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Greek Geothermal Update 2000-2004

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ABSTRACT

By the end of 2004 the installed thermal capacity of the direct geothermal uses in Greece amounted to roughly 75 MWt. Approximately, half of this capacity corresponds to thermal spas (in a few cases combined with space heating) and heating of open or closed pools. Two are the current trends of direct uses in Greece: the stagnation of greenhouse and soil heating (the latter showed a considerable increase in the previous five-year period) and the diversification of the uses. New uses include fish farming, spirulina growing and vegetable and fruit dehydration.

Earth-coupled and groundwater (or seawater) heat pumps have shown a significant increase in the past five years, but their market penetration is far away from the corresponding penetration in some central-northern European countries.

At present no electric power is produced from geothermal resources in Greece, despite the large high-enthalpy resources in the active Aegean volcanic arc. Moreover, in certain other areas (e.g. Lesvos, Chios and Samothraki Islands) organic Rankine Cycle (ORC) power plants could be installed.

The technical potential (the part corresponding to the existing wells) for direct geothermal uses in Greece exceeds 400 MWt and for electrical uses is about 10 MWe.

1. INTRODUCTION

The paper aims at reviewing the progress in the areas of exploration and applications of geothermal energy in Greece during the 2000-2004 period. Before proceeding with the objectives of the paper, a short historical note on thermal waters in Greece is presented.

Geothermal energy, in the form of thermal waters for balneology, has been known to Greeks from the prehistoric times. In fact, the word “geothermal” comes from Greek, meaning “of or relating to the internal heat of the earth” (gaea=earth and thermós=hot). Many natural manifestations, such as thermal springs, fumaroles, hot grounds and hydrothermal mineralizations, are widespread almost all over Greece. There are more than 750 thermal springs (the thermal springs at Thermopylae are flowing at a rate of 30 kg/s for at least 2500 years) and more than 50 spas in operation. In Greek mythology, certain thermal springs (like those in Western Peloponnese) were protected by the nymphs Anigrids, while all therapeutic thermal waters were sacred to Asclepius (the god of medicine), to Hygeia (the goddess of health and to the hero Hercules. The latter was the most renowned mythological user of thermal waters. In his wanderings, he was always searching for thermal springs for bathing and retaining his physique. Numerous thermal localities where named after him. The temple of goddess Artemis (Diana in Latin) in Lesvos Island was founded around a thermal spring. In the classical era, Hippocrates of Kos was the first physician who used balneology to cure his patients. Finally, it is said that Galen, the Greek physician and writer in the second century A.D., offered to his quests early-season vegetables, probably cultivated using geothermal waters.

The systematic exploration of the large geothermal potential of Greece, however, started only in the early ‘70s, by the Institute of Mineral and Geological Exploration (IGME). The first research program included the fields of Milos, Nisyros and Lesvos Islands, Methana and Sousaki. In the meantime, the first use of thermal waters (apart for balneology) was materialized for greenhouse heating. In the mid seventies, the Public Power Corporation (PPC) showed an interest in the generation of electric power from the high-enthalpy geothermal field of Milos Island. The initial research activities were mainly financed by the then Ministry of Industry and by PPC. After the entrance of Greece into the European Union in 1981, numerous research and development projects were funded or co-funded by the European Commission with the participation of several public or private organizations (IGME, PPC, Bank of Industrial Development, Universities, Research Institutes etc).

The first reference of geothermal energy in the Greek legislation system made in 1984 (Law 1575/84). With this law, the exploration and exploitation of geothermal energy was regulated by the “mining exploration decree” (decree 210/73). Recently, Law 3175/2003 (issued in July 2003) replaced the previous one, but kept the regulation. The geothermal potential is characterised as a renewable energy source (RES) which can contribute to the sustainable development for the benefit of the people. The concept of “field management” is introduced, which involves the coordination of the exploration efforts, the rational use of geothermal fluids, the distribution and selling of the thermal waters to individual uses etc. Permits for the exploitation of a field are provided by the Regions, provided that the temperature of water is less than 90°C, or directly from the Ministry of Development for fields with higher fluid temperature.

In order to reinforce private investments for, among other things, in the geothermal sector and other RES production and electricity generation from RES, the Development Law was decreed in 1998 (Law 2601/1998). By this law, a RES project can be subsidized up to 40% of the total budget, depending on the level of development of the region. Besides this, there are tax deductions up to 40% or 100%.

In 2002 the final energy consumption in Greece was 34.2 MTOE (million tonnes of oil equivalent) or 1540 PJ (1 PJ = 10^{15} J). A breakdown of the various sectors in Figure 1 shows that 37% of the final energy consumption was required in the domestic commercial sectors (for space-heating and hot water). A noteworthy proportion of this heat demand could be supplied either by direct geothermal heat (in the areas with geothermal resources) or by geothermal heat pumps, especially in the northern and mountain regions of the country, which exhibit higher heating needs.

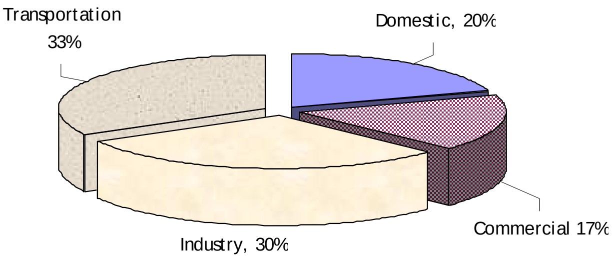

Figure 1: Distribution of the final energy consumption in Greece in the various sectors.

2. GEOLOGICAL BACKGROUND

The Hellenic area is characterized by high levels of heat flow higher than 80 mWm^{-2}, mainly in the internal Hellenides and the Aegean Sea. The high heat flow is due to the active tectonics and the volcanic activity, which since Tertiary is manifested in the area as result of the collision between the European and African tectonic plates.

This very intense volcano-tectonic activity caused the geological conditions for accumulation of heat energy, which is manifested in many places as hydrothermal systems of low-medium and high enthalpy geothermal fields. The most important high-enthalpy geothermal fields are located in the Southern Aegean (Figure 2), along the active volcanic arc (Milos, Nisyros). Medium and low enthalpy geothermal fields are mostly associated with grabens (Central Aegean) and post-orogenic sedimentary molassic basins (southern boundaries of the Rhodope and Servo-Macedonian Massifs).Sections and subsections should be numbered.

3. GEOTHERMAL EXPLORATION

The Institute of Geological and Mineral Exploration (IGME) carried out the main part of exploration activities. New promising geothermal areas have been discovered in the past five years. A brief description of the most interesting new findings follows..

3.1. Macedonia

Ivira-Achinos: This new area belongs to the Strymon Basin, one of the most well explored geothermal regions in Greece. In 2002 the Achinos-Ivira geothermal field has been confirmed through a new production well drilled down to 680 m identifying high artesian fluid (>30 kg/s) with temperature rising up to 58°C at the bottom hole.

Akropotamos-Kavala: A new very promising area has been explored during 2003 in the coastal area of the western part of Perfecture of Kavala. Two productive wells were drilled in the Akropotamos area identifying bicarbonate fluids between 275-400 m depth with temperatures 51-82°C and artesian flow rates exceeding 40 kg/s (Figure 3).

Figure 3: Picture of the recently drilled well in Akropotamos, Kavala, during testing.

Aridaia: In the Almopia basin, a new deep production well yields over 33 kg/s of water with a 38ºC temperature from the top of the metamorphic basement, at 780 m depth.

Alexandria: Located in the northern part of the extended Thessaloniki basin, a new deep production well at 800 m depth yields more than 33 kg/s of water (having a temperature of 36ºC) from Quaternary-Miocene aquifers.

Sani-Chaklidiki: Further to the previous exploratory work, a new productive well were drilled in the Sani beach resort to a depth of 605 m depth identifying geothermal fluids at 32°C, yielding up to 27 kg/s with a low content of gases (ration of gas to liquid flowrate 0.2), but rich in CH_4 and N2.

Aetos-Florina: This region of Western Macedonia is located in the NW boundaries of the Ptolemais sedimentary basin. Three production wells at a depth of 200 m yield over 54 kg/s with temperatures ranging between 30 to 36°C.

Langadas: Two production well at 120-170 m were drilled yielding 22 kg/s water of 38°C. Geothermal waters will be used for cascade applications in heating and cooling of greenhouses and buildings of the public sector, including the spa hotel.

3.2. Thrace

In Thrace recent geothermal research is limited to four new production wells. Two new promising geothermal fields were identified in the Perama-Sappes and Myrodato-Xanthi areas.

Aristino-Aetochori: A new production well was drilled down to 500 m. The high geothermal interest of this area was confirmed with fluids at 62°C and flow rates up to 18 kg/s. This well will be used for heating purposes of a 1 ha greenhouse complex.

Perama-Sappes: This region is located in the eastern boundaries of the post-orogenic graben of Petrota-Sappes. A production well carried out by a gold mining company revealed an important karstic geothermal aquifer down to 250 m yielding up to 42 kg/s of water at 38°C.

Mirodato – Xanthi: This region is located in the eastern boundaries of the Nestos molassic basin by the western part of the Avdira horst. Geothermal interest has been confirmed by a very recent low deep (150 m) production well with fluid temperature at 52°C. Waters will be used for heating purposes of a watermelon early cultivation under low covering.

3.3. Aegean Islands

Chios Island: A production well of 380 m depth was drilled in the area of Nenita, after the extended exploration works. The aquifer temperature reaches 82°C with a flow rate higher than 14 kg/s of saline water.

Lesvos Island: The Public Power Corporation (PPC) has completed an important drilling campaign in the areas of Argenos and Stipsi. Three production wells were opened at depths from 300 to 1085 m. Temperatures recorded vary from 90 to 100°C and yields from 14 to 30 kg/s. PPC plans to start a deep drilling program at depths up to 1600 m in the area located between Stipsi and Petra by the end of 2004, hoping to meet medium-enthalpy fluids for a Rankine organic cycle plant.

Milos Island: In the frame of an extended desalination project in the Island, eight production and three reinjection wells were drilled at depths between 80 and 150 m yielding in total up to 120 kg/s. Wellhead temperatures varied from 80 to 100°C, while the TDS of the waters ranged from 20 to 45 g/L.

3.4. Epirus – North-West Greece

Konitsa: Initial exploration works were resulted in a production well of artesian flow at a depth of 300 m. Located in the area of Kavassila this well produces about 22 kg/s water with a temperature of 32°C.

Antirrio: Motivated by a first promising exploratory well, a production well was drilled at a depth of 120 m, which encountered a very interesting geothermal aquifer of 32°C. The well flowrate is 33 kg/s.

4. DEVELOPMENTS IN DIRECT USES

Direct heat applications in operation during the winter 2003-2004 are listed in Table 3. The installed capacity of direct uses approaches 75 MWt, giving a 42% increase with respect to the capacity reported for 1999 (Fytikas et al, 2000). Certainly, the stagnation in new greenhouse projects has lead to the above, rather modest, increase with regards to the huge potential of the country in the installed thermal capacity. Despite of this, an optimistic development in the past five years was the effective diversification of low enthalpy geothermal applications in new promising sectors, such as aquaculture, spirulina production, water desalination, fruit and vegetable dehydration and large heat pump installations.

4.1. Space Heating

There are not any new major developments in this sector. The use of geothermal energy for space heating is practiced only in a spa complex in Traianoupoli, Thrace, in a hotel in Milos, in several individual houses in Macedonia and Thrace and in a high-school building in Thrace, as seen in Table 3. The heating of several houses in Milos is accomplished by a kind of “downhole heat exchanger”. These systems consist of a metallic U-tube submerged in a swallow (20 m) geothermal well with 60ºC water, which is directly connected to house radiators. The method uses a system of pipes placed inside a well and a working fluid (usually ‘clean’ water) is pumped through the pipes or allowed to circulate by natural convection to extract heat from the well water. The installed capacity of the space-heating units in the country has been estimated to 1.2 MWt.

4.2. Greenhouse and Soil Heating

During the past 10 years there is not any real increase in the covered area of geothermal greenhouses. Some new greenhouses were constructed, but others, mainly owed by community co-operatives, were abandoned, for reasons irrelative to geothermal energy. The greenhouses are located in Central Macedonia (Langadas and N. Appolonia in the Prefecture of Thessaloniki and Nigrita and Sidirokastro in the Prefecture of Serres), in Lesvos Island (Polichnitos and Geras), and in Milos Island. The total covered area in 2004 is around 20 ha. In the majority of the greenhouses, heating is obtained directly through plastic or metallic pipes.

Regarding soil heating for early season asparagus cultivation, the covered area remained constant at 12 ha. The Nymfopetra unit was expanded, but the Nigrita unit has not operated for the past two years. The soil heating is accomplished by the direct flow of the geothermal water through corrugated PP, 28-mm o.d. pipes, placed underground.

4.3. Bathing, Spas

There are 56 thermal spas and bathing centers operating in Greece today, mostly operated during the traditional balneological period (June-October). It is interesting, though, that more and more spas remain open all year.

Only recently there has been an interest for systematic work to assess the thermal use in the spas and bathing centers in Greece and to record the problems related to the geothermal waters (scaling, corrosion). The total water flowrate from the Greek spas exceeds 1000 kg/s, while the water temperatures range between 18 and 90ºC. 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 36 MWt, with a mean load factor of 0.16. These figures include the open and closed pools heated by geothermal waters (Aedispos, Loutraki-Pella, Milos Island etc.).

4.4. Industrial Uses

A tomato dehydration unit started operation in 2002 in N. Erasmio, 25 km south of Xanthi, and since then has produced more than 15 tons of "sun-dried" tomatoes (Andritsos et al, 2003). The unit uses low-cost geothermal water (which during winter and spring is used in soil heating for asparagus cultivation) to heat atmospheric air to 55°C in finned tube air heater coils. In addition, the plant has been used to dehydrate small quantities of figs and apricots.

A second industrial use involves a desalination plant in Kimolos Island, one of the numerous islands in the Aegean Sea facing severe problems of water supply, especially in the summer. The plant, based on the multiple effect distillation (MED) method, utilizes low-enthalpy water (60-70°C) from shallow bores, 50-200 m (Karytsas et al. 2002b). In this plant, a geothermal stream flows through a low-pressure vessel containing several chambers or stages, each operating at a slightly lower pressure than the previous one. As the water enters each stage, a portion of it "flashes" into steam and is then condensed using sea water to produce a pure distillate product, which is pumped into the fresh-water tank.

4.5. Fish Farming

Anti-frost protection/heating of aquaculture ponds in Porto Lagos and N. Erasmio is practiced since 1999-2000. In Porto Lagos, the water comes from two production wells near the farming ponds. The flow rate from the two wells reaches 40 kg/s and the mean temperature of the water is 27ºC. In the N. Erasmio installation, the water, at a flow rate of 40 kg/s and temperature 42ºC, is transmitted from a distance of 4 km in insulated plastic pipes. 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 severe damage of the fish stock that has occurred in other farms of the region.

4.6. Spiroulina Cultivation

Cultivation of the green-blue algae spirulina is practiced in Nigrita, utilizing the geothermal waters both for their heat and for the dissolved CO_2. The local geothermal waters contain about 4 kg of pure CO_2 per cubic meter of water produced. The cultivation is taking place in shallow, covered, temperature-controlled ponds.

4.7. Geothermal Heat Pumps

As stated in abstract, the use of geothermal heat pumps in Greece is not as widespread as in some other countries, despite the significant increase of the installed units in the past five years. Depending upon space limitations, favorable geothermal conditions, local climatic conditions and the size of the installation, these units consist of earth-coupled heat pumps (horizontal heat collectors, vertical heat exchangers), or low-temperature geothermal or ground water heat pumps. In the past five years a significant increase in seawater cooling (but also heating) has been also observed, especially for large hotels cooling. These units are not accounted for the estimated geothermal heat pumps capacity in Tables 4 and 5.

The exact number of geothermal heat pump units presently installed in Greece is not known exactly, but the authors have been recorded about 100, mostly small (10-20 kWt), as well as some larger (100-500 kWt) units (e.g. the 550 kWt system at the Technical University of Athens, Karytsas et al., 2002a). A conservative estimate yields a total geothermal installed power capacity of 4 MWt. Although, the great majority of these units are horizontal heat collectors placed in a depth in the rage of 1.5-3 m (a figure of such an installation is shown in Fig. 4), all large units are of the vertical configuration

The future development of the geothermal heat pumps is difficult to estimate. The main reasons for this situation are that there is no any real economic motive by the state (e.g. tax deduction), the dissemination of new technologies is rather slow in the country, and the lack of experienced technicians for installation and maintenance. Nevertheless, the recent mini oil-crisis and the success of most of the existing installations have considerably increased the interest of many individuals and organizations

Figure 4: Picture of an earth-coupled geothermal heat pump installation in Thessaloniki.

5. FUTURE DEVELOPMENT AND PROSPECTS

Very important geothermal projects are under development or planning, particularly in Northern Greece. The most important projects are as follows:

Macedonia airport: Heating and cooling of a 80.000 m2 total covered area of new Thessaloniki Airport buildings using geothermal water and heat pumps. The required heat energy quantities can be served by geothermal waters at a flow rate of 40 kg/s with temperature 45-55°C. For this purpose a production well will be drilled by the end of 2005 at a depth of 1000 m.

Prefecture of Imathia: Heating of a cactus greenhouse (1.0 ha) and asparagus cultivations (8.0 ha) will be ensured by a production well already performed at a depth of 800 m in the Alexandria region (36°C, 33 kg/s). In the same region low depth (150-200 m) aquifers with temperatures at 18-20°C will be used for heating and cooling purposes, by means of heat pumps, of public buildings (1000 m^2), a swimming pool and a small (0.1 ha) greenhouse. The new central building of the city of Veria (12.000 m2) will be heated and cooled by means of geothermal heat pumps.

Langadas: Production and reinjection wells, distribution networks and heat pumps units are already installed to offer heating and cooling to a greenhouse, two public schools, the courthouse and the health center of the city of Langadas in a cascade mode.

Prefecture of Xanthi: Anti-frost protection and heating of open type aquacultures (for farming giltheads) will be extended over 5 ha of earth ponds. Soil heating for asparagus earliness will be implanted in 5 ha, totalizing 12 ha by the end of 2006. This heating mode will be tested for earliness purposes in watermelon and lettuce cultivations under low plastic film covering (3.0 ha by the end of 2004). In the Porto-Lagos area geothermal waters of 35°C will be used for heating growing water of a gilthead hatchery.

Electric Power generation: As it is known, a double flash 2 MWe power plant was installed in 1985 in Milos and operated intermittently till 1989. The plant was shut down because mainly of the environmental protests due to H2S emission to the atmosphere. Because of the unfortunate fate of the Milos electrical plant, a renewal of interest for power generation in Milos and Nisiros with flash cycle units is not probable. On the other hand, the installation of small Organic Rankine Cycle (ORC) units cannot be excluded. In the past few years the Public Power Corporation has started exploratory work prospecting for the installation of a binary ORC unit in Lesvos Island. The construction of a small binary unit is also scheduled for construction to supply electricity for the Milos desalination plant. The potential for electrical generation using ORC units in several Aegean islands (Milos, Nisyros, Lesvos and possibly Chios) is large and a preliminary estimate is ~20 MWe. The substitution of fossil fuel derived electric power by a “green” power from ORC units, which may be located away from the coast, will undoubtedly have a positive impact on the environment (reduction of CO_2, NOx and CO emission), will reduce the noise associated with conventional power plants and avert possible oil spill during oil shipment.

6. WELLS DRILLED

The new wells drilled between 2000 and 2004 were 55, as presented in Table 6. Most of the wells were drilled in Central-Easter Macedonia (18), Thrace (4) and in Milos Island (14). It is reminded that 87 wells were drilled during the 1995-1999 (Fytikas at al. 2000). The average depth of the exploration wells is 400 m and that of production wells is 270 m. The deepest production well was 1100 m and the lowest 60 m.

7. PROFESSIONAL PERSONNEL

The number of professional person-years in the geothermal sector continued to decline during the past years. The professional personnel related to geothermal activities is estimated as follows: 24 in Government positions and in Public Utilities (including IGME and PPC), 5 in Universities and 10 in the private industry and in consulting companies:

8. INVESTMENT IN GEOTHERMAL

It is very difficult to have an exact estimate for total investment to geothermal activities prior to 2000 due to the big diversification of financing sources. A gross estimate is 3-4 million US$, 50% funded by public funds, a significant part of which (>85%) dealt with the research and development of some new low enthalpy fields Islands.

During the last five years the investment in research and field development is estimated to 2.6 million (in 2004) US$ (Table 8). In the same period investment in direct uses went mainly to asparagus cultivation (~0.5 ha), greenhouse expansion (0.4 ha), completion of the desalination plant in Kimolos Island and dehydration unit in Neo Erasmio-Xanthi. A significant increase of the total invested amount has been recorded in the field of geothermal heat pumps systems installed. (>1.0 million US$) The total investment in these direct uses (excluding cost for drilling and surface development) is estimated to 1.5 million (in 2004) US$, with the private sector funding standing to about 40-50%.

9. CONCLUSIONS

The growth in direct heat uses in Greece has exceeded 7% compounded annually over the past five years. Growth during the past five years could have been higher, but the stagnation of new geothermal greenhouses limited the growth of the geothermal growth. The optimistic sign, however, was the diversification of the geothermal applications with fish farming, vegetable and fruit desalination and water desalination. Promising was also the number of new geothermal heat pump installations, both in the public and in the private sector.

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TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT IN GREECE AS OF 31 DECEMBER 2004 (other than heat pumps and balneology)

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Nigrita	G	19.5	58	38			1.63	6.67	17.60	0.34
Nigrita	G	13.9	41	28			0.76	4.90	8.40	0.35
Nigrita	G	8.3	60	30			1.04	3.10	12.27	0.37
Nigrita	G	14.0	45	30			0.88	4.76	9.42	0.34
Nigrita*	O	4.8	50	30			0.40	1.54	4.06	0.32
Sidirokastro	G	25.8	60	35			2.70	8.52	28.09	0.33
Sidirokastro	G	13.9	37	26			0.64	5.28	7.66	0.38
Lagadas	G	5.6	36	20			0.37	1.96	4.14	0.35
Lagadas	G	8.3	37	25			0.42	2.75	4.35	0.33
N. Apollonia	G	7.0	46	32			0.41	2.55	4.71	0.36
N. Apollonia	G	13.9	42	28			0.81	4.80	8.86	0.35
N. Apollonia	G	16.7	46	22			1.68	6.35	20.10	0.38
N. Apollonia	G	11.0	45	30			0.69	3.70	7.32	0.34
Nimfopetra	G	19.4	42	25			1.38	6.68	14.98	0.34
Eleochoria	G	5.6	30	20			0.23	1.74	2.30	0.31
N. Erasmio	G	22.2	60	25			3.25	5.33	24.61	0.24
N. Erasmio	A	9.7	58	52			0.24	1.94	1.54	0.20
N. Erasmio	F	40.0	42	8			5.69	10.40	46.64	0.26
N. Erasmio	H	0.8	42	32			0.03	0.25	0.33	0.31
N. Kessani	G	5.6	60	30			0.70	2.07	8.19	0.37
Thermes Xanthi	H	0.8	51	49			0.01	0.30	0.08	0.37
Aristino	G	5.6	62	30			0.75	1.97	8.31	0.35
Trainoupoli	H	16.0	52	35			1.14	5.60	12.56	0.35
Polichnitos	G	16.7	80	35			3.14	5.70	33.83	0.34
Geras	G	5.6	38	25			0.30	1.90	3.26	0.34
Milos	G	4.2	46	24			0.39	1.02	2.96	0.24
Porto Lagos	F	40	27	8			3.18	10.10	25.31	0.25
Kimolos**	O	22.2	62	42			1.86	8.88	23.43	0.40
TOTAL		**377.1**					**34.73**		345.30	

*Cultivation of Spirulina ** Water Desalination

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2004

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)

H = horizontal ground coupled

W = water source (well or lake water)

O = others (please describe)

Report the COP = (output thermal energy/input energy of compressor) for your climate

Report the equivalent full load operating hours per year, or = capacity factor x 8760

Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319

or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

Locality	Ground or water temp. (°C)[1)]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2)]	COP[3)]	Heating Equivalent Full Load Hr/Year[4)]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Pilea Thes/niki	Ground	305	3	V	4	2500	2.1	
Skopelos	Ground	15.4	5	H	4	1500	0.1	
Hmathia	Ground	43	4	H	3.8	1800	0.2	
Thessaloniki	Ground	68	4	H	3.8	1700	0.3	
Katerini	Ground	20	1	H	4.2	1800	0.1	
Technical Univ Ath.	G-W	526	2	V	2.9	2500	3.1	
TOTAL		**977.4**	**19**				**5.8**	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

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]	1.20	14.3	0.35
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating	22.18	231.2	0.33
Fish Farming	8.87	72	0.25
Agricultural Drying[5]	0.24	1.5	0.20
Bathing and Swimming[7]	36.00	181.6	0.16
Spirulina Cultivation	0.40	4.1	0.32
Water desalination	1.86	23.4	0.40
Subtotal	**70.75**	**528.1**	
Geothermal Heat Pumps	4.00	39.1	0.31
TOTAL	**74.75**	**567.2**	**0.25**

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)		10			3.9
Production	>150^o C					
	150-100^o C					
	<100^o C		40			9.65
Injection	(all)		5			0.9
Total			**55**			**14.45**

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994						
1995-1999						
2000-2004	0.8	1.8	0.55		50	50

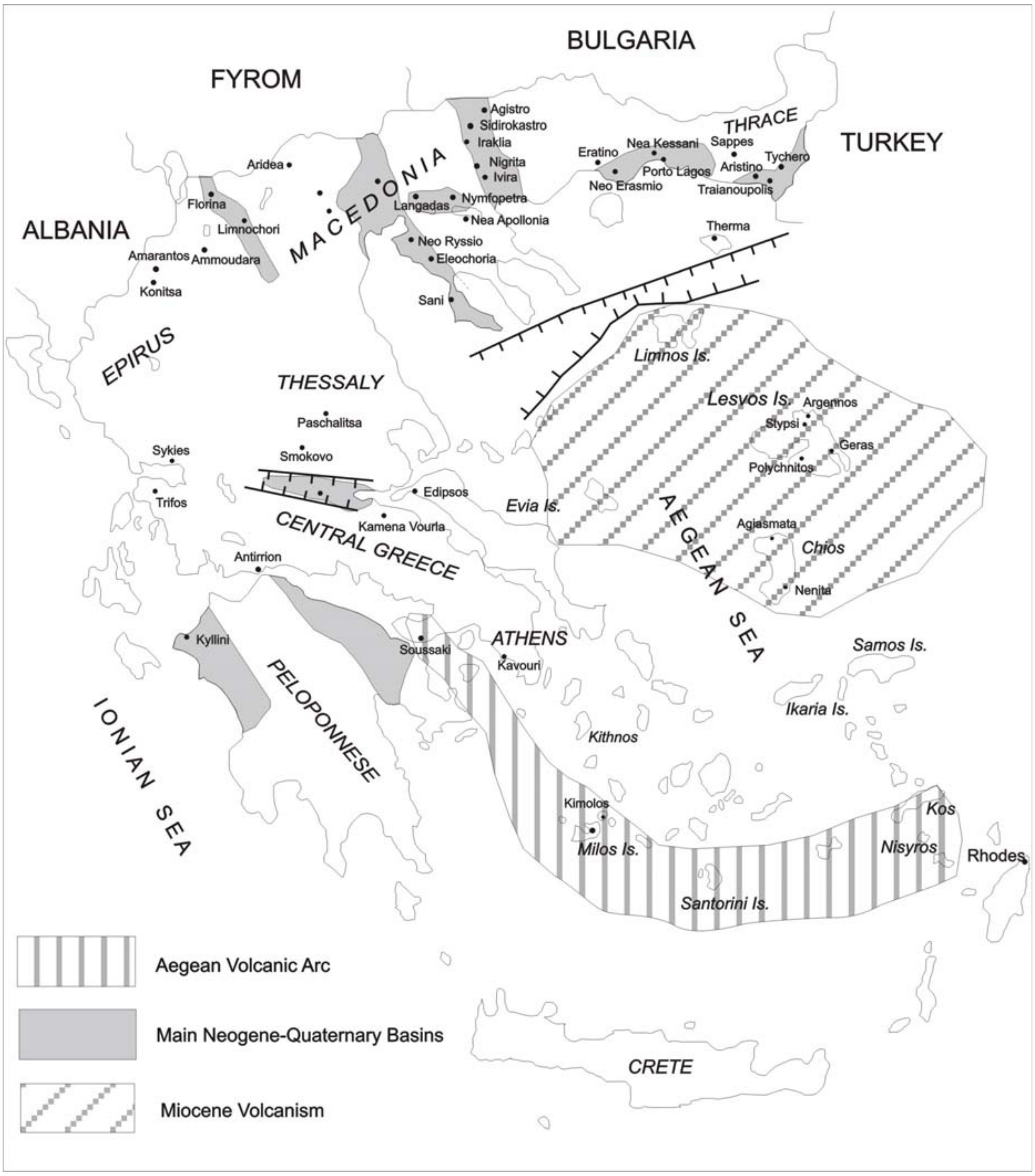

Figure 2: Geothermal map of Greece.