INTERNATIONAL GEOTHERMAL DAYS
SLOVAKIA 2009
CONFERENCE & SUMMER SCHOOL

III.2.

GREEK EXPERIENCE WITH GEOTHERMAL ENERGY USE IN AGRICULTURE AND FOOD PROCESSING INDUSTRY

Nikolaos Andritsos[1], Michael Fytikas[2] & Nikolaos Kolios[3]
[1]Dept. Mechanical Eng., University of Thessaly, Volos, Greece[2]Department of Geology, Aristotle University of Thessaloniki, Thessaloniki, Greece
[3]Institute of Geology and Mineral Exploration (I.G.M.E.), Branch of Central Macedonia, Thessaloniki, Greece

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. At the spring of 2008 the total installed geothermal capacity of direct uses in Greece accounted for more than 120 MWt. The main direct uses until about 2005, such as heating (district, space, greenhouse, soil), balneotherapy, and aquaculture, show practically no progress since 2005. On the other hand, the geothermal heat pump systems showed rapid expansion recently, contributing significantly in the total installed capacity. The covered area of geothermal greenhouses in the whole country remains rather constant since 1995 at about 18-20 ha. Off-season asparagus cultivation has been practiced with success in Greece during the past 12 years with a total cultivated area of about 21 ha. A similar soil system can be used for lettuce early cultivation. An interesting development in recent years is the use of an open-loop geothermal heat pump system for soil warming. Finally, a tomato dehydration unit has been operating since 2001 and during the eight years of its operation it produced almost 70 tn of high-quality dried tomatoes. An analytical recording of the agricultural uses in Greece is presented, and the technical problems pertinent to these applications are also discussed.

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).

Geothermal energy, in the form of thermal waters for bathing and for medical treatment, has been known in the area from prehistoric times (Fytikas et al, 2000). However, the systematic exploration of the geothermal potential of Greece started only in the early 1970s, and it was carried out mainly by the Institute of Mineral and Geological Exploration

(IGME). The total proven geothermal electricity generation potential from the high-enthalpy fields in the islands of Milos and Nisyros is 25 MWe, whereas the probable potential exceeds 250 MWe. Currently, no geothermal electricity is produced in the country. Regarding the thermal potential of low-enthalpy geothermal resources (with fluid temperatures less than 100°C) it is estimated to be higher than 1000 MWe. There are 25 areas, which are officially classified as proven and/or probable low-temperature geothermal fields. In spite of the enormous geothermal potential of Greece, the degree of exploitation is so far rather limited due to various obstacles for the penetration of geothermal energy such as licensing problems, lack of proper advising to prospective users, lack of incentive measures by the state (e.g. tax rebates, lowering VAT for renewable equipment, increase of feed-in tariff for electricity generation), small scale of Greek farming, etc.

Excluding the traditional balneological use of the thermal waters, the first direct use of geothermal energy in the country dealt with greenhouse heating. The first greenhouses were built in the early 1980s in Northern Greece. This application expanded rapidly and in mid 1990s the covered area of geothermal greenhouse was about 24 ha. At the same time, the use of low-temperature waters for soil heating for the off-season cultivation of asparagus was initiated in N. Erasmio, Xanthi, after a 4-year period of experimentation. Recently, a drastic increase in geothermal heat pump applications is taking place in the country.

The scope of this paper is to review the current status of geothermal uses in Greece with particular emphasis in agriculture and aquaculture. A short discussion is also made on the experience gained from the 25-year long use of geothermal waters for agricultural purposes, and on the problems and prospects of the agricultural applications.

2. DIRECT USES

Direct heat applications in operation during the winter 2008-2009 are summarized in Table 1. The estimated installed capacity of direct uses in the spring of 2009 exceeded 120 MWt, exhibiting a 65% 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 characterised by a diversification of direct applications in 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 geothermal heat pump systems (GHPS). In fact, the increase in the installed capacity reported here can be attributed solely to GHPS. All other applications do not show any clear change in the installed capacity, apart from a small increase in soil heating and in heating of indoor and outdoor pools.

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 utilising 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.

3. GREENHOUSE HEATING

The first geothermal greenhouses in Greece were constructed in the early 1980s in Northern Greece, namely in Nea Apollonia and Langadas (Perfecture of Thessaloniki), Nigrita (Serres), N. Kessani (Xanthi) and Polichnitos (Lesvos island). Approximately 18.2 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

13.1 ha, while the rest area is covered mainly 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 and cucumbers. Other agricultural products grown occasionally in these greenhouses include lettuce, green beans, 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 23 geothermal greenhouse units in the country run by 17 operators. All the greenhouse units but two cover almost entirely their heating needs with geothermal energy. The locations of the active greenhouses (with the exception of that in Milos island) are shown in Figure 1, whereas Table 2 provides some more information on active and non-active greenhouses.

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 illustrated in Figure 2. This figure depicts the temperature distribution of geothermal waters (in kg/s) use for greenhouse heating only. 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 characterized by low electrical conductivity, as can be clearly seen in Figure 3.

The geothermal water used in heating the active greenhouses comes from 20 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. The share of the various pumping methods with regards to pumping water volume in the greenhouses is illustrated in Figure 4.

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 greenhouse can be divided into four categories: (1) Concective 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 can be located below the ground level (soil heating), on the ground (next to the plant row), under or on the benches or they can be 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. Typical pictures of two heating methods are shown in Figure 5. A breakdown of the heating methods is illustrated in Figure 6. Clearly, the use of corrugated PP pipes is the choice for more than 50% of the covered greenhouse area.

Most geothermal waters for greenhouse heating are transported over distances less than 500 m, although a distance of 2500 m is reported in Geras, Lesvos. Almost 80% of transportation pipes are of PVC and they are not properly insulated. Currently, about 30% of the spent geothermal waters is reinjected in the reservoirs, but this percentage increases in the past few years due to environmental restrictions.

4. SOIL WARMING FOR OFF-SEASON ASPARAGUS CULTIVATION

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 (Nichols, 1990). Asparagus is marketed as a good source of several vitamins (e.g. folic acid, vitamin C, vitamin B6), calcium, iron, potassium and many other micronutrients. Asparagus is an important export vegetable for Greece and its cultivation started in the 1960s in the Prefecture of Pella. According to FAO statistics for 2005 (FAO, 2009), Greece is placed 9th in the world regarding asparagus production, but it ranked 5th regarding exports, with a total export quantity of 14100 tons. Greece's main export market is Central Europe, and particularly Germany, Spain, France and the Netherlands. Most Greek asparagus production is of the white or light green asparagus. Field cultivated areas of asparagus in Greece are currently about 3500 ha. Essentially all of Greek commercial production occurs in Macedonia and Thrace and it is harvested primarily in the March to June period.

Off-season asparagus cultivation is possible as it has been demonstrated in many situations through polytunnel cultivation during rainy season and low temperatures. 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, wholesale prices roughly average between 4-6 for fresh asparagus and prices begin dropping well below 4 €/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, as schematically shown in Figure 7. 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 analytically in Table 3, the total cultivated area with soil heating in the beginning of 2009 was 21 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 totalling 7 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 Chrysoupolis, 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.

A significant disadvantage for the asparagus cultivation in Greece is the lack of a strong domestic consumption base, although in the past few years there is an increasing demand for off-season asparagus.

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 8, along with a picture of packing asparaguses in N. Erasmio.

5. DEHYDRATION OF AGRICULTURAL PRODUCTS

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. The dehydration plant covers an area of about 400 m^2 housing two tunnel-type driers, washers, grading, cutting and packing equipment, offices and two storage rooms kept at a temperature less than 10°C. The length of each tunnel is 13.5 m, the height 2.2 m and the width 1.24 m. More information on the whole process can be found in Andritsos et al. (2003) and a schematic of one tunnel drier is depicted in Figure 7. Currently the plant is capable of producing more than 1000 kg per day of dehydrated tomatoes with 10% moisture from 10-12 tn of fresh produce. The final "sun-dried" product is stored in conditioned storage rooms. The colour of the product is one of most important characteristics. The relatively low drying temperature utilized in the plant helps tomatoes to retain their aroma, colour and flavour. During the first eight years of operation of the dehydration plant 68 tn of high-quality dried tomatoes were produced, sold in Greece and abroad. The annual evolution of dried tomato production is illustrated in Figure 4. The unit is capable of drying and other vegetables and fruits and indeed, more that 1500 kg of peppers, figs, aubergines, cherries and apples have been also dried upon demand in the past three years. 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.

A pilot-scale geothermal drying system for cotton pre-drying has been designed and tested in N. Kessani, Xanthi, in the years 1991 and 1992. This unit, overseen by the Hellenic Association of Curative Springs and Spas, demonstrated that the pre-drying of cotton is possible in a specially designed tower drier using geothermal water. A picture of this pilot unit is shown in Figure 5.

6. 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 m^3) is constantly replenished with water either from the sea or from the neighbouring 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 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 operation.

Spirulina is a photosynthesizing cyanophyte (blue-green algae) which grows in strong sunshine under high temperatures and highly alkaline conditions (Habib et al, 2008). It has been named as a "wonderful future food source" because spirulina has exceptionally high protein content, of the order of 60–70 percent of its dry weight. Spirulina is also a rich source of certain vitamins and minerals, most notably of potassium. 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 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 (by optimizing photosynthesis) and reduce its production cost.

Spirulina is cultivated between April and November 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 12). 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 neighbouring 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.

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 seems to be altering during the past 2-3 years with an impressive increase in the number of systems installed. The authors have recorded more than 350 applications of GHP systems in Greece with a total installed capacity of 30 MWt. The exact number of such units presently installed in the country is not known, but the above figure could well exceed 45 MWt. About 65% of the recorded installed capacity refers to open-loop systems. Out of more than 350 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.

9. CONCLUSIONS

The current level of utilization of geothermal energy in Greece 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 124 MWt today. This increase is mainly due to the rapid expansion of geothermal heat pump installations. Greenhouse and soil heating have the third largest share in the installed capacity, following GHP systems and balneotherapy. However, the total covered area of geothermal greenhouses has remained stagnant since 1995, while the soil heating cultivating area has been expanded somehow. 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, microalga, lettuce, dried fruits and vegetables).

References

Andritsos, N., Dalampakis, P. and Kolios, N.Use of Geothermal Energy for Tomato Drying. *GeoHeat Center Quarterly Bul.*, 24(1), 9-13, March 2003.

Andritsos, N., Karabelas, A.J., and Fytikas, M. Utilization of geothermal energy in Greece: current status, technical problems and prospects (in Greek), Proceedings, *6th National Conference on Renewable Energy Sources*, Vol. A, pp. 461-470, Volos, Nov. 3-5, 1999.

FAO Statistical Yearbook, Rome, 2009 [www.fao.org/es/ESS/index_en.asp assessed 25.4.2009]

Fournadzhieva, S., Pilarsky, P., Arvanitis, A., Fytikas, M., and Koultsiakis, E. Use of geothermal Fluids for cultivation of microalga Spirulina in Nigrita-Serres, Proceedings, *7th National Conferences on Renewable Energy Sources*, Vol. B, pp 97-104, Patras, Nov. 6-8, 2002.

Fytikas, M. Geothermal situation in Greece. *Geothermics* 17, 549-556, 1987.

Fytikas, M., Leonidopoulou, G.M., and Cataldi, R. Geothermal Energy in Ancient Greece: From Mythology to Late Antiquity (3rd Century A.D.). In *Stories from a Heated Earth*, ed. by R. Cataldi et al., Geothermal Resources Council, 1999.

Fytikas, □., □ndritsos, □., Dalabakis, P., and Kolios, N. Greek Geothermal Update 2000-2004. Proceedings *World Geothermal Congres-2005*, International Geothermal Association, Antalya, Turkey, 2005.

Gelegenis, J., Dalabakis, P., Ilias, A. Heating of wintering ponds by means of low enthalpy geothermal energy. The case of Porto Lagos. *Geothermics*, 35, 87-103, 2006.

Habib, M.A.B., Parvin, M., Huntington, T.C. and Hasan, M.R. A review on culture, production and use of spirulina as food for humans and feeds for domestic animals and fish. *FAO report*, pp. 33, Rome, 2008. [ftp.fao.org/docrep/fao/011/i0424e/i0424e00.pdf, assessed 22.4.2009]

Nichols, M.A. Asparagus - The world scene. *Acta Hort. (ISHS)*, 271, 25-32, 1990.

Table 1. Summary of the installed capacity of direct uses and of annual energy use in spring 2009.

Use	**Installed Capacity (MW_t)**	**Annual Energy Use (10^{12} J)**
Space heating	1.4	16
Greenhouse & soil heating	30.1	299
Agricultural drying	0.4	2
Aquaculture*	9.3	72
Bathing and swimming	38	192
Geothermal heat pumps	45	250
Total	**124.2**	**831**

* Fish Farming & Spirulina Cultivation

Table 2. Greenhouse heating applications in Greece by geothermal field (2008-2009).

Location	Covered area (ha)	Maximum Utilization			Energy Utilization (TJ/yr)
		Flow Rate (kg/s)	Inlet Temp. (°C)	Capacity (MWt)	
Nigrita, Serres (5 units, 4 operators): vegetables, cut flowers*					
In operation Inactive	3.50 4.80	52.0 39.0	37-52 45-58	3.65 2.75	36.6
Sidirokastro, Serres (6 units, 3 operators): cut flowers, potted plants					
In operation Inactive	2.70 0.40	55.1 10.1	37-63 45	3.40 0.60	39.8
Langadas, Thessaloniki (3 units, 2 operators): vegetables, cut flowers					
In operation Inactive	2.20 0.42	16.4 6.0	35-37 36	0.94 0.55	9.7
Nea Apollonia, Thesssaloniki (6 units, 6 operators): vegetables, cut flowers					
In operation	5.50	88.0	32-46	5.89	64.4
Eleochoria, Chalkidiki					
Inactive	0.20	5.6	30	0.23	
Neo Erasmio, Xanthi (1 unit, 1 operator): vegetables					
In operation	0.40	4.4	60	0.46	5.3
Nea Kessani, Xanthi					
Inactive	0.60	25.0	72	2.30	
Islands of Lesvos and Milos (8 units, 5 operators): vegetables					
In operation	3.95	32.0	46-85	5.45	53.5
Total					
In operation Inactive	18.25 6.40	248 85	32-85 30-72	19.8 6.40	210

* Refers to active greenhouse.

Table 3. Soil heating applications for off-season asparagus production by geothermal field (2008-2009).

Location	Cultivation area (ha)	Maximum Utilization			Energy Utilization (TJ/yr)
		Flow Rate (kg/s)	Inlet Temp. (°C)	Capacity (MWt)	
Nymfopetra, Thessaloniki	7.0	35.0	45	3.37	29.7
Neo Erasmio, Xanthi	10	40.0	60	5.86	50.8
Myrodato, Xanthi	2.0	10.0	50	1.05	8.9
Total (direct)	19.0	85.0	45-60	10.3	89.4
Chrysoupolis, Kavala (GHPS)	2.0	34.0	15	0.2	1.9
Total	21.0				91.3

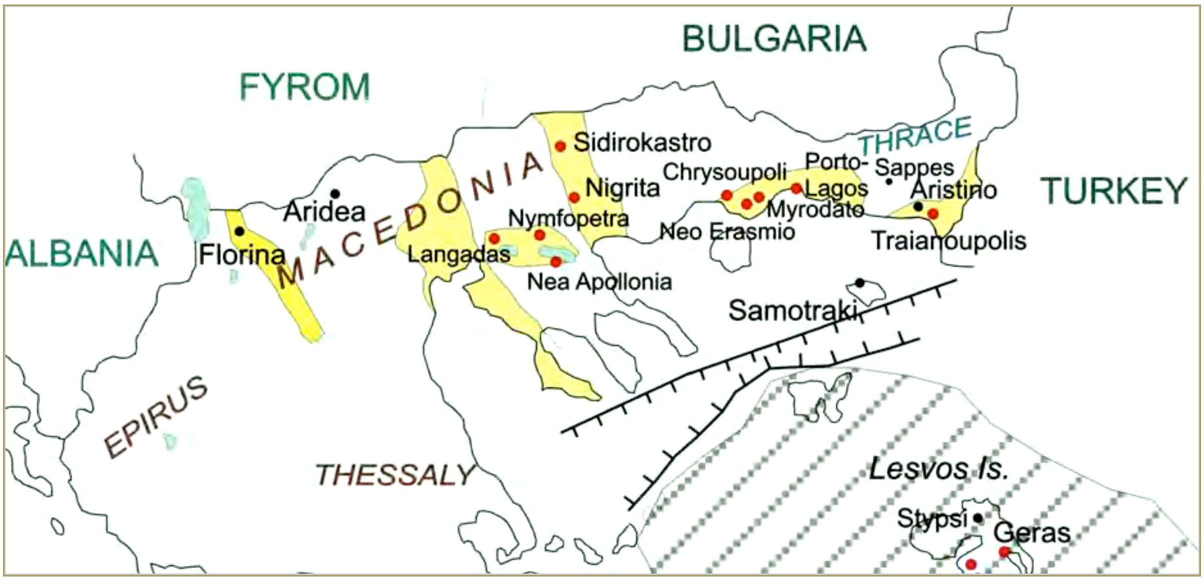

Figure 1. Geothermal map of Northern Greece indicating the sites of direct uses (the balneology sites are not shown).

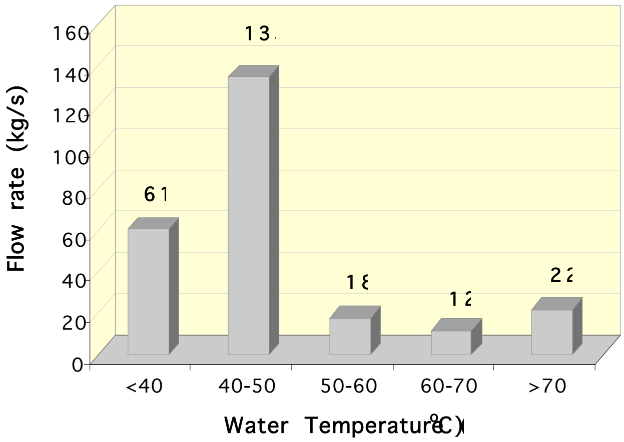

Figure 2. Distribution of water flow rates use in geothermal greenhouses by temperature range (total flow rate 248 kg/s).

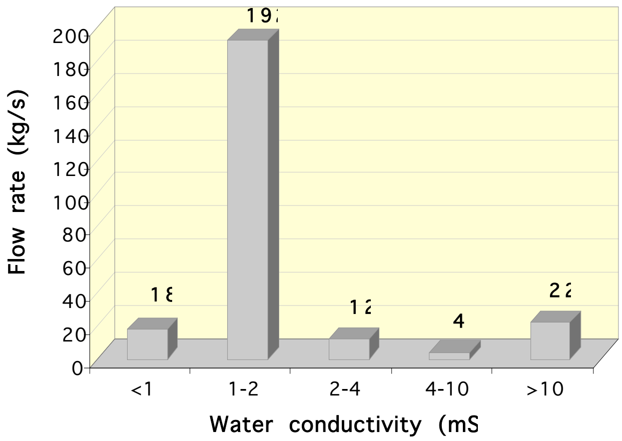

Figure 3. Distribution of water quantities used in greenhouse by electric conductivity (total flow rate 248 kg/s).

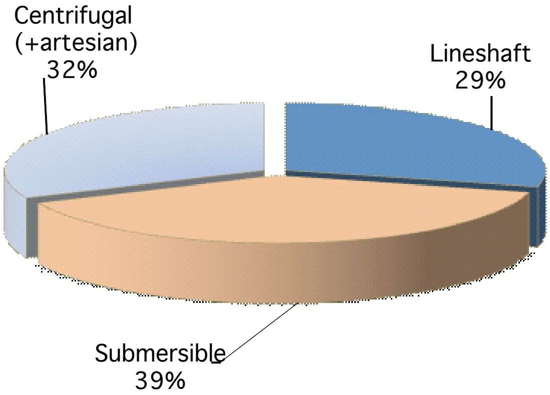

Figure 5. Share of the various types of pumping systems used in geothermal greenhouses (total pumping flow rate 248 kg/s).

Figure 5. Left, picture of PE heating tubes in a plastic greenhouse in Nigrita for vegetable cultivation, and, right, PP tubing laid on the soil in a glass greenhouse in Sidirokastro.

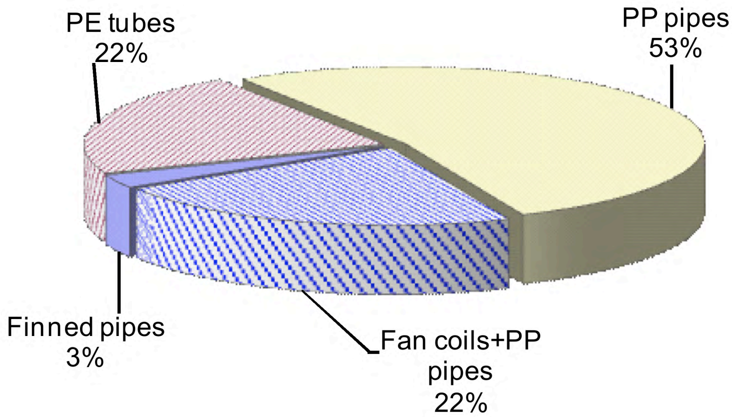

Figure 6. Distribution of the heating systems in geothermal greenhouses (total covered area 18.25 ha)

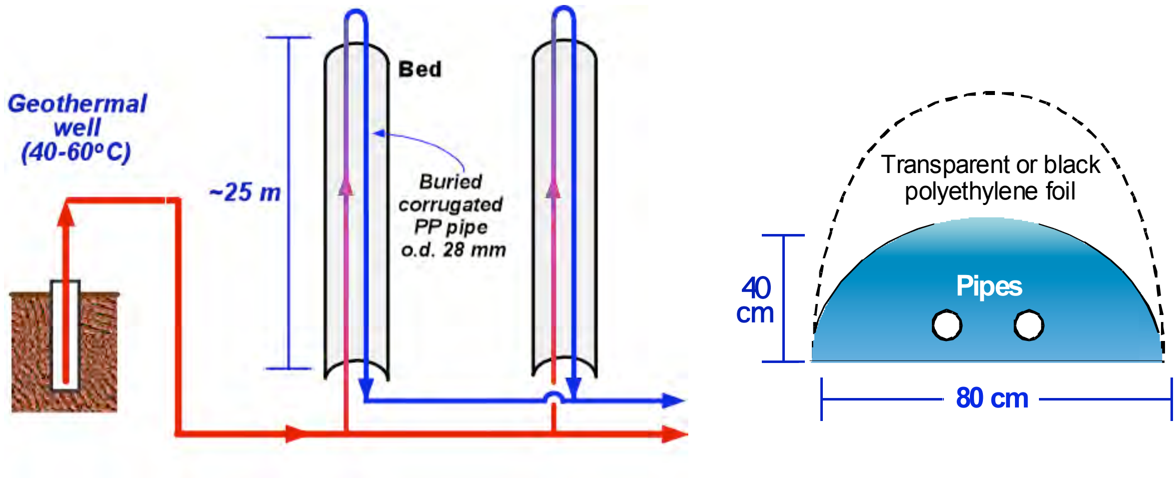

Figure 7. Left, schematic diagram of the soil heating system.
Right, cross-section of a covered asparagus bed.

Figure 8. Left, picture of "geothermal" asparagus packing in N. Erasmio, and, right, arch-type plastic covered rows for early lettuce cultivation in the same field.

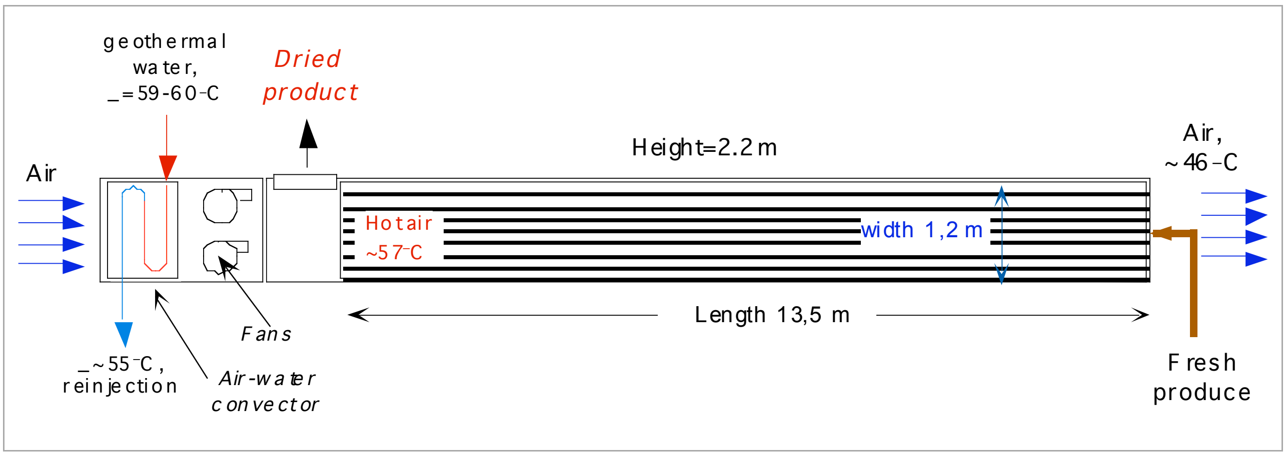

Figure 9. Schematic of the tunnel drier for tomato dehydration.

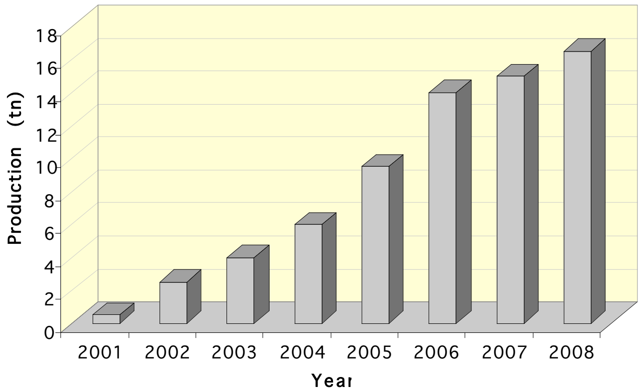

Figure 10. Annual production of “sun-dried” tomatoes in metric tons.

Figure 11. Picture of the pilot scale cotton drier.

Figure 12. Picture of geothermally heated raceway ponds for spirulina cultivation in Nigrita, Serres.