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Geothermal Activities in Greece During 2005-2009

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ABSTRACT

Greece holds a prominent place in Europe regarding the existence of promising geothermal resources, which can be economically exploited. There is no any electrical use in the country, despite the proven high-enthalpy geothermal potential in the Aegean volcanic arc. The exploration of new or existing low-enthalpy fields continued during the past five years and more than 50 wells were drilled. The recent discovered reservoirs have temperatures ranging from 30 to 90ºC. By the mid of 2009 the total installed geothermal capacity in Greece of low-enthalpy uses is estimated to be about 135 MWth. The installed capacity increased remarkably (80% increase) compared with the figures reported in the previous update, but most of this increase is attributed to the expansion geothermal heat pump market that presents more than 50% annual increase in sales.

1. INTRODUCTION

Greece, like several other Mediterranean countries (e.g. Italy and Turkey) has a great potential regarding geothermal energy (e.g. Fytikas, 1987). This is because the greatest part of the country is located in an area geodynamically very active, as a result of the movement of the African plate towards the Eurasian plate creating in some places an active volcanism and extension tectonics (crustal thinning).

Since the early 1970s several high and low temperature geothermal fields have been identified around the country. The total proven geothermal electricity generation potential from the high-enthalpy fields in the islands of Milos and Nisyros is estimated at 25 MWe, whereas the probable potential exceeds 400 MWe. So far, there is no electricity generation from geothermal sources in Greece. However, there is a project underway in Lesvos island by a subsidiary of PPC with the aim to find medium-enthalpy fluids for electricity generation in a binary cycle.

The potential of the known low temperature fields is estimated to exceed 220.000 TOE/year. There are 32 areas, which are officially classified as proven and/or probable geothermal fields. During the years 2004-2009 new exploration activities have been carried out in various areas of Greece as in Lesvos and Chios islands (Aegean Sea), Nea Apollonia, Almopia, Alexandria and Akropotamos (Northern Greece), Sykies - Arta (Epirus), Antirrio (Western Greece), Aedipsos - Yaltra - Lichada (NW Evia island, Central Greece) and the Sperchios graben (Central Greece). The direct uses, such as heating (district-space-greenhouse-soil), balneotherapy, and aquaculture, exhibited a modest increase of about 30% since 2004.

The paper aims at reviewing the progress in the areas of exploration and applications of geothermal energy in Greece during the 2005-2009 period. Before proceeding with the objectives of the paper, a short historical note on thermal waters in Greece is presented.

2. GEOTHERMAL EXPLORATION

Geothermal research in Greece has started in the early 1970s and, as it has been mentioned, it demonstrated a rich geothermal potential in both low and high-enthalpy resources. Geothermal exploration in the country has been carried out mainly by the Institute of Geology and Mineral Exploration (I.G.M.E.). This institution is responsible for the geothermal investigation in the country according to geothermal law 3175/2003. During 2002-2008, a budget of 4 million € has been devoted to geothermal exploration in many areas all over the country and a total number of 44 exploration and production geothermal wells were drilled by I.G.M.E. in several areas. A brief description of the drilling efforts (either carried out after 2005 or not reported in the previous country update) follows. Most of the geothermal fields investigated by I.G.M.E. with the temperature of encountered waters are depicted in the map of Figure 1. To the authors' knowledge, more than ten private geothermal wells have been drilled in the past few years at shallow depths (less than 400 m). Finally, a deep geothermal well was drilled in the island of Lesvos by a subsidiary of the Power Public Corporation Co.

2.1 Macedonia (Northern Greece)

Akropotamos - Kavala geothermal field. The field is located in the eastern coastal zone of the Strymonikos Gulf and it is one of the most significant low enthalpy fields in Greece. Six new production geothermal wells (AKR-1 to 6) were drilled during October 2003-February 2006. Information for the first two wells drilled in the region is given in the previous report. Well AKR-3 was drilled down to 515 m and the maximum temperature of 90ºC was measured at 498 m. This well yields about 55 kg/s CO_2-rich geothermal fluids with artesian flow. Next to this borehole, well AKR-4 was drilled at 180 m penetrating a shallow aquifer. During pumping test with constant flow rate, this well yielded 12 kg/s water of 48ºC. Well AKR-5, 422 m deep, was drilled in the western part of the study area close to the Strymon river's mouth. The temperature of 28ºC was recorded at 280 m into this borehole. The last geothermal well, AKR-6, was drilled down to 545 m in the eastern part of the field. The maximum temperature of 38ºC was recorded at depth of 503 m. The waters from geothermal wells AKR-1 to 6 with temperatures of 28-90ºC and TDS of 3.1-31 g/L are classified as of Na-Cl type. The water from well AKR-2 with T=46ºC and TDS of 2.15 g/L belongs to Na-HCO_3Cl type.

Nea Apollonia geothermal field. It is located 40 km east of Thessaloniki, in the Mygdonia basin and on the southwest coast of the Volvi Lake. Five new production wells (GV-1P to 5P) were drilled in the period 2003-2004 for the definition of the borders of the known lakeside geothermal area southwards and eastwards. Located in southernmost part of the field, well GV-1P has a depth of 320 m and yields 11 kg/s water of 31ºC. Well GV-2P was drilled down to 126 m in the eastern part of the field and the maximum temperature of 27ºC was recorded at 50-55 m. Well GV-3P, 192 m deep, is located in the easternmost part of the geothermal area and it has no geothermal interest because the maximum measured temperature is 22ºC at 190 m. Well GV-4P has a depth of 108 m yielding 14 kg/s water of 40ºC (the maximum temperature of 40ºC was recorded at 55-70 m). The temperature of 40ºC was measured at the wellhead of GV-5P, 126-m deep, with flow rate of 14 kg/s (by pumping). The maximum temperature of 41ºC was recorded at 70-75 m. Another production geothermal well (GV-67) was drilled in June 2005 by a private company at a small distance from the known thermal springs of the area. This well has a depth of 130 m (casing down to 120 m) and produces 12 kg/s waters of 54ºC. Pumping tests and evaluation of their results were carried out by I.G.M.E. The geothermal waters are of Na-SO_4HCO_3 type with low TDS content (0.5-1.0 g/L). Located SSW of the lakeside hot springs area, one more shallow production well was drilled by the Hellenic Association of Municipalities and Communities of Curative Springs and Spas yielding about 10 kg/s waters of 36-38ºC. Another production well was constructed inside the area of the N. Apollonia Spa Resorts, with waters of 57ºC, which is used for the heating of the main Spa hotel installations (2500 m^2).

Thermi area. Two geothermal wells were drilled in the area of N. Ryssio in the end of 2004, reaching 655 m and 442 m and yielding waters of 40ºC and 32ºC respectively. Due to technical problems with the deeper well, this well was finally used for injection, whereas the shallower one as production well for heating purposes using heat pumps. Another 610-m deep production well was drilled in 2007 by a private company for the Municipality of Thermi. The well yields 14 kg/s water of 31ºC with a low TDS content (0.56 g/L).

2.2 Epirus - Western Greece

Sykies - Arta geothermal field. Located in Epirus, this geothermal field was discovered during the period 1995-2000 by drilling 10 boreholes with water temperatures of 35-45ºC at depths of 280-320 m. Three more wells (GL-1, GA-1, GSP-2) were drilled in the period 2003-2004 for the delineation of this field. Exploration well GL-1 has a depth of 502 m and the temperature of 46ºC was measured at 472 m. The temperature of 27ºC was recorded at 447 m in exploration well GA-1, 470 m deep. Boreholes GL-1 and GA-1 are artesian. Production well GSP-2 was drilled down to 375 m and it yields 12 kg/s thermal water of 44ºC. It is estimated that the flow rate might reach 14 kg/s with probable water temperature of about 47-50ºC. The geothermal aquifer is located at depths of 280-480 m composed of Upper Senonian limestones. The geothermal waters belong to the group of Na-Cl waters with a TDS of 36-45 g/L.

Riza - Antirrio geothermal field. This field is located on the northern side of the Corinthian Gulf in Western Greece. The first exploration geothermal borehole was drilled at 402 m during 1998-99 in the Riza - Antirrio area. Two more wells (GL-1, GLP-1) were drilled in the period 2005-2006. Exploration borehole GL-1 was drilled down to 257 m and the temperature of 37ºC was recorded at 255 m. Production well GLP-1 has a depth of 229 m and it yields 25 kg/s waters of 36ºC and Na-Cl type with a TDS of 46 g/L. The thermal aquifer of the field composed of Eocene limestones is located below 200 m.

2.3 Central Greece

Sperchios basin - Damasta geothermal field. Located in Central Greece, the Sperchios basin has many natural springs with thermal and mineral waters (e.g. Thermopylae, Ypati, Platystomo etc). During June 2004-September 2007, nine wells were drilled in some localities of the Sperchios basin outside the springs protection zones. Exploration boreholes SP-P1, SP-A1, SP-Y1 and SP-L1 at depths of 243-378 m were drilled in Palaiovracha, Arhani, Ypati and Lamia-Stylida, respectively, with (19-25ºC) bottom-hole temperatures. The main geothermal interest was focused on the Damasta area situated about 5 km west of the famous Thermopylae thermal springs (T=40ºC), where a new geothermal field was discovered. Five geothermal wells (SP-D1, SP-D2, SP-D3, SP-D4 and SP-DP1) were drilled in the period 2005-2007 in this area. Exploration borehole SP-D1 has a depth of 157 m yielding water of 41ºC with flow rate 14 kg/s (air-lift pumping). Exploration well SP-D2 was drilled down to 130 m and the maximum temperature of 43ºC was measured at 50-60 m. Exploration borehole SP-D3, 332 m deep, has a maximum recorded temperature of 41ºC at 320 m. Exploration well SP-D4 was drilled to 317 m and the maximum temperature of 39ºC was encountered at 280 m depth. Production well SP-DP1 has reached a depth of 108 m yielding 32 kg/s waters with a temperature of 44ºC. A maximum temperature of 40ºC was recorded at 100-101 m within this well. The thermal waters are of Na-Cl type with a TDS of about 35 g/L.

Northern part of Euboea (Evia) island. During June 2002-Ocrober 2008, the geothermal exploration in the northern part of Euboea island was focused by IGME on three areas: the Lichada Peninsula, the Aedipsos area and the Limni-Rovies area. A geothermal drilling project was carried out in the period 2004-2007 in these areas. Seven geothermal wells were drilled in the Lichada peninsula. Five of them are exploration boreholes at depths of 72-274 m and they penetrated Quaternary and Neogene sediments, basal conglomerates and Triassic-Jurassic limestones constituting the geological basement of the area. The temperatures of 36-41ºC were measured at depths of 66-250 m except of borehole G-5. Two production wells (P-1, P-2) were drilled after the completion of geothermal exploration drilling activities. Production well P-1, situated close to exploration borehole G-1, has reached a total depth of 255 m with a casing down to 237 m and the maximum temperature of 40ºC at 210 m depth. This well yields 30 kg/s waters of Na-Cl type with a TDS of 39 g/L. Production well P-2, situated close to exploration borehole G-4, was drilled down to 310 m depth and was cased down to 293 m. The highest temperature logged is 44ºC at 290 m depth. This well yields 25 kg/s waters of Na-Cl type with a TDS of 40 g/L. The geothermal reservoir of this area is located at depths 45-270 in the Mesozoic limestones. In the Aedipsos area, exploration borehole L-4 was drilled down to 374 m depth with a casing down to 340 m and the maximum temperature of 80ºC was recorded at 350 m. Two exploration boreholes (L-1 and L-2) were drilled in the Limni-Rovies area. Borehole L-1, 290 m deep, was cased down to 281 m. The highest temperature logged is 29ºC at 250 m depth.

Borehole L-2 has a depth of 252 m and the maximum temperature of 28ºC was measured at 240 m.

Thessaly. Located South of Larissa and close to the villages of Karyes and Nikaia, a hot aquifer has been encountered at 350 m depth with a temperature of about 40ºC (Hatziyannis, 2007).

2.4 Aegean Islands

Chios island. In the period 1995-2000 the low enthalpy geothermal field of Nenita (SE Chios) was discovered by IGME with geothermal waters of up to 83ºC. The last geothermal exploration on Chios island was focused on two areas: in the Thymiana area and in the Nenita geothermal field. Seven geothermal wells (5 exploration and 2 production) were drilled during November 2003-August 2006 in these areas. Exploration boreholes GTH-1, GTH-2, GTH-3, GTH-4 and GTH-5 were drilled down to 150-473 m in the Thymiana area and the temperatures of 31-39ºC were recorded. The maximum temperature of 39ºC was measured within borehole GTH-5. Production well GTHP-1102 m deep, was drilled in this area and the temperature of 31ºC was measured at 100 m. This well yields at least 18 kg/s waters of Na-Cl type with a TDS of 38 g/L. One production well (CHNP-1) was drilled at a depth of 340 m in the Nenita geothermal field. The bottom hole temperature logged is 83ºC. This well produces 25 kg/s waters of 80ºC and Na-Cl type with high TDS content (74 g/l).

Lesvos island. A new production well (YG-14A), 150 deep, was drilled in 2008 in the Polichnitos area to replace an old well (picture in Fig. 2). This borehole was constructed by a private drilling company in order to support a pilot district heating project called THERMOPOLIS providing geothermal waters of about 88ºC. The location of the well site, the borehole design and the drilling supervision were performed by I.G.M.E. In the broader area of Stipsi three exploratory boreholes were drilled by PPC. The borehole S-1 reached a depth of approximately 1400 m and found fluids at 80ºC. STE-1 and STE-2 were drilled down to 350 and 1000 m, revealing temperatures of 106ºC and 101ºC respectively. Two more exploration boreholes were constructed in Argennos (North Lesvos), at 700 m and 500 m, but both showed negative geothermal gradient.

2.4 Thrace (Northern Greece)

Aristino. A production well, 490 deep, was drilled in 2004 by a private company for heating a new greenhouse investment in the Aristino field. The maximum temperature of 81ºC was recorded at 480 m depth and the electrical conductivity value logged was about 6850 μS/cm at the same depth. Finally, the investment was not performed and therefore this borehole has never been used.

3. DEVELOPMENTS IN DIRECT USES

All direct heat applications in operation, as of 31 May 2009, are presented in Table 1, whereas Table 2 offers a summary of the direct uses in the country. The estimated installed capacity in May 2009 reached 135 MWt, exhibiting a 80% increase compared with the capacity reported for the end of 2004 in the World Geothermal Congress 2005 (Fytikas, et al, 2005).

While the first half of the present decade was characterized by a diversification of direct applications with new uses, such as aquaculture, spirulina production, outdoor pool heating, water desalination and fruit and vegetable dehydration, the main characteristic during the past few years is the rapid expansion of geo-source heat pump systems (GSHP). In fact, the increase in the installed capacity reported here can be attributed solely to GSHP. All other applications show only a small increase in the installed capacity.

There are also certain negative developments to be noted: some geothermal greenhouses and the desalination plant built in Kimolos island are out of operation for reasons not related to the geothermal technologies and a 2-MW project for the heating and cooling of several public buildings has been abandoned. The former project is out of operation because it has not been connected via a pipeline with the main water tank of the island. The implementation of a 2-MWt project in the town of Langadas (Thessaloniki) for the heating and cooling of several public buildings with geothermal heat pumps by utilizing shallow wells with water temperature in the range 20-40ºC was suspended due to bureaucratic and administrative problems, despite the completion of the pipe work and the purchase of the heat pumps. The fate of the novel desalination project in Milos island is still unclear, despite the completion of eight production and reinjection wells.

Figure 2: Geothermal well drilling in the Polichnitos area.

3.1. Space Heating

The use of geothermal energy for space heating is practiced only in two spa buildings (in Traianoupoli, Thrace, and in N. Appolonia, Thessaloniki area), in a hotel in Milos (which, however, is closed in winter), in several individual houses in Macedonia and Thrace and in a high-school building in Thrace, as seen in Table 1. The heating of several houses in Milos is carried out by a kind of “downhole heat exchanger”, as described in the previous country update. The installed capacity of the space-heating units in the country has been estimated to be a little higher than 1.5 MWt.

3.2. Greenhouse and Soil Heating

The first geothermal greenhouses in Greece were constructed in the early 1980s in Northern Greece, namely in Nea Apollonia and Langadas (Prefecture of Thessaloniki), Nigrita (Serres), N. Kessani (Xanthi) and Polichnitos (Lesvos island). Approximately 21 ha of glass and plastic-covered greenhouses were heated with geothermal waters during the winter 2008-9. The area of greenhouses covered by glass is 16.2 ha, while the rest area is covered by polyethylene film and one unit is covered by polycarbonate. Most of the greenhouse area is used for vegetable cultivation (55% of the glass-covered and 80% of plastic-covered greenhouses). The main vegetables grown are tomatoes, sweet peppers, green beans and cucumbers. Other agricultural products grown occasionally in these greenhouses include lettuce, strawberries and certain herbs. The glass-covered greenhouses are equally used for vegetables and for cut flowers (roses, lilies, chrysanthemum), potted plants and in a lesser degree for nursery stock. It has to be also noted that more than 6 ha of greenhouses constructed to be heated by geothermal water are out of operation after a working period for reasons irrelevant to the geothermal energy. The above information is based on a survey originally conducted in 1999 (Andritsos et al, 1999) and updated in 2004 and recently, either by site visiting or by personal communication with the operators. Currently, there are 27 geothermal greenhouse units in the country run by 21 operators. All the greenhouse units but two cover almost entirely their heating needs with geothermal energy.

All geothermal wells are state-owned and the geothermal water is leased to the farmers at a low price, approximately 1-3% of the equivalent heating value of natural gas. Accordingly, the operating cost for heating of the geothermal greenhouses is very low.

Geothermal greenhouses in Greece utilize waters with temperature as low as 35ºC. The vast majority (79%) of the geothermal waters used in greenhouse heating has a temperature less than 60ºC, as also shown in Table 1. The main reason for this trend (i.e. use of mainly low-temperature waters) is the easiest handling of low-temperature waters, the use of cheap PVC pipes for water transportation, the good quality of most low-temperature waters, and the existence of several low-temperature fields (Langadas, N. Apollonia, Nigrita) located close to a big city, Thessaloniki. The low-temperature waters are usually characterized by low electrical conductivity, and any leaking in the greenhouse area does not case any damage.

The geothermal water used in heating the active greenhouses comes from 26 low-depth wells. The depths of the wells range between 10 and 450 m with a mean depth of 115 m. A considerable proportion of the wells are artesian. The artesian waters are transported to the application sites mostly with centrifugal pumps. The centrifugal pumps are either placed directly on the head of the well or next to it, in a holding tank, where the water is directed from the artesian well. In non-artesian wells electric submergible pumps and line-shaft pumps are used.

All currently in operation geothermal greenhouses (and all soil warming installations) use the geothermal water directly. Heat exchangers were utilized in the past in three, now inactive, units in Nigrita and N. Kessani, because of $CaCO_3$ scaling problems, and in one small unit in Milos, due to corrosion problems.

The various heating methods employed in the geothermal greenhouses can be divided into four categories: (1) Convective air heating with forced-air heaters installed along the sides of the greenhouses is connected with water temperatures higher than about 60ºC. The water after passing the heat convectors flows through the greenhouse in corrugated polypropylene (PP) pipes, in a cascading use. (2) Corrugated polypropylene (PP) pipe heaters of o.d. 28 mm. These pipes are located below the ground level (soil heating), on the ground (next to the plant row), under or on the benches or they are suspended at a certain height. (3) Large plastic tube heating. These cheap polyethylene tubes have a diameter of about 0.2 m and are placed on the ground next to the plant rows. The upper part of the tube heats the air and the lower warms the soil. They are used only for one cultivating period. They are used only for vegetable cultivation. (4) Finned metallic pipe heating. At the moment this method is only applied in one floriculture installation. The use of corrugated PP pipes is the choice for more than 50% of the covered greenhouse area.

The consumption of both fresh and canned asparagus has significantly increased during the past few decades. Asparagus (*Asparagus officinalis L.*) is a perennial plant, native to Europe, which usually grows commercially in temperate climates. Asparagus is an important export vegetable for Greece and its cultivation started in the 1960s in the Prefecture of Pella. Field cultivated areas of asparagus in Greece are currently about 3500 ha.

Since there is a worldwide increase in consumer demand for off-season asparagus, low-cost geothermal waters can be used for soil heating. In mid 1990s, a project was initiated in Neo Erasmio, Xanthi, for off-season asparagus cultivation using geothermal energy. Soil heating usually starts in mid January and off-season asparaguses are produced between February and April, having much higher market prices that the in-season produced asparaguses. Indeed, during off-season in Germany, the largest asparagus market worldwide, wholesale prices roughly average between 4-6 €/kg for fresh asparagus and prices begin dropping well below 2-3 €/kg once domestic production (in Germany and elsewhere) starts in late April depending upon the prevailing climatic conditions.

This project was the first geothermal application world-wide in non-covered intensive cultivations. The soil heating is accomplished by the direct flow of the geothermal water through corrugated PP pipes with an outside diameter of 28 mm, located 30-40 cm below the ground level. The inlet water temperature in the PP pipe system is 60ºC and the used water is reinjected at a temperature of 25ºC. The total cultivation area in N. Erasmio is currently 10 ha and it is run by four operators. The geothermal water flows continuously in the pipe system at a rate of 40 kg/s for the entire area. Soil heating can raise the soil temperature by 4-10ºC, depending upon the ambient conditions, the water flow rate and temperature, the presence of the plastic foil etc.

As shown in Table 1, the total cultivated area with soil heating in the beginning of 2009 was 17 ha. A 3.5-ha field in Nigrita, established in 1999, stopped operating in 2005. On the other hand, the Nymfopetra unit was expanded a few years ago by 2.0 ha, currently totaling 5 ha. A new 2.0-ha soil-heating unit was installed in Myrodato, Xanthi, in 2005. Originally, it was designed for off-season production of watermelons, but the cultivation was switched to asparagus the following year.

A promising application of geothermal heat pumps has been carried out in the past years in Chrysochori, Kavala. Soil heating of an area of 2.0 ha for off-season asparagus cultivation is accomplished with an open (ground water) geothermal heat pump system. The use of such a system proved to be quite economical, since the electricity cost for running the system accounted only for well less than 15% of the producer's price, which was in the range of 3-5 €/kg product, depending upon the earliness of the production.

Soil warming in connection with an arch-type plastic cover of rows supported by frames can be also used for protected vegetable cultivation aiming at early growth and at shorter cultivation periods. One vegetable that can be grown economically in this way is lettuce, especially in areas that are cold at night. Lettuce is generally grown at low light intensities and at rather cool temperatures. Lettuce plants prefer a daylight temperature of 16-20ºC, whereas high temperatures often results in spindly growth. During the past winter months more than 1000 kg of lettuce were grown in N. Erasmio at reduced heating cost. A figure of the plastic covered rows for lettuce growth is shown in Figure 3.

Figure 3: Picture of arch-type plastic covered rows for early lettuce cultivation in N. Erasmio.

3.3. Bathing, Spas

There are more than 60 thermal spas and bathing centers operating in Greece today. The majority of these centers are state-owned (or owned by municipalities) and, provided they are functional, they usually operate during the traditional balneological period in the country (June-October). It is interesting, though, that more and more spas remain open all year around, but only two of these centers are heated with geothermal waters.

The total water flowrate from the Greek spas exceeds 1500 kg/s, while the water temperatures range between 18 and 100ºC. A conservative estimate (assuming the water leaving the bathing centers has a temperature of 30ºC) of the total thermal capacity of the Greek spa resorts is 38-40 MWt, with a mean load factor of 0.19. These figures include the open and closed pools heated by geothermal waters (Aedispos, Platystomo, Sidirokastro, Loutraki-Pella, Milos Island etc.).

3.4. Industrial Uses

The first tomato dehydration unit worldwide has been operating since 2001 in the geothermal field of N. Erasmio, located 25 km south-west of Xanthi (Thrace). The unit uses low-salinity geothermal water (with a temperature of 60°C) to heat atmospheric air to 55-57°C in finned tube air heater coils. In fact, the plant uses the same geothermal well that during winter provides geothermal water for asparagus cultivation. The hot air then passes above trays with fresh tomatoes placed in the drying tunnels. More information on the whole process can be found in Andritsos et al. (2003).

Currently the plant is capable of producing more than 1000 kg per day of dehydrated tomatoes. The color of the product is one of most important characteristics. The relatively low drying temperature utilized in the plant helps tomatoes to retain their aroma, color and flavor. During the first nine years of operation of the dehydration plant 83 tn of high-quality dried tomatoes were produced, sold in Greece and abroad. The unit is capable of drying and other vegetables and fruits (peppers, apricots, cherries). Recently, the curing of fresh olives (a process to render the olives edible by removing its pungent taste) by drying has been investigated in the plant in order to substitute the classic method of brine curing, which leaves residual quantities of salt in the olives. The preliminary tests proved quite optimistic.

The raw produce (well but not over-ripened tomatoes of the roma variety) is grown locally, haft of the quantities needed are grown by the operators, although specific fresh produce (e.g. cherry tomatoes, organic tomatoes) has been hauled in from a distance of 250 km.

3.5. Aquaculture

Aquaculture is a significant direct use of geothermal energy, utilizing very low-temperature geothermal waters. Geothermal aquaculture projects have been in place in Greece since the late 1990s and deal with cultivation of spirulina and with heating of fish wintering ponds.

Anti-frost protection/heating of aquaculture ponds in Porto Lagos and Neo Erasmio (both in the Perfecture of Xanthi, Thrace) is practiced since 1998. Anti-frost protection refers mainly to the heating of wintering ponds (earth channels) with gilt-head sea bream and other valuable fish, which are very sensitive to an abrupt drop of temperature in winter time. In Porto Lagos, the water comes from two production wells near the farming ponds. The protection of a 0.48 ha wintering pond against freezing requires a flow rate of up to 11 kg/s of geothermal fluids with a mean temperature of about 34ºC. The water volume in the ponds (about 20,000 m3) is constantly replenished with water either from the sea or from the neighboring shallow Lagos Lagoon. The injection of warm water into the pond not only protects the fish stock from bad weather, especially during winter time, but it has been shown that it also increases fish production (Gelegenis et al, 2006).

In the Neo Erasmio installation, good-quality geothermal water, at a flow rate of 17 kg/s and temperature 60ºC, is transported from a distance of 4.5 km through insulated plastic pipes (HDPE). Due to the high water temperature, geothermal water is initially mixed with seawater before entering the ponds with a mean temperature of 30°C.

The installed thermal capacity of both installations exceeds 8.5 MWt. The use of geothermal energy in these fish farms proved indispensable during the heavy frosts in the 2001-2002 and 2002-2003 winter periods and averted a massive reduction of fish population that has occurred in other farms of the region. It is estimated that both investments were repaid during the first three years of operations.

3.6. Spirulina Cultivation

Spirulina is a photosynthesizing cyanophyte (blue-green algae) which grows in strong sunshine under high temperatures and highly alkaline conditions. Mass cultivation of spirulina is usually carried out in shallow ponds, equipped with paddle wheels to mix the culture. Spirulina shows an optimum growth between 35º and 37ºC.

In Nigrita, Serres, a project started in the late 1990s for the cultivation of spirulina using geothermal energy. The cultivation of spirulina requires the injection CO_2, most of which comes from the dissolved CO_2 in the local geothermal waters. These geothermal waters contain more than 4 kg of pure CO_2 per cubic meter of water produced. The local geothermal water cannot be used directly in the cultivation ponds, because it contains small concentration of toxic substances (e.g. 0.5 ppm of As) for spirulina. The geothermal water, with a temperature of 51°C and a flow rate of 10 kg/s, is first directed to a separator and then flows through a heat exchanger system. The heating of the cultivation water with geothermal energy (with optimum temperature in the range 33-36°C) and the use of geothermal CO_2 increase significantly micro-algal production and reduce its production cost.

Spirulina is now cultivated around the year in 8 shallow raceway ponds made of concrete in which spirulina cultures are mixed by paddle wheels. Each pond occupies an area of 225 m^2 and can hold about 40 m^3 of water (see picture in Figure 4). Smaller ponds are used for the initial stages of the algal production. All the cultivation ponds are situated in a greenhouse, covered by polyethylene foil.

The output of dry spirulina was 4000 kg in 2007 and 4500 kg in 2008, in the form of capsules or powder. The wet spirulina product is dried in a neighboring greenhouse by placing the product on plastic tables. The drying season lasts from August to November, so most of the greenhouse heating comes from the sun. However, some geothermal heating is also supplied in October and November by circulating geothermal water through finned metallic pipes in the drying area. An increase of the spirulina production is expected for the next year next year by expanding the cultivation raceways and extending the cultivating period. Meanwhile, another spirulina project is under way in the vicinity of the existing plant.

3.7. Geothermal Heat Pumps

The use of geothermal heat pumps in Greece is not as widespread as in some other countries, especially in Central and Northern Europe. However, this situation has been changing in the past 2-3 years with an impressive increase in the number of systems installed. The authors have recorded more than 360 applications of GSHP systems in Greece with a total installed capacity of more than 33 MWt. Precise numbers for these installations are hard to estimate due to lack of any official statistics. Thus, conservative estimates can raise the above number at 50 MWt. Table 3 summarizes the distribution of the systems installed as small systems (<100 kWt) and as large ones (>100 kWt) and classifies them according to the type of heat exchanger (closed-loop horizontal, closed-loop vertical and open-loop). About 65% of the recorded installed capacity refers to open-loop systems. Out of more than 360 GHPS applications, only two are related to agriculture and food processing. One application is the abovementioned off-season asparagus cultivation and the second deals with the heating of a poultry farm. Currently, there is no any Greek manufacturer of GHPs, but one company is almost ready to launch a series of geothermal pumps in the following months.

The significant increase of the GHP systems is due to several factors: the easing of the permits for the drilling of a “closed” well, the change of the attitude of the people to the “new” technology, the increased interest of the air-conditioning sector, and, certainly, the soaring oil prices in 2008 in connection to the almost stable prices of electricity in the country. No state support exists at the present for the domestic installations,

4. WELLS DRILLED

The new wells drilled between 2005 and 2009 are about 50 (according to information known to the authors). The great majority of the wells (37) were drilled on behalf of I.G.M.E., five for PPC, three for the Hellenic Association of Municipalities with Thermal Springs and the rest were private. The geographical distribution of the wells is as follows: 15 wells in Central Greece, 11 in Macedonia, 7 in Chios island and 5 in Lesvos island. The depth of the wells ranged from 108 m to 1450 m and the total length of the wells is estimated at 13.7 km.

Figure 4: Picture of geothermally heated raceway ponds for spirulina cultivation in Nigrita, Serres.

5. PROFESSIONAL PERSONNEL

The number of professional person-years in the geothermal sector increased during the past few years due to the involvement of more than 30 companies and consulting firms in the area of geothermal heat pump systems. However, the number of person-years referring to the classic geothermal sector declined. The professional personnel related to geothermal activities is estimated as follows: about 2 in government agencies (including I.G.M.E. and Center of Renewable Energy Sources), 5 in Universities and more than 20 in the private industry and consulting companies.

6. CONCLUDING REMARKS

Geothermal energy is used in Greece only for direct utilization. No geothermal electric power is generated in the country, despite the large high-enthalpy geothermal potential. In addition, the current level of utilization of geothermal energy represents only a very small fraction of the identified geothermal resources. The installed thermal capacity of the direct uses in Greece increased from 75 MWt at the end of 2004 to 135 MWt today. This increase is mainly due to the rapid expansion of geothermal heat pump installations. Balneotherapy/pool heating and greenhouse /soil heating comprise significant shares in the geothermal energy used. Uses introduced during the past 10 years include fish farming, spirulina cultivation, and vegetable and fruit dehydration. Geothermal energy offers the possibility (both technically and economically) for further development of certain added-value agricultural products (e.g. asparagus, lettuce, dried fruits and vegetables).

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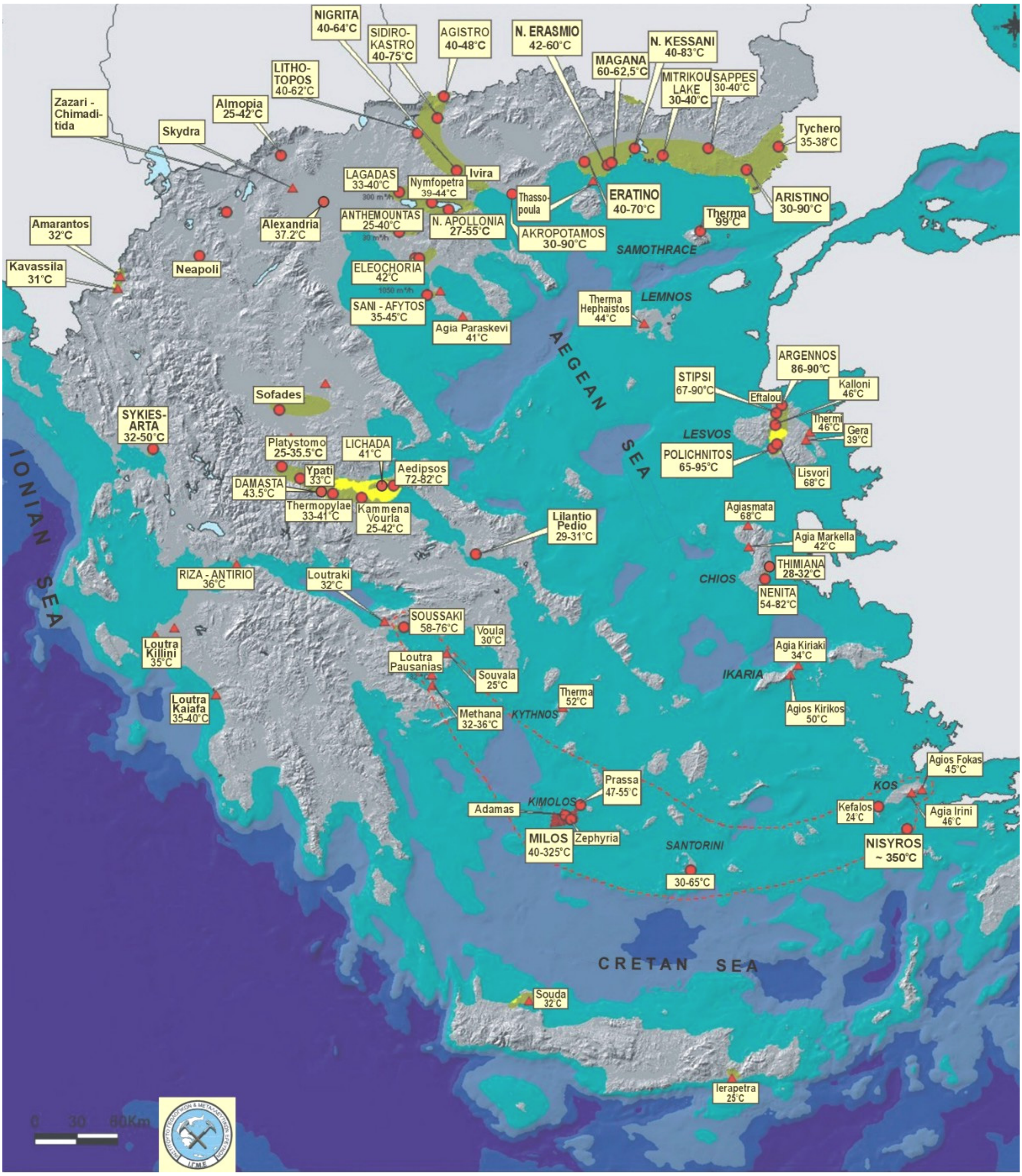

Figure 1: Geothermal fields and areas of geothermal interest in Greece. (This map has been compiled by I.G.M.E. - Division of Geothermal Energy and Thermal Mineral Waters, with recent modifications and additions by Arvanitis A. The officially characterized as proven and probable geothermal fields are written with capital letters into the frames and the other areas of geothermal interest with no classification are written in small letters).

Table 2: Utilization of geothermal energy for direct heat as of 30 November 2009

[1)] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

[3)] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4)] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5)] Capacity factor = [Annual energy use (TJ/yr) x 0.03171]/Capacity (MWt)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Locality	Covered Area in ha (type)	Type[1)] (cultivation)	Maximum Utilization				Annual Utilization		
			Flow Rate (kg/s)	Temperature (^{o}C) Inlet	Temperature (^{o}C) Outlet	Capacity[3)] (MWt)	Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
Nigrita 2	0,5 (glass)	G (flowers)	15.0	42	27	0.94	5.40	10.68	0.36
Nigrita 2b	0.5 (Plastic)	G (veg.)	9.0	37	25	0.45	3.00	4.75	0.33
Nigrita 3	1,5 (glass)	G (veg.)	10.0	51	30	0.88	3.20	8.86	0.32
Nigrita 3c	0.8 (glass)	G (green beans)	10.0	51	28	0.96	2.60	7.89	0.26
Nigrita 4	0.5 (glass)	G (tom+cucum.)	10.0	37	21	0.67	2.80	5.91	0.28
Sidirokastro 1a	0.4 (glass)	G (flowers)	10.0	48	34	0.59	3.50	6.46	0.35
Sidirokastro 1b	0.4(glass)	G (flowers)	7.8	63	35	0.91	2.80	10.34	0.36
Sidirokastro 1c	0.3 (glass)	G (flowers)	8.3	43	33	0.35	3.00	3.96	0.36
Sidirokastro 2a	0.8 (glass)	G (flowers)	14.0	37	25	0.70	5.80	9.18	0.41
Sidirokastro 2b	0.4 (plastic)	G (flowers)	5.0	36	25	0.23	2.00	2.90	0.40
Sidirokastro 3	0.4 (plastic)	G (veg)	10.0	45	30	0.63	3.50	6.92	0.35
Langadas 2	3.5 (glass)	G (flowers)	14.0	36	22	0.82	4.60	8.49	0.33
Langadas 2b			5.0	36	22	0.29	1.60	2.95	0.32
Langadas 3	0.4 (plastic)	G (veg.)	6.0	35	22	0.33	2.00	3.43	0.33
N. Apollonia	0.6 (glass)	G (veg.)	7.0	51	32	0.56	2.20	5.51	0.31
N. Apollonia 2	0.4 (plastic)	G (flowers)	10.0	41	27	0.59	3.00	5.54	0.30
N. Apollonia 3	0.8 (glass)	G (flowers)	12.0	45	30	0.75	4.50	8.90	0.37
N. Apollonia 4a	1 (plastic)	G (veg.)	10.0	47	28	0.79	3.70	9.27	0.37
N. Apollonia 4b		G (veg.)	7.0	32	22	0.29	2.30	3.03	0.33
N. Apollonia 5	0.9 (plastic)	G (veg.)	13.0	45	30	0.82	4.00	7.91	0.31
N. Apollonia 6	2 (glass)	G (flowers)	4.0	36	22	0.23	2.00	3.69	0.50
N. Erasmio	0.4 plastic	G (veg.)	5.0	60	35	0.52	1.60	5.28	0.32
Polychnitos (4 units)	3.5 (glass)	G (veg.)	50.0	83	35	10.04	16.00	101.30	0.32
Polychnitos 2	0.5 (glass)	G (veg.)	9.0	67	35	1.20	2.90	12.24	0.32
Geras, Lesvos	0.4 (plastic)	G (veg.)	5.8	40	25	0.36	1.90	3.76	0.33
Milos	0.55 (glass)	G (veg.)	4.2	46	24	0.39	0.90	2.61	0.21
N. Erasmio	10.0	G (s.h.)	40.0	60	25	5.86	11.00	50.78	0.27
Myrodato	2.0	G (s.h.)	10	50	25	1.05	2.70	8.90	0.27
Nymfopetra	5.0	G (s.h.)	35.0	43	25	2.64	7.80	18.52	0.22
Trainoupoli		H	16.7	52	38	0.98	5.90	10.89	0.35
N. Appolonia		H	10.0	57	45	0.50	3.30	5.22	0.33
N. Erasmio		H	0.8	42	32	0.03	0.25	0.33	0.31
Thermes Xanthi		H	0.8	51	49	0.01	0.28	0.07	0.35
N. Erasmio		A	9.7	58	51	0.28	1.94	1.79	0.20
N. Erasmio		F	38.0	42	8	5.41	9.40	42.16	0.25
Porto Lagos		F	40	27	8	3.18	10.10	25.31	0.25
Nigrita*		O	4.8	50	30	0.40	1.54	4.06	0.32
TOTAL			476.90			45.64	145.01	429.84	0.30

*Cultivation of spirulina

Table 3: Summary table of geothermal direct heat uses as of 30 November 2009

[1)] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2)] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3)] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]	1.5	16.5	0.34
District Heating [4)]			
Air Conditioning (Cooling)			
Greenhouse Heating	34.8	340	0.31
Fish Farming	9.0	74.3	0.26
Agricultural Drying[5)]	0.3	1.5	0.19
Bathing and Swimming[7)]	39.0	238	0.19
Subtotal	**84.6**	**670.3**	0.25
Geothermal Heat Pumps	50.0	270	0.17
TOTAL	**134.6**	**940.3**	**0.22**

[4)] Other than heat pumps
[5)] Includes drying or dehydration of grains, fruits and vegetables
[7)] Includes balneology

Table 3: Characteristics of recorded geothermal heat pump applications (as of November 2009)

	No of appl.	Type of pump system (kW_t)		
		Closed, horizontal	Closed, vertical	Open* groundwater
Large applications (>100 kW)	66	-	4152	18883
Small applications (<100 kW)	>300	2781	4164	2569
Total	>360	2781	8316	21452