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Geothermal developments in Greece – Country update 2015-2020

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ABSTRACT

The intense tectonic and volcanic activity in the Hellenic area has caused the accumulation of thermal energy in relatively shallow and, thus, economically accessible depths. This is manifested as numerous low, medium and high enthalpy hydrothermal systems across the country. The geothermal exploration has, thus far, identified more than forty (40) areas of geothermal interest, thirty-two (32) of which are officially characterized as "geothermal fields". However, only a small fraction of the proven geothermal resources is exploited. Reaching an estimate of around 260 MWth, the installed geothermal capacity pertains to heating/cooling and recreation/healing uses. The local geothermal market is dominated by the Ground Source Heat Pumps (63% of the total installed capacity), whereas direct uses are limited to balneotherapy and greenhouse heating, followed by small-scale applications, such as soil heating, dehydration and aquaculture. All new and important exploitation projects are realized in low temperature fields of Northern Greece, where the social acceptance and the support from local authorities have created a favorable investment environment. On the other hand, the share of geothermal energy in the electricity production sector remains zero. In July 2018, an international tender announced by "PPC-Renewables" was concluded successfully, with the selection of a strategic partner for the construction of small power plants (5-8 MWe) in four geothermal areas (Lesvos, Methana, Nisyros and Milos-Kimolos complex). Regarding exploration, the on-going projects concern further research in known low enthalpy areas (Strymon Basin, Akropotamos, Evros Delta, etc.), as well as reconnaissance studies in other promising areas, such as eastern Thessaly, Lesvos and Lemnos islands.

1. INTRODUCTION

The development of Renewable Energy Sources (RES) has been one of the major energy policy lines of Greece for more than a decade. In 2010, Greece endorsed the National Renewable Energy Action Plan (NREAP, 2010), which had set specific targets for the RES shares in gross final consumption for 2020 (40% electricity, 20% heating and cooling, 10% transport). So far, only the target for heating and cooling has been met.

Regarding geothermal energy, the 2020 target for electricity, heating and Ground Source Heat Pumps (GSHPs) was 120 MW, 51 ktoe and 50 ktoe, respectively. In reality, the power generation from geothermal energy is absent. The contribution in heating remains at low levels, with a greater share in the tertiary and the agricultural sector (mainly for balneotherapy and greenhouse heating). The target for the GSHPs will most probably be accomplished, given the steadily increased use of shallow geothermal systems in Greece.

In the islands of Milos and Nisyros (the two confirmed high enthalpy fields of Greece), the public confidence towards geothermal electricity generation has not been restored yet; however, the social environment is much more positive in other prospective geothermal regions, e.g. in Lesvos island or in Macedonia and Thrace, where exploitable medium enthalpy resources most probably exist.

The use of low enthalpy geothermal energy for direct applications is better perceived, as it is evident by the new and important investments in northern Greece and the first geothermal district heating project that is under development in Thrace. In addition, several exploration/exploitation projects have been carried out or are still in progress in eastern and central Macedonia, Thrace, central Greece, Lemnos Island, etc.

In 2019, a new National Energy and Climate Plan (NECP, 2019) entered into force, foreseeing a very small share of geothermal energy in the electricity generation system, i.e. 100 MWe from geothermal energy in 2030 and 300 MWe in 2040. The contribution of geothermal energy (including GSHPs and ambient heat) in the final energy consumption (residential and tertiary sectors) is expected to be 734 ktoe in 2030 and 896 ktoe in 2040. In order to meet these targets, the Greek State has committed to implement a series of measures, regulatory initiatives and financial support programs. One of them is the, long anticipated, new geothermal Law that came into effect in March 2019, as an effort to modernize the institutional framework for the research and exploitation of geothermal energy. Moreover, since January 2016, Greece has a new RES support scheme. The feed-in tariff (FiT) has been replaced by a technology-specific sliding scale Feed-in Premium (FiP). FiT remains applicable only for small RES plants (≤ 0.5MW).

2. GEOTHERMAL RESOURCES

2.1 Geology Background

Due to the country's geotectonic regime, the geologic conditions are favorable, or even ideal, for the formation of important geothermal systems, in both continental Greece and the Aegean islands (Figure 1). In these areas, the intense tectonic and, in some cases, magmatic/volcanic activity, have created extended thermal anomalies and very high geothermal gradients.

The Aegean area constitutes one of the most rapidly deforming segments of the Alpine-Himalayan belt, displaying the highest deformation rates in the whole Africa-Europe collision zone (Francalanci et al., 2005; McKenzie, 1972; Papazachos and Comninakis, 1971). The deformation is associated with the subduction of the eastern Mediterranean lithosphere under the Aegean plate along the Hellenic Arc and the westward motion of Anatolia along the North Anatolia Fault. This geodynamic and tectonic regime, and especially the formation of the South Aegean Active Volcanic Arc (*SAAVA*), have contributed to the increase of the heat flow and the development of important high temperature geothermal reservoirs at relatively shallow depths. The active volcanic zone extends from the Saronikos Gulf as far as Nisyros and the SW edge of Kos Island, including the active centers of Methana, Milos, Santorini and Nisyros (Figure 1).

The Cenozoic volcanism in the Aegean area took place in successive phases from the Upper Eocene/Lower Oligocene until the present (Fytikas et al., 1984). It started in the northernmost part of the Aegean area and progressively shifted southwards. The volcanism in northeastern Greece and the islands of Samothrace, Lesvos and Lemnos (north Aegean region) is extinct, whereas Milos, Nisyros and Santorini islands belong to the high heat flow zone of the Aegean. This is attributed to the presence of large solidified magma chambers at relatively shallow depths, as well as to the intrusions of molten magma close to the surface (3-5 km below surface) due to strong extensional tectonic activity (Fytikas, 1989; Fytikas & Andritsos, 2004).

The existence of **high temperature (>320°C) reservoirs** in Milos and Nisyros Islands has been confirmed since mid-1970s. On the other hand, *north* and *northeastern Greece*, a typical back-arc region, is characterized by significant **low to medium temperature reservoirs (up to 150°C)**, without excluding even higher temperatures at depth, as indicated by application of chemical geothemometers (Mendrinos et al., 2010).

In eastern Macedonia and Thrace important geothermal systems have been developed inside the sedimentary Tertiary basins (such as Evros Delta basin, Xanthi Basin, Nestos Delta basin, Strymon Basin, etc.) that were created during the tectonic phases that followed the Alpine orogenic event (Figure 2). The existence of these geothermal fields is associated to the active extensional tectonics, crustal thinning, magmatic intrusions, large open faults (that affect both the metamorphic basement and the sedimentary sequence and favor the quick rise of thermal fluids), and the presence of very permeable geologic formations (Kolios et. al., 2007).

In central Macedonia, the low temperature geothermal fields of Langadas and Nea Apollonia (Mygdonia Basin) owe their existence to very large and deep NW-SE active faults.

In *central Greece*, the E-W tectonic graben of Sperchios and the north part of Euboea island belong to the back-arc region and host some of the most well-known thermal springs of Greece (Thermopylae, Edipsos, etc), associated to the volcanic center of Lichades island complex. These areas are characterized by very high heat flow, attributed to the effect of the North Anatolian Fault, which is extended to the NE Aegean Sea and ends up in central Greece. The main geothermal reservoirs are most probably developed inside the Cretaceous limestones of the basement, but have not been thoroughly explored yet.

The increased heat flow and the low to medium temperature reservoirs of the *east and northeast Aegean islands* (Samothrace, Lesvos, Chios, and Ikaria) are mainly related to Miocene volcanism and recent extensional tectonic activity.

Western Greece is less favored, with only a few areas of geothermal interest (low temperature fields) and significantly lower heat flow rates. The geothermal gradients measured in the *Ionian Islands, Peloponnese, Crete and the south Dodecanese islands* are very low, mostly due their geotectonic position, i.e. along the Hellenic Trough and the sedimentary arc (low heat flow zone).

2.1 Geothermal Exploration

Geothermal exploration in Greece started in the 1970s, targeting the high enthalpy resources in the volcanic islands of Milos and Nisyros. It then progressively moved to other promising areas across the country, focusing in Northern Greece, for the investigation of low temperature (up to 90-99°C) resources.

So far, thirty-two (32) areas are officially determined as "geothermal fields" and several more have been identified as areas of geothermal interest. Since 2015, the exploration activities mostly focused on additional investigation and further drilling exploration in known low temperature areas of Northern Greece, as well as on reconnaissance studies in Lemnos, Lesvos, Euboea and Santorini Islands and in Eastern Thessaly.

The plans for exploring the medium enthalpy resources in Chios and Samothrace islands, Evros River Delta and Nestos River Delta, as well as for Sperchios basin, Akropotamos (Kavala), Soussaki, and Ikaria island (see Andritsos et al., 2015), were never implemented because the awarded contractors withdrew from the projects.

During the period 2015-2020, the following exploration activities were carried out:

- → *Lesvos Island:* A new preliminary study was conducted at the eastern part of the island, which included a geophysical survey, as well as temperature measurements and sampling at springs and shallow wells. This study revealed a new geothermal area near Mytilene, where waters of 30-33°C are produced from depths up to 150m (Xenakis et al., 2016).

→ *Lemnos Island*: The reconnaissance study resulted in the identification of an interesting area at the south-eastern part of the island (Moudros area). The measured wellhead temperatures at existing very shallow (70-105 m) wells ranged between 24 and 29.6°C (Arvanitis et al., 2016a).

Figure 1: Main geothermal areas of Greece

→ *Euboea Island (Edipsos)*: The exploration work pertained to the mapping and geochemical study of the numerous onshore and submarine hot springs of the area, in an attempt to provide further information and a more complete understanding of the local hydrothermal system. The recorded temperatures ranged from 30 to 82°C (Vakalopoulos et al., 2016a). It was concluded that the northwestern Euboea island (along with the neighboring Sperchios basin geothermal system) is characterized as the first so-far documented active terrestrial mineralizing geothermal system associated with ore-bearing travertines in Greece (Kanellopoulos et al., 2017).

→ *Eastern Thessaly (central Greece)*: Reconnaissance studies were conducted in five (5) areas (Faros-Paliourio, Chalki-Kileler, Mikrothives-Almyros, Krini-Agios Georgios and Ampelia-Farsala). At the area of Ampelia, the wellhead temperatures at existing wells (depths between 235 and 410m) reach 41.3°C (Vakalopoulos et al., 2016b). After the evaluation of the regional geology and the geophysical/thermometric/geochemical data, the drilling of four (4) new large diameter exploration wells was proposed at the area of Ampelia-Farsala, where the higher temperatures (35.1-41.3°C) had been measured (Vakalopoulos et al., 2016b).

→ *Santorini Island*: The exploration project included temperature and electrical conductivity measurements in 141 existing shallow wells across the island, selective sampling and chemical analyses. The scope of this study was to evaluate the geothermal resources of Santorini, with a particular emphasis on the shallow aquifers, and to suggest further research/development activities. The thermometric investigation revealed a very interesting zone of geothermal anomaly in the central part of the island, with temperatures exceeding 26-27°C, at very shallow (40-190 m) depths (Papachristou et al., 2016).

→ *Strymon Basin (Macedonia, Northern Greece)*: Three (3) low temperature geothermal fields were further explored:

i. **Sidirokastro**: An area of extensive hydrothermal alteration was recognized and mapped in the northern part of the field and four (4) new large diameter exploration/production wells were sited. Geothermal fluids of ~75°C are expected to be found at depths of 100-300m (Arvanitis et al., 2016b). The drilling works are scheduled to start in March 2020.

ii. **Lithotopos-Iraklia**: Following an extensive surface exploration project, described in Arvanitis et al. (2015), four (4) new production wells were constructed in the period 2016-2018, with depths ranging between 353 and 520 m. They produce fluids of 37.5-74.5°C, with low flow-rates (5-80m^3/h).

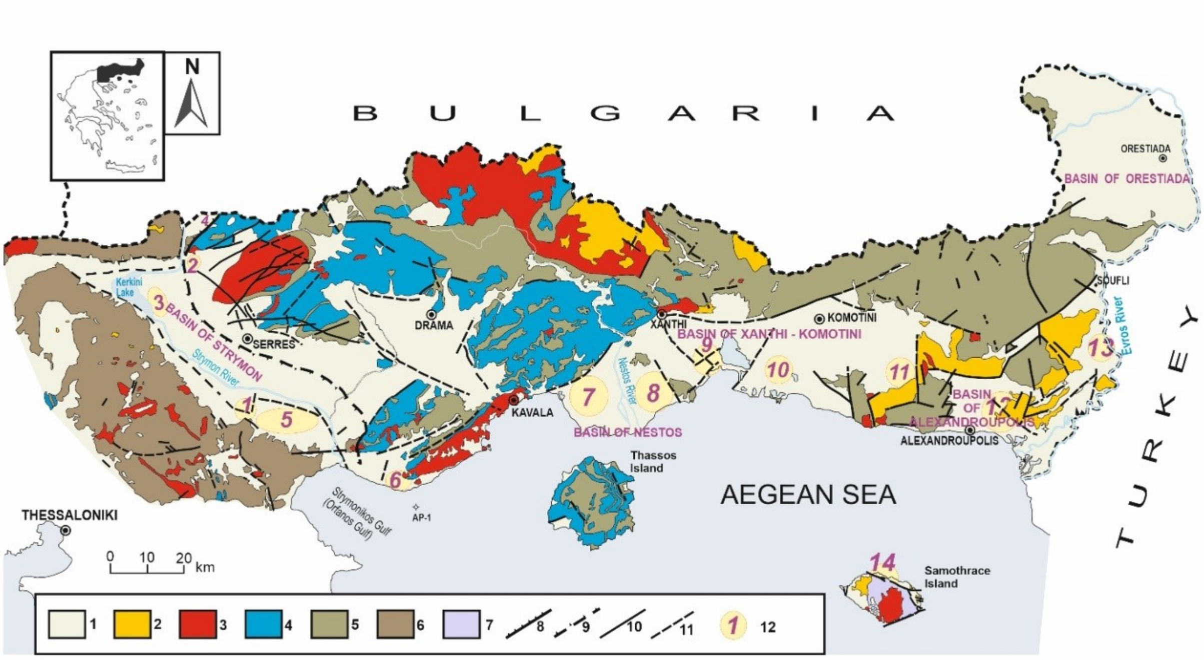
iii. **Nigrita**: A new large-diameter production well was drilled at the depth of 216m, which produces 240-250m^3/h of 61°C fluids.

→ *Strymonikos Gulf (Macedonia, northern Greece)*: The past geothermal exploration and drilling research had identified and confirmed the existence of an important anomaly along the coastal zone, in the area of **Akropotamos** (westwards of Kavala). The deeper geothermal reservoir is located at 515m below surface, providing fluids of 90°C, whereas shallower reservoirs exist at depths of 130m (46°C) and 230m (85°C). Recently, long term production tests were performed in two of the existing (since 2003-2006) but unused geothermal wells, which showed high rate artesian flow (*AKR-1*: 220-230 m^3/h, *AKR-3*: 150-160 m^3/h) and produced fluids with temperatures 84-90°C (Papachristou et al., 2019).

→ *Nestos Delta Basin (Macedonia, northern Greece)*: New exploration/exploitation activities took place in the two (2) low temperature fields of Nestos Basin:

i. The low temperature geothermal field of **Eratino-Chrysoupolis** lies on the western side of Nestos River, eastwards of Kavala. The exploration indicated high temperature gradients, up to 120°C/km, at the center of the field (Kolios et al., 2007). Low enthalpy (70-80°C) fluids were found at 600-700m, inside the carbonate formations that lie beneath a thick sequence of relatively impermeable sediments. Based on geology, lithology and geothermal gradients, it is highly probable that the main reservoir, with temperatures 150-180°C, is located at larger depths (1500-1800m), inside the metamorphic basement. In the frame of the Eratino exploitation project, one injection and two new deep (750m) production wells were drilled in 2015, providing fluids of 70-77°C at flow rates higher than 100-120m^3/h each.

ii. The low temperature geothermal field of **Neo Erasmio-Magana** lies on the eastern side of Nestos River, south-southwest of Xanthi. Stratified aquifers are supplied by an active fault system that affects the basement of migmatitic gneisses. Temperature inversions have been observed in some wells, indicating lateral flow. Hot waters of 30-68^{o}C have been found at depths of 150-500m in the basal part of the post-alpine sedimentary sequence and at the top of the basement (Kolios et al., 2005; Dalabakis et al., 2015). During October-November 2015, two production wells (255 and 243m deep) were drilled in order to cover greenhouse heating requirements. These wells cased to depths of 246 and 234m provide 120 m^3/h waters of 59 and 57^{o}C, respectively. In August-October 2019, two additional production wells, 332 and 258m deep, were constructed and produce 120 m^3/h and more than 160 m^3/h waters of 62 and 70.2^{o}C, respectively.



1: Tertiary and Quaternary sediments, 2. Tertiary volcanic rocks, 3. granites and granodiorites, 4. marbles and limestones, 5. metamorphic rocks of Rhodope Massif, 6. metamorphic rocks of Serbomacedonian Massif (SRB), 7. metamorphic rocks of Circum Rhodope Belt, 8. SRB and Rhodope contact, 9. SRB and Rhodope probable contact, 10. Faults, 11. Probable faults, 12. low temperature geothermal fields (*1= Nigrita, 2=Sidirokastro, 3=Lithotopos, 4=Agkistro, 5=Ivira-Achinos-Mavrothalassa, 6=Akropotamos, 7=Eratino-Chrysoupolis, 8=Nea Kessani, 9=Mitrikou, 11=Sappes, 12= Aristino, 13=Tychero Evros, 14=Samothrace*)

Figure 2: Simplified geologic map of northeastern Greece with the main geothermal fields (Kolios et al., 2007)

→ *Evros Delta Basin (Thrace, northeastern Greece)*: The geothermal field of **Aristino** is located eastwards of Alexandroupolis, near the Traianoupolis thermal springs. An exclusive area of 16 Km^2 has been leased since 2013 to the Municipality of Alexandroupolis for further exploration and exploitation. The geothermal anomaly is characterized by high thermal gradients (>200°C/km), due mainly to the presence of sub volcanic bodies, deep slip normal active faults that intersect the geothermal area, and the extended vertical and lateral convective cells. Two distinct hot water bearing zones have been recognized: one towards the north, in the volcanic province, and the other towards the south, inside the volcano-sedimentary sequences.

The drilling exploration revealed two geothermal systems: the upper system of low temperature (50-55°C), which develops at depths 100-200 m in altered volcaniclastics of low permeability and low production rates (20-25 m^3/h), and the lower hot reservoir, but certainly not the main one, which has been found in tuffaceous horizons and/or in the widespread hyaloclastic breccias (assumed as ignimbrite) at depths between 200-400 m. Its temperature and production rates range from 32 to 99°C and 40 to 150 m^3/h, respectively.

A new production well was drilled in 2016 at the depth of 410 m. In this, very enigmatic, well borehole temperatures varies, in steady state conditions, from 75°C to 78°C, representing a thermal regime that is in full contradiction with the non-completely stabilized temperature of 99°C that was measured at the end of a pumping test with a maximum flow rate of 45m^3/h. This temperature is the highest ever encountered in the 'low enthalpy' geothermal fields of northern Greece.

3. GEOTHERMAL UTILIZATION

3.1 Power Production

The confirmed high temperature geothermal resources of Milos and Nisyros islands remain unexploited, thirty years after the shut off of the 2 MWe power plant in Milos. All past attempts for the exploration and exploitation of medium enthalpy resources (Andritsos et al, 2015) were not concluded successfully.

In July 2018, an international tender for a new geothermal power project was concluded successfully. It had been announced in 2017 by the Public Power Corporation (PPC) S.A. and regarded the selection of a strategic partner for the financing, development and management of small (5-8 MWe) power plants in the island complex of Milos and Kimolos, in Nisyros and Lesvos islands, and in Methana peninsula (NE Peloponnese). The company "HELECTOR S.A." was declared as the highest bidder and will hold a 51% stake in its joint venture with PPC. Given the, unchanged throughout the years, opposition of the locals in Milos and Nisyros, the project will start from Lesvos and Methana.

3.2 Direct Uses

Geothermal energy is mainly used in Greece for balneotherapy and greenhouse heating, whereas its utilization for soil heating, aquaculture and space heating is much less significant in terms of number and size of applications. The total installed capacity from direct uses is approximately 84.45 MW_{th} (Table 5).

3.2.1 Balneotherapy

The exploitation of thermal waters for their therapeutic properties constitutes the older and the most common geothermal use in Greece. More than 750 thermal and mineral springs have been recorded across the country, half of which are classified as "curative". The temperature of the thermal springs ranges between 25 and 92°C; however the temperature of the water that enters the bathing facilities does not usually exceed 35-39°C. Geothermal water is used in nearly 70 spas and bathing centers, as well as in more than 25 outdoor swimming pools. Most of the recreational centers operate from June to October, with only a few exceptions that remain open throughout the year. In addition to healing and recreation, the geothermal fluids were also used for heating the bathing and accommodation facilities in two cases: in Nea Apollonia (central Macedonia) and in Traianoupoli (Thrace). Unfortunately, the operation of the spa center in Nea Apollonia was very recently (early 2019) halted, due to financial problems.

The energy use in balneotherapy cannot be accurately calculated due to the absence of any systematic study and the lack of the necessary data. Nonetheless, taking into account an average ΔT=10°C and a maximum flow rate about 1000 kg/s, the energy use can be conservatively estimated to 260 TJ/y, corresponding to an installed capacity of 43 MW_{th} (Table 5).

3.2.2 Greenhouse Heating

Most of the 18 geothermal greenhouses of Greece are located in the north (Macedonia and Thrace). Some of the older units are currently either closed or they use different energy mix. Nevertheless, the total greenhouse surface area has increased since 2015, reaching more than 40 ha in 2019. Most greenhouses are of glass type and produce various types of vegetables (tomatoes, cucumbers, etc.) and flowers, mostly for the domestic market. Their installed capacity is 38 MW_{th}, while the annual energy use is estimated at 407 TJ/y (Table 3).

During the past five years new and significant investments were made in geothermal greenhouse heating, in two low temperature fields of northern Greece:

Neo Erasmio (Xanthi, Thrace): The biggest and most promising geothermal investment ever realized in Greece launched in this field in 2014. A new multi span geothermal greenhouses complex for hydroponic cultivation of tomatoes and cucumbers was constructed in 2014 by the company "THRACE Plastic Co S.A., which has been awarded the exploitation rights for this field. The unit has been gradually expanded from 4.2 ha in 2015 (Andritsos et al., 2015) to 18.5 ha in 2019 and will reach 20 ha in 2020. The investment has so far exceeded €20 million, offering 120-150 job positions to the nearby communities.

The heating requirements are covered by five wells that can produce more than 500 m^3/h of good quality geothermal water at 58-60°C. The circulation of the fluids inside the greenhouses is achieved through two independent, iron and plastic pipe arrangements, placed on the ground in the circumference of the planting rows. After their use, the geothermal fluids are reinjected with a mean temperature of 30-33°C. The installed capacity and annual thermal energy use in this greenhouse complex are 14.64 MW_{th} and 164.88 TJ, respectively (Table 3).

Eratino-Chrysoupolis (Nestos Delta Basin-eastern Macedonia): The local authorities (Municipality of Nestos) invested more than €10 million for the construction of the heat distribution infrastructure (two production and one injection wells, thermal stations and an 18 km distribution network) that can provide up to 8 MW of geothermal heat exclusively for agricultural use. This project was completed in 2015 and was fully operational in 2016. The same year, the first geothermal greenhouse (3.5 ha) was constructed by the company "SELECTA Hellas", for breeding and producing rooted cuttings of ornamental plants. The heat demands are totally covered by geothermal energy. The temperature of the circulating fluids is 75°C and the maximum flow-rate is about 50m^3/h. The average required flow-rate however, is much smaller and does not exceed 9m^3/h. The installed capacity and the annual thermal energy use are 2.38 MW_{th} and 24.27 TJ, respectively (Table 3). "SELECTA Hellas" has already invested €7 million in this undertaking, but the total invested amount will reach €10 million with the construction of additional units (2.5 ha) within the following years.

3.2.2 Soil Heating

The use of low temperature geothermal fluids for soil heating was applied for the first time in 1998 in Neo Erasmio (Xanthi). In 2005 a similar soil heating system was installed in Myrodato (Xanthi). Both plantations produce early-season white and green asparagus, and, occasionally, other vegetables (lettuce, watermelons, etc.) The total installed capacity and annual energy use are 0.83 MW_{th} and 10.55 TJ, respectively (Table 3)

The soil heating is achieved by the circulation of geothermal fluids (up to 58°C) through plastic PP or PE pipes, placed either inside the subsoil beneath the asparagus crowns or in the ground at the base of the soil ridges, in a U-bond arrangement (Andritsos et al., 2015). The required heating loads range between 100-150 kW/ha, depending on the outdoor temperature and the heating onset. Heating usually starts in early February, whereas the harvesting period lasts from early March to mid-April.

The heated plantation surface in Neo Erasmio has decreased from 20 ha in early 2000s to 3.0 ha in 2019. This significant reduction is mainly attributed to the exceeding of the plants' life span (12-15 years), in combination to financial difficulties related to the general economic recession in Greece. In Myrodato, the cultivated area (3.0 ha) is heated by geothermal fluids of 50°C.

3.2.3 Fish-Farming

Geothermal energy had been used for several years for the anti-frost protection and heating of fish farming ponds in Porto Lagos and Neo Erasmio (both in Thrace Region). Unfortunately, the fish farm in Neo Erasmio has closed due to administrative issues, whereas the anti-frost protection in Porto Lagos is no longer implemented by geothermal energy, due to technical problems of the geothermal wells.

Moreover, the small pilot unit for ornamental fish breeding in geothermal water that was installed in Neo Erasmio in early 2014 (Andritsos et al., 2015), is no longer in operation. However, it has been a particularly interesting case of geothermal energy use, because the geothermal water (T=48°C, Conductivity = 1040 μS/cm) was not only used as a heating source but also served as the growing medium. After a few years of operation, it has been safely concluded that the adaptability of ornamental fish to geothermal water was excellent, and all the thermodynamic targets had been absolutely achieved, even with extreme outdoor temperatures (-10 to -12°C).

3.2.4 Aquaculture: Spirulina Cultivation

Spirulina cultivation in geothermally heated water has been practiced in Greece since the late 1990s. Today, three companies are active in this sector, with three plants operating in the low temperature field of Nigrita (Strymon Basin, northern Greece). The total surface of the raceway ponds is 0.9 ha. The average required flow-rate, for maintaining the temperature of the cultivation water at 33-36°C, is 20-21 m^3/h, whereas it might reach 35-40 m^3/h during very cold days. The installed capacity of the three units is 0.75 MWth. (Table 3).

3.2.5 Dehydration

The only geothermal dehydration plant in Greece operates since 2001 in the geothermal field of Neo Erasmio (Xanthi, northern Greece). Up to now, it has produced more than 300 tn of dried tomatoes and, in recent years, increasing quantities of olives, other vegetables (e.g. asparagus, peppers and eggplants) and fruits (e.g. apples, lemons, melons). The unit typically operates each year for drying of tomatoes during the period June-September (and throughout the year when it is needed), using fluids of 58°C at an average flow rate of 32 m^3/h. The fluids pass through a water-air heat exchanger that produces hot air at 55-58°C, which is driven to the drying tunnels at a rate of 14.000m^3/h (Andritsos et al., 2003). The installed capacity of the unit is 0.24 MW_{th} (Tables 3 and 5).

3.2.5 Space Heating

The use of geothermal energy for space heating is very limited. During the past years, a small school building in Traianoupolis, two spa centers (Nea Apollonia and Traianoupolis), a 2000 m^2 surface of offices and process facilities in the Erasmio greenhouse unit, and a few houses in northern Greece were heated by low temperature geothermal fluids. As mentioned above, the spa center of Nea Apollonia closed in early 2019, but efforts are being made to re-open under a new ownership scheme. The installed capacity of the space heating installations is currently at 1.65 MW_{th} (Table 3).

3.2.6 District Heating

Greece does not have geothermal district heating (DH) systems that operate with the direct use of geothermal fluids. In 2016 a small (2.5 km) DH system supplied by GSHPs and solar panels was constructed in Attiki (Central Greece).

The project "Thermopolis" in Lesvos Island, which would use geothermal fluids of 88°C for the heating of five public and municipal buildings in the nearby town of Polichnitos (Andritsos et al., 2015), remains out of operation due to the failure of the submersible pump. A proposal for the replacement of the pump and the maintenance of the equipment is underway.

The first integrated geothermal district heating project is under implementation in the geothermal area of Aristino (Thrace) and will be ready for the startup procedures by the end of 2021. The main components of the district heating system, including end-users for agricultural purposes, are: two production wells, with a maximum total flow rate of 150 m^3/h and mean operational temperature of 89°C, a thermal station with three couples of plate heat exchangers, automations and an integral reinjection system comprising a storage tank and three parallel multi-stage injection pumps. The total length of the three independent recirculation networks is 16 km. End users will receive thermal energy at a maximum distance of 2200 m from the thermal station. 20% of the total installed heat capacity (2 MWth) will be delivered to the ensemble of local edifices of public interest (schools, municipal administration buildings, churches, charitable organization "SOS Village", etc.) covering a total area of 8000 m^2. The rest 80% (8 MWth) will be available on demand to private end-users for agricultural uses, with emphasis to the greenhouses. The final budget of the project has been finalized at €6 million.

3.3 Ground Source Heat Pumps

The shallow geothermal market remains the largest segment of the geothermal sector in terms of installed capacity and energy produced. The first documented shallow geothermal system was installed in Greece in the early 1990s. However, considerable growth of the GSHP market has been recorded after the mid-2000s, following a number of pilot projects and informative/training workshops, funded by European or National Programs. The market exhibited different phases of development. In the beginning (mainly in the 2000s) the market penetrated mostly new constructed houses and small buildings and represented a very small share of the total residential heating equipment. The development of the market was definitely affected by the severe economic crisis during the 2010s, but in a different direction for houses and for large commercial and public buildings. For houses and small buildings there was a strong competition from natural gas (in areas in which it is available) and from air-source heat pumps, which, according to some designers of heating systems, overran GSHPs by 10 to 1. On the other hand, there is a strong trend in incorporating GSHP in large buildings (e.g. hotels, hospitals, schools, university buildings, and airport and port facilities) in order to meet the standards set by the (Hellenic) Regulation on the Energy Performance of Buildings (KENAK), which sets minimum requirements for the energy performance of buildings

Official up-to-date data at national-scale are not kept, so it is extremely difficult to know with confidence the exact number or the size of the installed systems, especially of those in individual dwellings. Nevertheless, an estimate of more than 3500 operating systems at the end of 2020 is rather realistic. The total installed capacity is estimated to exceed 175 MW_{th} (Table 4). Most of the systems have a capacity of less than 100 kW (avg. 30 kW), whereas about 200 systems exceed 100 kW (avg. 350 kW).

The GSHPs are commonly used in Greece for both space heating and cooling, as well as for domestic water heating. Most installations regard residential and office buildings, however their use has progressively become popular in hotels, department stores, swimming pools, school complexes, etc.

The penetration of GSHP systems in the agricultural sector is poor; a soil heating system supplied by geothermal heat pumps was installed 13 years ago in a 19 ha asparagus plantation in Chrysoupolis (Kavala, northern Greece) for early season production. It has been operating effectively ever since, providing energy at low cost. Unfortunately, the asparagus plantation and a demonstration greenhouse in Thessaly (central Greece) are the only cases of using shallow geothermal resources in agriculture.

Recent data from GSHP installations in northern Greece, show that, after 10 years of continuous operation, the mean annual savings for heating and cooling exceed 65% (>70% for heating and ~50-55% for cooling), compared to conventional systems (oil boiler coupled to split air-conditioning units). Depending on the size and the type of the building, the payback period ranged between (3) and (9) years. A few indicative cases of new GSHP applications are as follows:

Building of Central Macedonia Regional Authority (Thessaloniki): The installation of an innovative hybrid shallow geothermal system in this new public building constitutes one of the largest GSHP projects in Greece. It was completed in 2016 but it has not been in operation yet for reasons related to bureaucratic obstacles. The total installed capacity is 850 kW and can cover the heating and cooling requirements of a 22000 m^2 surface. The obtained COP is 4.2. The installation cost for the heat exchangers reached €1 million, whereas, the annual savings were estimated to reach 70%.

The heat exchange is accomplished by a combination of open and closed loop systems that operate simultaneously:

(i) a 42000 m long horizontal (slinky) heat exchanger
(ii) four (4) coaxial geo-exchangers (each 150m deep)
(iii) an open loop system (doublet) that provides 45 m^3/h of water

The coaxial geo-exchanger was developed by the company "AM Constructions", according to which their innovative design and geometry (tube in tube) guarantee much higher output and top performance, reducing the installation and operation cost of the system.

District Heating/Cooling System in Nea Ionia (Attiki, central Greece): A 2500 m long network for the heating and cooling of (9) public buildings was completed in 2016 in the city of Nea Ionia, near Athens. The system is supplied by GSHPs (1350 kW_{th}) and solar panels (100 kW_{th}) and cost €1.19 million. The pay-back period is estimated, under the current status of operation, at more than 10 years, however if more buildings are connected to the network, it can be decreased to less than 6 years. The expected annual energy cost savings have been estimated at approximately 55%. The replacement of fossil-fired installations results to the reduction of CO_2 emissions by 612tn/year.

De-icing of pavements in Karpenisi (Evrytania, central Greece): A geothermal snow melting system was installed in 2014 at the center of the town 'Karpenisi', in order to prevent icing of the 1.2 km long pedestrian walkways. The system operated for the first time during the winter of 2015-2016. It is supplied by warm water (28°C) from a closed-loop GSHP, coupled to 18 borehole heat exchangers (100m deep). Heating is automatically turned on when the outdoor temperature drops below +2°C.

Heating and cooling of a winery: The first winery in Greece that uses geothermal energy is "Ktima Brintziki", located in NW Peloponnese, near ancient Olympia. The heating, cooling and chilling requirements of the facilities are covered by a closed loop GSHP system, which consists of 14 borehole heat exchangers (100m deep) and two heat pumps that provide 57 kW heating and 53 kW cooling each. The temperature of the water delivered by the heat exchangers to the heat pumps is 16°C in heating mode and 20°C in cooling. The installation cost was €60000, with a five-year payback time. The Brintziki winery is the first in Greece with zero carbon footprint, as, in addition to the GSHPs, photovoltaic panels are used to cover the electricity demands.

Bioclimatic Building of CRES: The GSHP heating/cooling system of the CRES bioclimatic building was renovated in the framework of the Horizon 2020 innovative action "Cheap-GSHPs". The system consists of one open loop doublet with titanium plate heat exchanger (borehole depth = 60m, flow rate = 1.25m^3/h) and four different types of borehole heat exchangers: 304L stainless steel coaxial with inner PEX insulated pipe (50m), spiral (15 m deep), single-U (120m) and double-U (120m). The GSHP provides heating and cooling to the building through fan-coils with seasonal performance efficiency (SPF) of 4.2.

4. REGULATORY FRAMEWORK

The National Renewable Energy Action Plan, endorsed in 2010, and the National Energy and Climate Plan that came into effect in 2019 set the main targets for the penetration of RES in the country's energy market. Moreover, the Energy Performance of Buildings Regulations (2010) is considered as the main legislative tool for the promotion of RES systems for heating and cooling at the tertiary and residential sector (Andritsos et al., 2015), and has, in fact, become the key factor for the growth of the GSHP market.

Recently enforced legislation comprises the new geothermal Law (n. 4602/2019), the new RES support scheme (L. 4416/2016) and the establishment of Energy Communities (L. 4513/2018), which are discussed in the following paragraphs.

4.1. New Geothermal Law

As of March 2019, Greece has a new geothermal Law (L. 4602/2019 "Exploration, exploitation and management of the country's geothermal potential") that replaced L 3175/2003 "Exploitation of geothermal potential, district heating and other provisions". The detailed concession procedures, contracts, terms, royalties etc., are expected to be re-determined by secondary legislation and Ministerial Decisions, which are under development

The exploitation of shallow geothermal resources is mentioned in L. 4602/2019 and is further regulated by a number of Ministerial Decisions, which will probably be reformed as well.

The main changes in the new legislation can be summarized as follows:

- The threshold for the classification of a resource as "geothermal" is 30°C instead of 25°C
- A "geothermal field" is defined as the area where geothermal resources (T>30°C) have already been identified or accessed
- The geothermal fields are no longer classified as 'low' or 'high temperature' neither as "proven" or "probable", but only as of "local" or "national interest", depending on whether the product temperature is below or above 90°C, respectively.
- The term "area of geothermal interest" is introduced, describing the wider region with indications for the existence of geothermal resources with temperatures 30- 90°C
- The concepts "exploitation" and "management" of geothermal potential are explicitly defined and distinguished as:
  (i) *Exploitation*: all the activities aiming at the extraction of geothermal products and by-products and the safe disposal of the sub-products
  (ii) *Management*: all the activities regulating the exploitation of geothermal fluids, ensuring the sustainable, rational and integrated exploitation of the entire geothermal field
- The right to exploit is disconnected from management. Therefore, the concession may concern (i) exploration, (ii) exploitation, or (iii) exploitation and management
- The exploitation or exploitation/management leasing period increases from 35 (30+5 years extension) to 50 years (30+20)
- Pilot exploitation is allowed to begin even if the exploration leasing period has not been completed

The necessary permits and authorizations or special environmental provisions depend on the size, type and location of the geothermal project/plant. The licensing procedure for installing shallow geothermal systems is much simpler and requires the involvement of only one competent authority (Regional Administration).

The Law 4602/2019 also establishes a new legal entity for the geologic and mineral investigation on behalf of the Greek State that replaces the Institute for Geology and Mineral Exploration (IGME); it is called Hellenic Survey of Geology and Mineral Exploration (H.S.G.M.E.). One of the HSGME objectives is to perform geothermal investigation, to conduct geothermal studies, to provide consultancy and opinions on geothermal issues to the State, as well as to monitor geothermal areas and activities and create a national register for geothermal wells. thermal springs and monitoring stations.

4.2 RES Support Scheme

Greece has a new support scheme for renewable energy sources (RES), which complies with the general conditions set by the European Commission. The new scheme is described in Law 4414/2016 on "New Support Scheme for Renewable Energy Power

Plants and High Efficiency Combined Heat and Power Plants". Detailed provisions of the RES support scheme are determined in several Ministerial Decisions (ΑΠΕΗΛ/Α/Φ1/οικ.187701-187706) adopted in December 2016.

The basic principle of RES scheme is to promote the integration of renewables into the national electricity market at an optimum level of cost and benefit. More specifically:

(i) Renewable energy is given priority in regard to the use of the grid, in order to meet the renewable electricity generation targets
(ii) The feed-in tariff-based (FiT) scheme has been replaced by a technology-specific sliding scale Feed-in Premium (FiP). RES support is granted in a competitive "technology-specific" bidding process. Feed-in tariffs remain applicable only for RES plants ≤ 0.5 MW. The RES power plants installed on islands that are either not interconnected with the mainland of Greece or do not have a fully operational daily electricity market, will continue to access a FiT-based scheme (through the Power Purchase Agreement
(iii) The FiP is calculated on a monthly basis as the difference between technology- and capacity-specific Reference Prices and technology-specific reference market prices. The Reference Price for **geothermal energy** is 139 €/MWh for plants ≤ 5 MW_e and 108 €/MWh for plants > 5MW_e.

A new tax regulation mechanism and subsidies are available under the Development Law (2016) along with a net metering scheme. Renewable energy sources for heating purposes profit from a new tax regulation mechanism and subsidies foreseen in the Development Law, as well as from income tax relief. A scheme supporting GSHP and other energy saving interventions in private buildings provides direct subsidies and low interest loans to building owners.

4.3 Geothermal Communities

Following the European guidelines, Greece endorsed in January 2018 the Law 4513/2018, which introduces the establishment and operation of "Energy Communities", a concept widespread elsewhere in Europe, but until recently, quite unknown in Greece. The Energy Communities are, as a rule, non-profit organizations, with individuals, public or private legal entities and local or regional authorities, as participants. The main target is to deal with the energy poverty in Greece, as well as to create and promote more democratic and decentralized energy systems, by encouraging citizens to be directly and actively involved in energy projects, as both producers and consumers. The Energy Communities can be active in the fields of RES, Combined Heat and Power, Rational Energy Use, Energy Efficiency, Sustainable Support, Management of Demand and Production.

So far, it seems that this effort has had a positive response from several local communities, farmers, etc., since more than 60 Energy Communities (mostly for PV, none for geothermal energy yet) have been founded and many more are in the process. An initial sum of € 25 million will be made available for subsidies, through the National Strategic Reference Framework (ESPA).

5. GEOTHERMAL CONCESSIONS

As of the fourth trimester of 2020, the geothermal concessions regarded (17) geothermal fields, most of which in northern Greece. PPC has the exclusive rights for exploration, exploitation and management for the high temperature potential in Milos-Kimolos-Polyegos complex, in Nisyros island, Lesvos island and Methana peninsula, whereas the rights to explore or exploit the low temperature (up to 90-99°C) potential in five (5) important geothermal fields in Macedonia and Thrace (Lithotopos, Sidirokastro, Akropotamos, Eratino, Aristino) have been leased to the local municipalities.

Geothermal exploration or development activities have been carried out in those fields that private companies or local municipalities are involved. On the contrary, no real progress has been made, so far, as regards the four (4) allocated areas mentioned above.

6. ON-GOING GEOTHERMAL ACTIVITIES

The most important geothermal projects in progress are:

- *Geothermal Power Production Project*: The joint venture of PPC and HELECTOR S.A. is still going through a series of approvals and conditions.
- *Geothermal field of Aristino*: The geothermal energy exploitation project that has been carried out by the Municipality of Alexandroupolis is still in progress. An amount of €6 million will have been totally invested for the implementation of heat transfer and distribution networks.
  Two new reinjection wells at 550 m depth are under construction, constituting a vital part of exploitation project that is under implementation. This first exploitation attempt has been scheduled to cover, even for peak loads, district heating and greenhouses needs, for a maximum installed capacity of 10 MWth.
- *Geothermal field of Nea Kessani*: The company 'AGRITEX Energy" was awarded the rights to exploit a part of the low temperature geothermal field. The investment pertains to the use of geothermal fluids (T_{max}=82°C) for the heating of a 5 ha hydroponic greenhouse for cluster tomatoes. According to the investment plan the greenhouse units will gradually reach 10 ha and the total investment is estimated at €10 million.
- *Geothermal field of Akropotamos*: The Municipality of Paggaio has been awarded the rights to exploit the low temperature geothermal field and plans to invest €10 million for district heating/cooling networks and the distribution of heat to semi-urban settlements, greenhouses and spa resorts. The project is still in the early implementation phase.
- *Geothermal field of Lithotopos*: The exploration rights for the exploration of the low temperature field have been granted to the local authorities (Municipality of Iraklia). The exploration stage (drilling works and productivity tests) was recently completed. The Municipality of Iraklia will soon submit the relative feasibility study with the proposed investments for the field development.
- *Geothermal field of Nymfopetra (Mygdonia Basin, Macedonia)*: The exploration rights are leased to a private company which will use geothermal heat for agricultural purposes and plans to drill three new exploration boreholes and

rehabilitate two pre-existing productive geothermal wells. The geophysical prospecting (electrical resistivity tomography) that was performed recently in the area, revealed a very low resistivity anomaly, most probably associated to a geothermal resource, in depths less than 250m.

5. DISCUSSION AND CONCLUSIONS

The current exploitation of geothermal energy in Greece remains far lower than its exploitable resources. This is a known fact for many countries; however it has a particular importance when, despite the urgent necessity to reduce the energy import dependency, Greece continues to import oil in order to provide power to islands, such as Milos and Nisyros, instead of using their significant high enthalpy potential.

The very long stagnation period and the total absence of geothermal electricity generation in Greece is the result of four main factors, related not only to past failures but also to present misconceptions, myths and constant delays: (i) the very negative public perception towards geothermal power production in the most favored geothermal areas of the country (i,e. volcanic islands of Milos and Nisyros), (ii) the failure of the involved parties to overcome bureaucratic, technical and social obstacles, and (iii) the high country investment risk since the beginning of the financial crisis in 2009, and (iv) the hesitation, if not unwillingness, of the decision/policy makers to proceed faster and efficiently to the development of the confirmed or probable high temperature resources.

Unlike power production, the geothermal market for direct uses has shown positive trends. During the past five years new significant investments have been made in the geothermal heating sector, mostly for agricultural uses (greenhouse heating). The successful operation of the new geothermal greenhouses in northern Greece proves that geothermal energy is a very attractive option for low cost energy. The cost of a geothermal MWh ranges from €10 to €30, depending on the energy use and the characteristics of the reservoir, whereas the investment cost per MW_{th} generally varies from €150000 to €300000. For the climatic conditions of northern Greece, 1 MW_{th} can cover more than 90% of the annual heating requirements of a 7-10 ha greenhouse unit.

The total amount invested in geothermal energy (GSHPs excluded) exceeds 32.4 million US$ (Table 8). More specifically, 1.596 million US$ was invested for research and development activities, 12.8 million US$ for field development and 19.6 US$ for utilization, indicating a 73.5% increase compared to the 2010-2014 period. All new investments regard geothermal fields in northern Greece. The total installed capacity from direct uses is 84.45 MW_{th} (Table 5).

The exact number of the installed GSHP units is not known, but it can be reasonably estimated to more than 3500, with a mean COP at 4.5 (Table 4). The total installed capacity is 175MW, corresponding to 1380 TJ/yr energy use, for both heating and cooling (Table 4). The growth of the shallow geothermal market can be attributed to the simplified licensing procedures, but mostly to legislative initiatives and the implementation of certain measures and regulations that aim at fully decarbonizing the heating sector. All new buildings that accommodate services of the public sector must totally cover their primary energy consumption through energy supplied for RES, CHP, district heating and heat pumps. The same rule will stand for the private sector after 31.12.2019. Moreover, in November 2015, the EU Energy Efficiency Directive was enforced in Greece, for compulsory audits in large enterprises and minimum energy requirements for the public sector during refurbishing or purchasing of old buildings.

As regards exploration, most projects are focusing on northern Greece (Macedonia and Thrace) for the further investigation and development of known low or low to medium temperature resources. Since 2015, 13 new geothermal wells have been drilled (11 production and 2 injection) with a total depth of 5638 m (Table 6).

Although the Greek citizens have progressively become more sensitive to energy issues (climate change, greenhouse gas emissions, etc) and more familiar to the use of green technologies, geothermal energy remains less, if not the least, promoted and developed among other renewables, e.g. solar and wind energy. The public view has been the key factor for the development of the geothermal sector in Greece, so it cannot be taken lightly. The environmental, economic and social impacts of geothermal energy should be discussed more openly and thoroughly in the frame of a public dialogue, especially when various concerns and ethical issues are raised. Therefore, the necessity of informational campaigns, especially through national or regional mass media, is imperative for the future of geothermal energy in Greece.

Local authorities have played a very important role, either positive or negative, in all geothermal regions. Northern Greece has attracted important investments because both local authorities and communities consider geothermal energy as a source of environmental, social and financial benefits. Furthermore, in some cases, like in Aristino and Eratino geothermal fields, the local authorities have been actively involved in exploration and exploitation projects, and operate today as managers of the field and/or distributors of heat.

For the past few years, the energy sector in Greece is being restructured, setting the base to move towards low-carbon-intensity energy systems. For that reason, several reforms have been implemented or planned, among which, the new geothermal Law, the new Development Law, the establishment of Energy Communities and so on. It is too soon to arrive to any conclusions about the effectiveness of the new geothermal legislation; it has been, however, a necessary and positive step for the reformation and modernization of the relative regulatory framework that could facilitate the further penetration of geothermal energy to the country's energy mix.

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TABLE 1: PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	0		12,000		3,630				5773*	11,300	21,403	55,240
Under construction in December 2019	0											
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020	0		12,000						6,500		22,500	57,000

*PV: 2492 MWe, Wind: 2693 MWe, Smal Scale Hydro: 239 MWe, Biomass/Biogas: 83 MWe

TABLE 3: UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF DECEMBER 2020 (other than heat pumps)

Locality	Type[1)]	Maximum Utilization: Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Enthalpy[2)] (kJ/kg) Inlet	Enthalpy[2)] (kJ/kg) Outlet	Capacity[3)] (MWt)	Annual Utilization: Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
Nigrita	P (veg.)	7.5	57	25			1.00	2.50	10.55	0.33
Sidirokastro	G (flowers)	22	40	25			1.38	7.00	13.85	0.32
N. Apollonia 1a	G (veg.)	7	41	25			0.47	2.50	5.28	0.36
N. Apollonia 1b	G (veg.)	17	41	25			1.14	5.50	11.61	0.32
N. Apollonia 1c	G (veg.)	12	41	25			0.80	4.00	8.44	0.33
N. Apollonia 2a	G (flowers)	10	46	25			0.88	3.50	9.69	0.35
N. Apollonia 2b	G (flowers)	10	46	25			0.88	3.50	9.69	0.35
N. Apollonia 2c	G (flowers)	3.4	45	25			0.28	1.20	3.17	0.35
N. Apollonia 2d	G (flowers)	10	45	25			0.84	3.50	9.23	0.35
N. Apollonia 3	G (flowers)	27.7	50	30			2.32	9.50	25.06	0.34
Polychnitos 1	G (veg.)	19	82	43			3.10	6.00	30.86	0.32
Polychnitos 2a	G (veg.)	23	82	43			3.75	7.50	38.58	0.33
Polychnitos 2b	G (veg.)	9	82	43			1.47	3.00	15.43	0.33
Polychnitos 2c	G (veg.)	10	82	43			1.63	3.50	18.00	0.35
Milos	G (veg.)	4.2	46	24			0.39	1.00	2.90	0.24
N. Erasmio 1	P (veg.)	140	58	33			14.64	50.00	164.88	0.36
N. Erasmio 2	P (veg.)	4.5	60	40			0.38	2.00	5.28	0.44
Eratino_Chrysoupoli	P (veg.)	14.16	75	35			2.37	4.60	24.27	0.32
N. Erasmio 3	G (s.h)	3	58	30			0.35	2.00	7.39	0.67
Myrodato	G (s.h)	5.5	50	30			0.46	4.00	10.55	0.73
Trainoupoli	SH	16.7	52	38			0.98	5.90	10.89	0.35
N. Apollonia	SH	10	57	45			0.50	3.30	5.22	0.33
N. Erasmio 4	SH	4	42	32			0.17	1.30	1.71	0.32
N. Erasmio 5	D	9.7	58	52			0.24	6.00	4.75	0.62
Nigrita	SP	10	48	30			0.75	6.00	14.25	0.60
TOTAL		**409.36**					**41.18**	**148.80**	**461.54**	

G: Greenhouses-Glass
P: Greenhouses-Plastic
G(s.h): Soil Heating
SH: Space Heating
D: Dehydration
SP: Spirulina

TABLE 4: GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF DECEMBER 2020

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[5] (TJ/yr)	Cooling Energy[6] (TJ/yr)
TOTAL GREECE	15	175000	3700	V, H, W	4.2	2190	1380	

TABLE 5: SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF DECEMBER 2020

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	1.65	17.83	0.34
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating	38	407	0.34
Fish Farming			
Animal Farming			
Agricultural Drying[5]	0.24	4.75	0.62
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	43	260	0.19
Other Uses (spirulina and soil heating):	1.56	17.94	0.70
Subtotal	84.45	707.52	
Geothermal Heat Pumps	175	1380	0.25
TOTAL	259.45	2087.52	

TABLE 6: WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 2020 (excluding heat pump wells)

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 2020 (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)					
Production	>150° C					
	150-100° C					
	<100° C		11			4,672
Injection	(all)		2			0.966
Total			13			5,638

TABLE 7: ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

	(1) Government	(4) Paid Foreign Consultants
	(2) Public Utilities	(5) Contributed Through Foreign Aid Prograr
	(3) Universities	(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	6	24	4	0	0	n.a.
2016	6	24	4	0	0	n.a.
2017	6	24	4	0	0	n.a.
2018	6	25	5	0	0	51
2019	6	25	6	0	0	51
Total						

TABLE 8: TOTAL INVESTMENTS IN GEOTHERMAL IN (2019 & 2020) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	na	na	na	na	na	na
2000-2004	na	na	na	na	na	na
2005-2009	na	na	na	na	na	na
2010-2014	1.068	0.041	7.49	0	87.1	12.9
2015-2020	1.596	12.8	19.6	0	63	37

na = not available