the Municipality of Iraklia.

In the period 2014-2015 a geothermal project was carried out in the island of *Santorini*. It was conducted by the University of Thessaly in collaboration with the Aristotle University of Thessaloniki, funded by the Municipality of Thera. The project regarded, among others, the geothermal evaluation of the island's shallow aquifers. The extensive thermometric research revealed a very interesting zone of geothermal anomaly in the central part of Santorini, with temperatures exceeding 26°C at very small depths (5-100m). The applied geothermometers (SiO_2, Na/K and Na/K/Ca) indicate initial reservoir temperatures up to 150°C, similar to those estimated by Fytikas et al. (1989) and Mendrinos et al. (2010). The probable depth of the medium enthalpy reservoir is 700-1000m, inside the crystalline karstified and/or fractured limestones of the basement.

Furthermore, the Municipal authorities of Alexandroupolis and Chrisoupolis have expressed their interest to develop the following local low to medium enthalpy geothermal resources for cogeneration of heat and power:

- possible deep geothermal resources of >90°C below 500m depth in Aristino.
- possible deep geothermal resources of >120°C at ~1.5 km depth in Eratino.

4. GEOTHERMAL ENERGY USES

4.1. Power Production

No geothermal power is currently produced in Greece. PPC Renewables S.A. owns the geothermal concessions for the confirmed high enthalpy geothermal fields of Milos and Nisyros islands, as well as for exploring the geothermal potential of Kimolos and Lesvos islands and the geothermal fields of Methana (Peloponnese) and Akropotamos (Kavala, Northern Greece).

As a first development stage, PPC-R intends to carry out exploration activities aiming at developing 5-8 MWe geothermal heat and power cogeneration plants in the above mentioned areas. The accompanying thermal applications may include seawater desalination, district heating and cooling, as well as agricultural thermal uses, according to local needs.

Milos island: The proven high enthalpy geothermal resources are more than enough to cover local power needs of 8 MWe for the residential and tourist sectors and 8 MWe for industrial use.

Kimolos island: The potentially high enthalpy geothermal prospect, adjacent and interconnected to Milos Island, will be exploited.

Nisyros island: The confirmed high enthalpy geothermal potential can cover the power needs of the island and the near-by, interconnected by submarine cable, Kos island.

Lesvos island: The first geothermal cogeneration plant of Greece is likely to be installed in Lesvos, with a capacity of 8MWe plus 8MWth, exploiting the medium enthalpy resources of the island. The local power needs amount at around 50 MWe and are currently served by a fuel oil thermal power plant.

Methana Peninsula: A potentially high enthalpy geothermal resource, as in the area the second active volcano of Greece is located, with last eruption at 230 BC and reported activity in the beginning of last century.

Akropotamos Kavala: It is a newly acquired geothermal concession by PPC-R, corresponding to a low to medium enthalpy geothermal prospect.

The geothermal potential of the shallow reservoirs in Milos island (with temperatures up to 90-100°C), which was supposed to be exploited for binary cycle power production during the 2000's, remains unexploited. Nevertheless, there has been renewed interest by the local Municipality of Milos to develop these shallow geothermal resources.

4.2. Direct Uses

The direct use of geothermal energy in Greece includes balneotherapy (bathing and swimming), space/soil/greenhouse heating, aquaculture, vegetable drying and ground-source heat pumps. The installed capacity and annual energy use of such applications are presented in Table. 2. The total installed capacity as of March 2016 is estimated to 231.76 MWt, showing a 22% increase compared to the corresponding data for 2013 (Andritsos et al., 2013).

The GSHP applications represent more than 60% of the total installed capacity in the country, followed by balneotherapy and greenhouse heating. The relative value for balneotherapy is indicative, and rather conservative, since no systematic study for the energy use in this sector has been carried out. Furthermore, official data for the GSHP installations exist only for 2014. The numbers for the installed capacity and annual energy use of GSHPs presented in Table 2 have been estimated according to the increase rate over the past few years.

Table 2: Installed capacity and annual energy use of direct applications (March, 2016)

Use	Installed Capacity (MWt)	Annual Energy Use (10^{12} J)
Balneotherapy	42	251
Greenhouse Heating	33.38	571
Soil heating	4.42	19.06
Dehydration	0.58	5.54
Space Heating	1.65	17.82
Aquaculture	1.26	18
Fish Farming	0.05	0.91
Subtotal	**83.76**	**883.33**
GSHP*	148	709
TOTAL	**231.76**	**1592.33**

** estimated. For 2014: 135MWt, 648 TJ (CRES, 2016)*

Balneotherapy

The therapeutic properties of thermal mineral waters are well known since antiquity. Balneotherapy is widely practiced till our days and constitutes the most common use of geothermal waters in Greece. More than 750 thermal and mineral springs have been recorded in the country, most of which can be exploited as "curative". Currently, 348 springs are used for balneotherapy and drinking, however, approximately only 80 of them are officially declared as "curative springs". The temperature of the thermal springs varies from 25 to 92°C, with the hottest spring being in Polichnitos (Lesvos Island). The temperature of the water used in the bathing facilities varies from 25-48°C, however, it does not usually exceed 35-39°C. One of the best and more impressive balneological sites in Greece is Edipsos (Euobea Island, Central Greece), with more than 70 thermal springs and temperatures up to 86°C.

Most of the nearly 70 operating spas and bathing centers, as well as the 25 outdoor swimming pools that use geothermal waters, provide their services from June to October and only a few remain open throughout the year. The geothermal fluids are exploited only for therapeutic purposes, except from two cases (Nea Apollonia and Traianoupolis Spa Centers, Northern Greece), where the hot water is also used for the heating of the facilities.

The energy use in the balneological centers of Greece was approximately estimated to 251TJ, corresponding to an installed capacity of 42MWt, taking into account an average ΔT=10°C and a total maximum flow-rate about 1000kg/s.

Greenhouse heating

Geothermal energy is used for greenhouse heating in Greece since the early 1980's. The first facilities were constructed in Northern Greece (Apollonia, Langadas, Nigrita, Nea Kessani) and Lesvos island (Polichnitos).

Some of the older greenhouses are currently either closed or they use a different heating mix, for reasons not related to geothermal energy but rather to bureaucratic/licensing issues.

About 63% of the operating greenhouses are actually plastic-covered and utilize waters with temperatures 35-60°C. In majority, the cultivated plants are vegetables, such as tomatoes, cucumbers, peppers and green beans.

The geothermal water is generally used directly to the heating installations due to its good quality. The heating methods include: (i) circulation of hot water through pipes located inside the soil or on the floor or are suspended at certain height, (ii) forced circulation of warm air, and (iii) finned metal units or combination of the above (Andritsos et al., 2010; 2013; 2015)

As of March of 2016, 19 greenhouses were in operation in continental Greece and in the islands of Milos and Lesvos. The total installed capacity is estimated to 33.38 MWt and the annual energy use to 571 TJ/y, corresponding to an average capacity factor of 0.43.

In 2014 a new hydroponic geothermal greenhouse was constructed in Neo Erasmio (Xanthi, Northern Greece). It consists of four plantation units covering 4.0 ha in total, which produce 800 tons of tomatoes and 900 tons of cucumber, annually. The investment reached approximately €5.000.000 and has created more than 60 working positions, constituting the most important investment in the Greek geothermal energy market. Heating process is achieved by using 250m^3/h of geothermal fluids from two geothermal wells, with an average temperature of 60°C. Geothermal fluids circulation is achieved through two independent pipe arrangements, either iron or plastic, placed on the ground in the circumference of the planting rows (Figure 4).

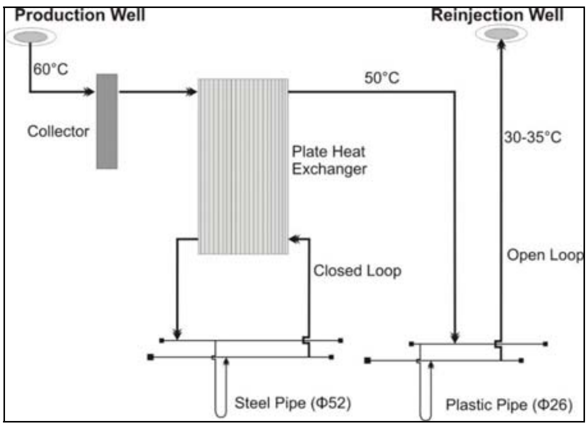

Figure 4: Heating system of the greenhouses in Neo Erasmio (Xanthi, Northern Greece)

Geothermal fluids are re-injected with a mean temperature of 30°C. The greenhouse installations were expanded by another similar 4.0 ha unit in 2015 and two new production wells incorporated to the geothermal layout. The new wells tap the same geothermal aquifer at 250m depth, with water temperature close to 60°C. The maximum production yield in Neo Erasmio geothermal field is actually totalizing more than 500m^3/h. The installed heating capacity and the annual energy use are 13,81 MWt and 296.78TJ, respectively.

<u>Soil Heating</u>

The use of low enthalpy geothermal fluids for soil heating in intensive non-covered cultivations was applied for the first time worldwide in Neo Erasmio (Xanthi, Northern Greece) for the production of off-season white and green asparagus. The same heating method has been occasionally applied in the same area for early lettuce and other vegetables (strawberry & watermelon) cultivation.

The asparagus cultivation area in Neo Erasmio currently covers 2.0 ha, exhibiting a significant decrease since the beginning of this project in 1998. This reduction is in no way related to the availability of geothermal energy, but mostly to the exceeding of the crop productive period (>12-15 years).

The heating baseline is simple: the asparagus rhizomes are planted into linear soil trenches at a mean depth of 25cm. Geothermal fluids circulate through plastic PP or PE pipes placed either on the subsoil beneath asparagus crowns or on the ground at the base of the soil "ridges", in a U-bond arrangement. They enter the pipes with temperature that can vary from 30 to 60°C, following the available initial temperature of geothermal waters. Reinjection temperature doesn't exceed 28-30°C in order to avoid adverse overheating of the crops. The required heating loads range between 100-150 KW/ha, depending on the outside temperature and the period of the heating procedure onset. The installed capacity and the annual energy use are about 3.37 MWt and 10.16 TJ, respectively.

In 2005 a similar 3.0 ha heated asparagus cultivation was installed in Myrodato (Xanthi, Northern Greece), using geothermal fluids of 50°C. The installed capacity is 1.05 MWt and the annual energy use 8.90TJ.

Geothermal soil heating in non-covered off-season asparagus cultivation is also applied since 2006 in Chrysoupoli (Kavala, Northern Greece), using open-loop geothermal heat pump systems. This case will be discussed in the GSHP section.

<u>Space/District Heating</u>

The use of geothermal energy for space and district heating is limited. Currently, a small school building in Traianoupolis (Thrace, Northern Greece), two spa facilities (Nea Apollonia, and Traianoupolis), a 2000m^2 area of offices and process facilities in the Neo Erasmio greenhouse unit, as well as a few houses in Northern Greece and one small hotel in Milos are heated with low enthalpy geothermal fluids. The total installed capacity of the space heating units is approximately 1.65 MWt.

The district heating project “Thermopolis” in Polichnitos (Lesvos Island), which was completed a few years ago, would use geothermal waters of 88°C for the heating of five public and municipal buildings. The system is still out of operation due to the failure of the submersible pump.

Dehydration of Agricultural Products

The pioneering concept of using low enthalpy geothermal fluids for tomato drying was realized for the first time worldwide in Neo Erasmio (Xanthi, Northern Greece). The dehydration plant operates since 2001 during the period August-September and has produced, so far, more than 150tn of excellent quality dried tomatoes. The unit uses geothermal fluids of 59°C, which pass through a water-air heat exchanger that produces hot air at 55-58°C. The latter is then driven to the drying tunnels with the aid of two fan units. The mean flow rate of the geothermal water is $25m^3/h$, while the air flows inside each tunnel at a rate of $14.000m^3/h$. The unit is also used for the occasional dehydration of other vegetables and fruits, such as olives, asparagus, peppers, eggplants, apples, melons, etc. Detailed discussion on the design, operation and performance of the plant can be found in Andritsos et al. (2003) and Kostoglou et al. (2013).

Aquaculture/Fish farming

The geothermal aquaculture/fish farming projects regard spirulina cultivation and ornamental fish breeding. The fish farming facility that was using geothermal water for anti-frost protection in Neo Erasmio (Xanthi, Northern Greece) is out of operation, due to administrative issues not related to geothermal energy. Moreover, the anti-frost protection in the Porto Lagos (Xanthi, Northern Greece) fish-farms is no longer accomplished with the use of geothermal energy, due to technical problems of the wells.

Spirulina cultivation started in Nigrita (Serres, Northern Greece) in the late 1990’s. Today three plants are in operation in this area, covering 0.9ha in total. The geothermal fluids (50°C) are not used directly to the raceway ponds because they contain small concentration of toxic substances. The total average required flow-rate, in order to maintain the cultivation water temperature at 33-36°C, is $25m^3/h$ and the maximum $55m^3/h$. The total installed capacity of the three units is 1.26MWt.

A small pilot unit for ornamental fishes breeding in geothermal water operates since 2014 in Neo Erasmio (Xanthi, Northern Greece). This case is particularly interesting because the geothermal water is not only used as a heating source but also serves as the growing medium. The aim of this project is the investigation of the optimum prerequisites for the oviparity, pre-fattening and fattening of the fish under the specific weather and geothermal conditions. The unit consists of 52 plastic breeding tanks of different sizes (from $4.5m^3$ to 700lt). The geothermal water enters the unit with a temperature of 48°C at a maximum flow rate of 2 m^3/h. Optimum water temperatures in the growing tanks are in the order of 23-26°C. This thermodynamic target has been absolutely achieved even with extreme outside temperatures (-10 to -12°C). After almost two years of operation, it can safely be concluded that the adaptability of ornamental fish to the geothermal water is excellent.

4.3 Ground Source Heat Pumps

Geothermal (Ground Source) heat pumps (GSHP) market (Figure 5) has been developed in Greece by the Centre for Renewable Energy Sources and Saving (CRES) during the 2000s, starting by a series of pilot projects (2000-2006) and followed by several well-targeted workshops (2007 onwards), funded by European and National programmes. By late 2000s, sufficient capacity of installers had been created, who continued to further develop the market, with the support of CRES by additional workshops, seminars, feasibility studies and specialized services (Thermal Response Tests – TRT).

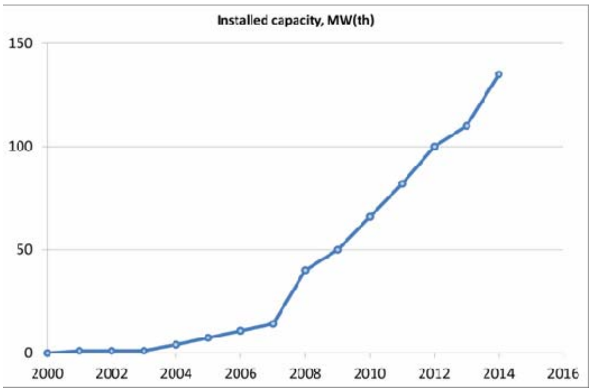

Figure 5: GSHP market development in Greece

During the 2010s, and despite the financial crisis, GSHP market grew further, assisted by newly introduced favourable legislation, reaching 2632 installations by the end of 2014. More specifically, CRES has recorded 2449 GSHPs with low capacity (avg. 29KW) and 183 of high capacity (avg. 349 KW), totaling an overall capacity of 135 MWt. There are no official data for 2015, but a 15% increase for the low capacity and 5-10% for the high capacity installations, would be a reasonable estimation (see Table 1).

The vast majority of the GSHP installations regard heating and cooling of residential and office buildings, however the use of heat pumps is also widespread in the hotel sector. Many installations use sea water as heat source, whereas a few use open loop GSHPs exploiting the saline water table near the coast. The few GSHP applications related to the agriculture/industrial sector include soil heating of asparagus plantations (19ha), five greenhouses (1.4ha), a poultry farm and a winery.

Despite the prevailing low oil prices since the second half of 2014 (Figure 6), GSHPs market is expected to further grow during the next years, mainly in areas not accessible by the natural gas network, aided by the favourable legal framework.

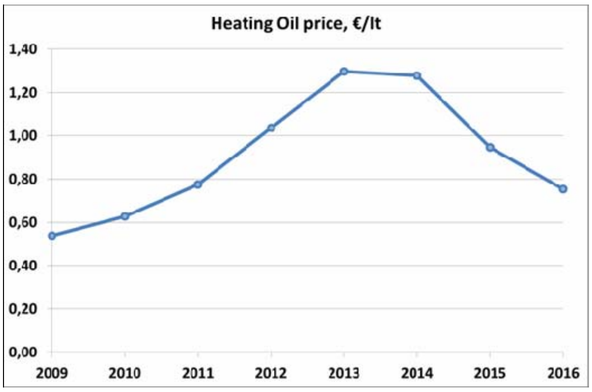

Figure 6: Heating oil price evolution in the Greek market

A few selected examples of new or innovative GSHP applications are described in the following paragraphs.

Heating of swimming pool of Ilida

A series of GSHPs have been installed during the past years for heating public swimming pools. One such example is the newly constructed open Olympic swimming pool of Ilida (Western Peloponnese) of 1050 m² surface and 2205 m³ volume. The heating needs of the swimming pool and for the sanitary water at the swimmers baths are covered by two ground source heat pumps of 400 kW(th) capacity each. Both heat pumps are placed in series, fed by an open loop doublet comprising two 100m deep wells, supplying 70m³/h of groundwater with a temperature of 18°C through a heat exchanger. The water is re-injected at 10°C. The capital costs of the GSHP system were around 500 k€ and the estimated payback time was, approximately, 1 year.

Heating and cooling of hotel Amalia in Nafplio

Use of heat pumps for heating, cooling and sanitary hot water is widespread in the hotel sector in Greece. There are many installations using sea water as heat source and a few using open loop GSHPs exploiting saline water table near the coast. One such example is the 4 star Amalia hotel in Nafplio, a building with around 9000 m² air-conditioned spaces. Hotel heating and cooling needs are covered by 4 GSHPs supplying 740 kW heating and 566 kW of cooling with fan-coils. The GSHPs are fed through a heat exchanger by an open loop geothermal doublet comprising one production and one reinjection well 60 m deep each, supplying 60 m³/h of groundwater at 18 °C. System SPF values are 4.77 in heating and 3.65 in cooling mode.

De-icing of pavements in Karpenisi centre

During the recent renovation works at the centre of Karpenisi, a small town and well known tourist resort located in Evrytania (Central Greece), a geothermal pavement heating system was installed. It is supplied by 28°C warm water from a closed loop GSHP, coupled to a 100 m deep BHE of 14 °C ground temperature. The geothermal system is turned on automatically when ambient temperature drops below +2°C and effectively melts and clears the snow and ice from the pedestrian ways, as proven during its first year of operation last winter (2015-2016).

Heating and Cooling in Winery

The first winery in Greece using geothermal energy is located in Latzoi, a small village near ancient Olympia in NW Peloponnese. Brintzikis winery is a small family owned business, which produces annually 500 tons of wine from locally grown grape varieties. It is also the first winery in Greece with zero carbon footprint, thanks to its two ground source heat pumps systems coupled to photovoltaic panels. The heat, cool and chill that are required for the wine storing, the treatment and decantation of must, the alcoholic fermentation and to maintain the space temperature at 18°C during the period May-October, are provided by a pair of ground source heat pumps providing 57 kW heating and 53 kW cooling each. The seasonal energy efficiency (SPF) of the GSHPs is equal to 4.75 for heating and 5.30 for cooling. The 100m deep borehole heat exchangers deliver water of 16°C to the GSHPs in heating mode during winter and of 20°C in cooling mode during summer. Useful energy delivered by the GSHPs is estimated at 152 MWh for cooling plus 17 MWh for heating with 32 MWh(e) corresponding electricity consumption. In addition, the PVs provide another 150 MWh(e) of renewable electricity every year. GSHP system installation costs were 60 k€ and payback time is estimated to 4-5 years.

Heating and cooling of AB green store

AB green store is located in Stamata, a north suburb of Athens. It belongs to one of the market leading chain of supermarkets operating in Greece. The indoor spaces of the store comprises 1334 m², consisting of sales areas, supporting offices, spaces and warehouse facilities at the basement. AB green store was built with the objective to minimize energy use and improve the environmental footprint of AB supermarkets to 772 kg CO_2/ m².

Space heating and cooling needs of the store are provided by a ground source heat pump supplying two air handling units and fan-coils, operated automatically by the store BEMS (Building Energy Management System). The air handling units, the building loop water vessel and pumps are located at the roof. Building loop water temperatures are 40/45°C in heating mode and 7/12°C in cooling mode. The GSHP delivers 101 kWth of heating in winter and 87 kWc of cooling in summer. The corresponding electricity consumption is ~23 kWe. The efficiency of the GSHP is COP=4.35 in heating mode and COP=4.04 in cooling mode. The GSHP system provides high quality indoor thermal comfort with zero noise levels.

The GSHP is coupled to a horizontal ground heat exchanger, which covers a horizontal area of 1900 m² beneath the parking place. The water temperature supplied by the ground heat exchanger to the heat pump varies in the range 5-18°C during winter heating and 15-28°C during summer cooling.

Soil heating in Chrysoupolis

Water to water geothermal heat pump systems have been installed and are already working in five white asparagus plantations (19 ha) in the wider area of Chrysoupolis (Kavala, Northern Greece) since 2006. The region of Chrysoupolis is well known for the extended asparagus fields that cover almost 1000 ha.

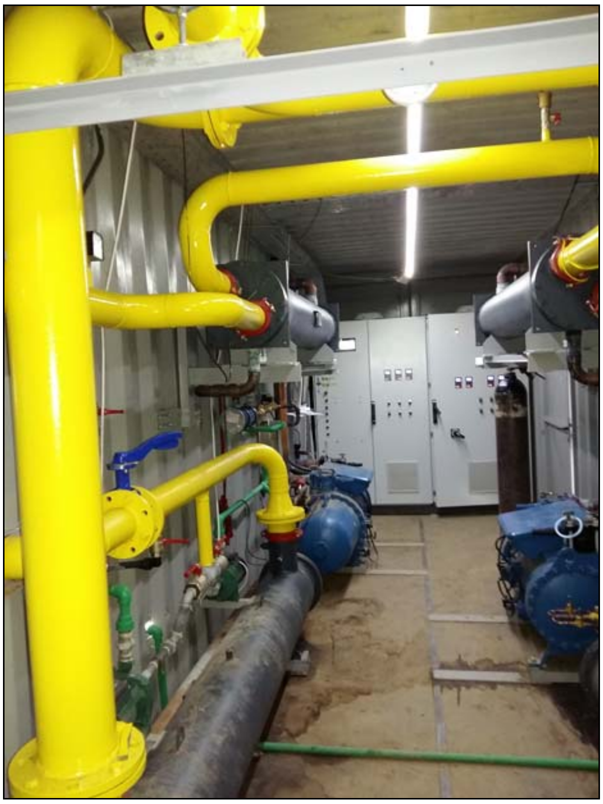

Figure 7: Two stage 1.1 MW open loop heat pump installations in a 9ha asparagus plantation in the area of Chrysoupolis (Kavala, Northern Greece).

The total heating power provided to the plantations reaches 2.2MW. The fluid in the secondary loop of the evaporator's side of the heat pumps is the water of low depth aquifers (30-100 m) that enters the heat pumps with temperature ranging between 16.0 and 19.5°C. When the temperature of the water exceeds 18°C, heat extraction is realized by successive evaporation in two stages, in a serial configuration enhancing the rational management of the water resources. The heat extracted from the water (open loop) is transferred to the asparagus field within PE pipes (20 mm diameter) (closed loop). The maximum field-entering temperature does not exceed 35°C. The obtained coefficient of performance (C.O.P.) ranges from 4.0 to 5.0. The heat pumps provide (at very low cost compared to conventional fuels) the thermal energy required by the asparagus field (white or green) to accomplish the desired early production (Figure 7)

Bioclimatic building of CRES

In the framework of the ongoing Horizon 2020 innovative action Cheap-GSHPs "Cheap and efficient application of reliable ground source heat exchangers and pumps", CRES is renovating the GSHP heating and cooling system of its bioclimatic office building. A new ground loop is under installation comprising one open loop doublet with plate heat exchanger, as well as 4 different types of BHEs: coaxial, spiral, single-U and double-U. In addition, new BHE drilling technology is tested and ground thermal properties are defined through TRTs and laboratory testing of formation core samples.

Except the above-mentioned examples of GSHP installations, some other non-residential applications can be briefly referred, such as: the under construction building of the Region of Central Macedonia in Thessaloniki (the largest application in the country), an indoor swimming pools in Veria (Northern Greece) and Chalandri-Attiki (closed loop system), schools in various areas (e.g. Serres, Thessaloniki, Athens, Chalkidiki, Nafpaktos, Messolonghi), nurseries and preschools (Attiki), vacation apartments (Sivota Thesprotia, Pelio), gas station (Thiva, open loop system), warehouses (Thessaloniki), greenhouse (Thessaly), commercial properties (Thessaloniki, Komotini), Casino Mont Parnes (Parnitha, Attiki), hotels (Athens, Attiki), etc.

5. ONGOING GEOTHERMAL ACTIVITIES

The international open tenders announced in 2011 for the leasing of the exploration or exploitation rights of certain geothermal fields (Evros River Delta, Nestos River Delta, Samothrace Island, Chios Island, Sperchios, etc) have been officially declared void, as no contract was ever signed. These tenders regarded exploration/exploitation activities focusing at finding geothermal resources suitable for binary cycle power generation.

Since then, the geothermal activities are limited to the exploitation of low enthalpy resources, mainly in Northern Greece. The most significant under way geothermal projects are described as follows:

(1) Geothermal field of *Aristino* (Alexandroupolis, Northern Greece): The exploitation rights have been awarded to the Municipal Authority of Alexandroupolis. The investment plan pertains to the cascade utilization of 89°C geothermal fluids for the district heating of 20 public buildings and 4.0ha of greenhouses, using an 18.5km long distribution network, as well as to the construction of a new production and two reinjection wells at the depth of 500m. The budget for the required infrastructure works (heat production, transmission/distribution, pumping stations, in-building equipment), which will be launched by 2016, reaches 4.5 million Euros. The Municipal

Authority has recently expressed its interest for the exploration of the probable medium enthalpy resources (130-140°C) in the same field.

(2) Geothermal field of *Eratino-Chrysoupolis* (Kavala, Northern Greece): The exploitation rights have been awarded to the Municipal Authority of Nestos. One reinjection and two deep (750m) production wells were drilled, providing 10-15 MWt for agricultural uses (asparagus cultivation, greenhouses, dehydration etc), through two heat exchanging thermal stations (Figure 8) and 18km of distribution networks. The infrastructure works have been completed and are expected to be fully operational in 2016. The investment reached 10.5 million Euros.

Figure 8: Thermal station in the area or Eratino-Chrysoupolis (Kavala, Northern Greece)

(3) Geothermal field of *Neo Erasmio* (Xanthi, Northern Greece): The exploitation rights have been awarded to the Thrace Plastics Co S.A., which has constructed 8.2 ha of geothermal greenhouses for the production of tomatoes and cucumbers. The heating of the plantation units and the auxiliary installations is accomplished by the use of 60°C geothermal fluids from four recently drilled production wells. The target of this project is the construction and operation of 20ha of geothermal greenhouses by the end of 2020.

(4) Geothermal field of *Nigrita* (Serres, Northern Greece: Another 0.2 ha of spirulina "greenhouses" were constructed recently in Nigrita. The new installations consist of several covered cultivation ponds made of stainless steel, which improves significantly the efficiency of the system.

6. PROFESSIONAL GEOTHERMAL PERSONNEL

The number of professional geothermal personnel working in research institutes, universities, public authorities (ministries, regional authorities, PPC-R S.A., etc.) has remained the same, i.e. approximately 35 people, 6 of which regard the geothermal electric power sector. The personnel related to the direct uses and the shallow geothermal sector has increased and could be roughly estimated to 200 people.

7. LEGISLATIVE ISSUES-NATIONAL TARGETS

The current geothermal legislation (Law 3175/2003 "Exploitation of geothermic capacity, district heating and other provisions" and relative Ministerial Decrees) classifies the geothermal fields as "high" (T>90°C) or "low" (T<90°C) temperature fields. The geothermal fields are also classified as "proven" or "probable", depending on their preceding exploration. By the end of 2015, a total number of 32 areas had been officially characterized as "geothermal", corresponding to more than 40 'proven/probable' and 'high/low' temperature geothermal fields.

The terms, procedures and regulations for the concession of the geothermal exploration and management rights are determined in the Ministerial Decree "Geothermal Regulations" (Gazette B' 635/12.05.2005 and 1530/7.11.2005). The procedures for the exploitation of shallow geothermal energy are provided for by the L3175/2003 and the Ministerial Decree published in the Gazette B' 1249/24.6.2006.

The national energy policy in Greece is regulated by the Law 3851/2010 and the National Action Plan 20-20-20. The 2009/28/EC Directive has set the 2020 renewable energy targets for Greece as follows:

- *Overall target*: 18% of share of energy generated from renewable sources in gross final energy consumption;
- *Heating and cooling*: 20% of heat consumption met by renewable sources;
- *Electricity*: 40% of electricity demand met by electricity generated from renewable energy sources;
- *Transport*: 10% of energy demand met by renewable energy sources.

In 2010 Greece endorsed its National Renewable Energy Action Plan (NREAP) aiming to reform the country's energy sector in order to achieve the above mentioned targets. The Law 3851/2010 (*Accelerating the development of RES to deal with climate change and other regulations addressing issues under the authority of the Ministry of Environment Energy and Climate Change*) establishes a supportive legislative framework to achieve these ambitious goals.

Both the NREAP and the L3851/2010 set specific targets regarding the share of RES in final energy consumption, electricity generation and contribution in heating, cooling and transport. More specifically, the annual geothermal energy use (geothermal heat pumps excluded) is set at 51 ktoe, which is more than double the annual energy use at the end of 2015 (21 ktoe). The respective number for the geothermal heat pumps has been set to 50ktoe. Achieving the above targets by 2020 requires an annual increase of the geothermal energy use around 20%. The latter seems achievable for the GSHP sector, but rather unlikely, at least under the current circumstances, for the classical geothermal applications.

As for the geothermal energy contribution in the electricity sector, the plan of the NREAP includes power production from medium/small scale geothermal plants in the interconnected system and local plants in the non-interconnected islands. For the year 2020 the expected installed capacity from the geothermal power plants is 120 MW. This is practically impossible, judging by the zero geothermal power production in 2015, which is rather far from the target of 20MW foreseen in the NREAP for this year. The Feed-in-Tariffs set by L3851/2010, valid from June 2010 and for 20 years, is €150/MWh for the electricity production from low temperature fluids (T<90°C) and €99.45/MWh for electricity from high temperature fluids. These FITs stand for both mainland and non-interconnected islands.

District heating/cooling installations from geothermal energy are also foreseen in the NREAP, as a contribution to meet the national targets for 2020. However, the only district heating systems that might be in operation by 2020 is the DH system in Alexandroupolis (Aristino field, Northern Greece), which is still only on paper. Hence, the respective contribution is estimated to be rather low.

The implementation of the Energy Performance of Buildings Regulation in 2010 has aimed to achieve tangible results for significant energy saving in the building sector. The EPBR has been an important step towards promoting RES systems for heating and cooling at the tertiary and residential sectors, as well as in agriculture and industry.

The GSHP market has been favored by the implementation of L3851/2010, as well as from other recently introduced legislation, which included:

- Energy labelling of buildings, introduced in April 2010.
- Total coverage of their primary energy consumption through energy supplied from RES, CHP, district heating and heat pumps for all new buildings that accommodate services of the public sector. The same stands for the private sector after 31.12.2019.
- Compulsory (since 2011) energy audit certificates for all building transactions: buying-selling, letting-renting, leasing, erecting, refurbishing.
- Additional taxation on heating oil, imposed in October 2012.
- The enforcement in February 2013 of the EU Energy Performance of Buildings Directive
- The enforcement in November 2015 of the EU Energy Efficiency Directive for compulsory energy audits in large enterprises and minimum energy requirements for the public sector during refurbishing or purchasing of used buildings.

8. CONCLUSION REMARKS

In a country rich in geothermal resources as well as in innovative and pioneering ideas for novel geothermal applications, one would normally expect the geothermal sector to have a more remarkable growth. However, it seems that the Greek geothermal market still suffers from the “infantile diseases” inherited by the first unsuccessful exploitation attempts in combination to several legislation and bureaucratic obstacles that have limited creativity and development.

The confirmed high enthalpy potential of Milos and Nisyros islands remains untapped after the “eventful” operation and shut-down of the geothermal plant in Milos. The targets of the National Renewable Energy Action Plan foresee 120 MW of geothermal power by 2020, however there is little or no chance this will goal will be achieved.

At present, the direct utilization of geothermal energy represents only a very small fraction of the identified and estimated shallow depth (<500m) low enthalpy resources, providing around 80 MWt. Apart from the balneology sector, the majority of the geothermal activities take place in Northern Greece, where important projects are in progress and will be hopefully completed in the near future. The biggest investment ever made in the Greek geothermal market was the geothermal greenhouses in Neo Erasmio (Xanthi, Northern Greece). In fact, this has been the most (if not the only) notable addition to the geothermal energy balance since 2013.

The exploitation of shallow geothermal energy continues to evolve, with more than 2600 reported GSHP installations at the end of 2014. The financial incentives, the favourable legislation and the simplified licensing procedures are the main reasons for the significant growth of this sector.

According to the Greek Ministry of Environment and Energy (www.ypeka.gr, 2016), the top priority of the State is, among others, to “…secure the reliable, uninterrupted and affordable supply of energy for all users…” as well as to ensure the “viable and sustainable development of the energy sector from the stage of production to the end use, while protecting nature and safeguarding the environment”. Geothermal energy can contribute considerably to the achievement of the above targets and has the capacity to meet the energy needs in several regions, especially in Northern Greece and in some Aegean islands.

REFERENCES

Andritsos, N., Arvanitis, A., Papachristou, M., Fytikas M. and Dalambakis P.: Geothermal Activities in Greece during 2005-2009, *Proceedings of the World Geothermal Congress 2010*, Bali, Indonesia, (2010), paper #0138, 1-10.

Andritsos, N., Arvanitis, A., Dalambakis P., Karytsas, C., Mendrinos, D. and Papachristou, M.: Geothermal Energy Use, Country Update for

Greece, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy, (2013), paper #CUR-14, 1-10.

Andritsos, N., Dalambakis P., Arvanitis, A., Papachristou, M. and Fytikas M.: Geothermal Development in Greece-Country update 2010-2014, *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, (2015), paper #01048, 1-11.

Arvanitis, A., Vougioukalakis, G., Xenakis, M., Athanassoulis C., Karmis, P., Fragogiannis, G. and Christopoulou, M.: Exploration of probable low temperature geothermal field of Lithotopos - Iraklia in the Prefecture of Serres, *I.G.M.E., Technical Report,* Athens, 2015.

Arvanitis, A., Vougioukalakis, G., Xenakis, M., Kavouri, K., Christopoulou, M. and Statha, F.: Exploration and development of geothermal energy in the Thermopigi - Charopo area in the Prefecture of Serres, *I.G.M.E. Technical Report*, Athens, 2016.

Arvanitis, A., Xenakis, M., Christopoulou, M. and Statha, F.: Geothermal exploration in Lemnos Island, *I.G.M.E. Technical Report*, Athens, 2016.

Eurostat: 2014 Energy Balance (January 2016 edition) http://ec.europa.eu/eurostat/web/energy/data (accessed 8.03.2016)

Fytikas, M., Karydakis, G., Kavouridis, Th., Kolios, N., Vougioukalakis, G., 1990a, Geothermal research on Santorini, in: Hardy D.A., Keller J., Galanopoulos, V.P., Fleming N.C., Druitt, T.H. (eds), Thera and the Aegean World III, *The Thera Foundation*, London, 2, 241-249.

Mendrinos, D, Choropanitis, I., Polyzou, O. and Karytsas, C.: Exploring for geothermal resources in Greece, *Geothermics*, **39**, (2010), 124-137.

NREAP (National Renewable Energy Action Plan in the Scope of the Directive 2009/28/EC (2010)

Vakalopoulos, P., Efthimiopoulos, T., Arvanitis, A., Xenakis, M., Gaga, M., Vougioukalakis, G., Christopoulou, M., Fragogiannis, G., Statha, F. and Kanellopoulos C.: Geothermal exploration in Eastern Thessaly, *I.G.M.E. Technical Report*, Athens, 2016.

Vakalopoulos, P., Xenakis, M., Vougioukalakis, G., Kanellopoulos C., Christopoulou, M. and Statha, F.: Geothermal exploration for medium - high enthalpy resources in Aedipsos, *I.G.M.E. Technical Report*, Athens, 2016.

Xenakis, M., Arvanitis, A., Athanassoulis M., Vougioukalakis, M., Karmis, P., Statha, F., Christopoulou, M. and Kanellopoulos C.: Geothermal exploration of Eastern Lesvos, *I.G.M.E. Technical Report*, Athens, 2016.

www.ypeka.gr (accessed 13.03.2016)

Acknowledgements

PPC-R is acknowledged for the information on their geothermal power prospects and feed-in premium target values they made available to the authors.

In addition, the authors are grateful to Prof. Emeritus Michael Fytikas for his assistance in collecting updated information and data.

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 (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2015 *	0	0			0	0
Under construction end of 2015	0	0			0	0
Total projected by 2018	0	0			0	0
Total expected by 2020	23	180	20000	61000	0.1%	0.3%
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):					6 exploration licences 1 exploitation licence	

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2015 pro-duction * (GWh_e/y)
Milos island	Milos GPP	1987	1	R	1F	2	0	0
total						2	0	0

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 *	0	0	39.7	170.69	1.65	4.95	42	69.72
Under constru-ction end 2015	0	0	10	58.85	-	-	-	-
Total projected by 2018	0	0	59.7	278.89	2.0	5.25	43	71.5
Total expected by 2020	8	21	74.7	357.74	2.5	7.66	45	74.8

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. (%)
-	-	-	-	-	-	-	-	-

Table D2: Existing geothermal direct use other than DH, individual sites*

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
-	-	-	-	-	-	-	
total							

* there are no large systems (>500 MW_{th})

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* (*Estimated*)	~3000	148	197	376	14	12
Projected total by 2018	4250	200	250			

* estimate. The reported installations for 2014 are 2632, capacity =135 MW_{th}, production=177.5 GWh_{th}/yr)

** estimate. The corresponding reported data for 2014 are 404 additional GSHP, 16MW_{th}

Table F: Investment and Employment in geothermal energy

	in 2015		Expected in 2018	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power		6	25	50
Geothermal direct uses	0.6	11	1	15
Shallow geothermal	26.4	182	26.4	182
total	**27**	**199**	**52.4**	**247**

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	NONE	DIS by national research programmes	DIS by national research programmes
Financial Incentives – Investment	LIL from EIB	NONE	DIS, LIL from EU structural funds
Financial Incentives – Operation/Production	FIP, target prices €/kWh(e) up to 5 MWe: 0,140 > 5 MWe: 0,108	NONE	NONE
Information activities – promotion for the public	NONE	Workshops, conferences, short courses	Workshops, conferences, distribution of brochures, by CRES
Information activities – geological information		Legislation, publications of IGME+ Universities, books	Geologic Maps of IGME
Education/Training – Academic	Lectures and Courses for pre- and post-graduate students on geothermal energy (research exploitation, management)		
Education/Training – Vocational	NO	NO	NO

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)