Geothermal Energy Use, Country Update for Greece (2016-2019)

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ABSTRACT

The most important geothermal activities in Greece since 2016 mainly pertain to a few new investmentsin the agricultural sector and some under-way exploration and exploitation projects. More specifically, during the past three years, a new geothermal greenhouse unit (3.5 ha) was put into operation, another one was expanded from 8 to 17 ha and a third (5 ha) is under consideration. All three units are located in thoroughly studied areas of Northern Greece, where the easily accessible geothermal systems and the strong support by the local communities and authorities, have created favourable economic and social conditions. Furthermore, the first geothermal district heating project in Greece is under development in Aristino (Thrace, N. Greece). Fluids of 90°C will be used for the heating and cooling of twenty (20) public buildings, the heating of greenhouses (4 ha) and the operation of a geothermal pellet unit. A similar project has been recently initiated in Akropotamos (Strymonikos Gulf) but is still in the early implementation phase. GSHPs have a 65% share of the country's total installed geothermal capacity and more than 3.300 installed units, constituting the lead sector of the country's geothermal market. Geothermal power production remains an unattained target, although some positive steps have been taken during 2018. As regards to exploration, a few projects are in progress in Northern Greece (Strymon Basin, Delta Evros, Strymonikos Gulf, etc), in known low temperature areas, where new exploration and production wells were drilled.

1. INTRODUCTION

Greece holds a prominent place in Europe in regard to the existence of several areas with geothermal resources that can be easily and economically exploited. The intense tectonic and volcanic activity has caused the accumulation of thermal energy in relatively shallow depths and the development of numerous low, medium and high enthalpy reservoirs across the country.

The geothermal exploration has thus far identified thirty two (32) 'geothermal areas', within which forty five (45) 'proven' and 'probable' geothermal fields are located. A significant target of the current (or planned) exploration projects is the investigation of known low enthalpy areas for medium enthalpy resources that almost certainly exist at larger depths.

Despite the significant high and low-temperature potential, the geothermal resources in Greece remain under-exploited. Only a few new investments have been made during the past three years, all in the geothermal heating sector and most of them in agribusiness. On the other hand, the utilization of shallow resources with GSHPs enjoys growing popularity and constitutes the larger sector of the domestic geothermal market.

The total installed geothermal capacity in Greece has grown by 17% since 2016, mostly due to the new greenhouse units in Northern Greece and the increase of GSHPs installations. However, among all other renewables, geothermal energy has the smallest share in the country's energy balance.

2. ENERGY USE IN GREECE

The Greek energy sector still depends on fossil fuels, most of which are imported. The energy requirements are covered by petroleum products, which are used in the transport sector, for heating and for power production (diesel generators in not-interconnected islands), natural gas, which is also imported, lignite and renewable energy sources (RES).

According to the latest available data from EU (EU Energy in Figures, 2018 Edition), the primary energy production in 2016 was 6.78 Mtoe, exhibiting a significant decrease in comparison to the previous years, whereas the final consumption has been almost flat. The decline in primary production is attributed to the decrease of lignite production for electricity

generation. More recent data by BP for 2017 (BP Statistical Review 2018), show that the final energy consumption had a small rise (4%) compared to 2016, the first one since the onset of economic crisis in 2010.

The contribution of RES in primary energy production and gross consumption is 2.501 ktoe (37%) and 2.640 ktoe (9%), respectively (Table 1).

Table 1: Primary production and gross energy consumption by source type for 2016 (EU Energy in Figures, 2018)

Energy Source	Primary Production (Mtoe)	Gross Consumption (Mtoe)
Solid fuels	3.97	4.37
Oil	0.24	12.23
Natural Gas	0.01	3.49
Wastes	0.06	0.06
Electricity		[1]0.76
Derived Heat		0.05
Total RES ([2]Geothermal)	*2.5 (0.05)*	*2.64 (0.05)*
All Products	**6.72**	**24.14**

[1]*imports*
[2]*estimated (GSHPs included). Eurostat: 0.01 Mtoe (GSHPs excluded)*

The total installed capacity of electricity from RES at the end of 2016 was 8424 MW (Ministry of Environment and Energy, www.ypeka.gr), showing a 9% increase, mainly due to the installation of new wind parks and biomass plants. Hydro, wind and solar energy cover 98% of the total renewable power production, whereas no electricity is produced from geothermal energy.

The total contribution (final energy consumption) of RES for heating and cooling in 2016 was 1120 ktoe (Table 2), decreased by 365 ktoe compared to 2015.

Table 2: Contribution (final energy consumption) of RES in heating and cooling (ktoe) (source: www.ypeka.gr)

Energy Source	2015	2016
Geothermal (GSHPs excluded)	9.9	10.1
Solar	196.4	200.2
Biomass	1072.1	910.2
Heat Pumps (geothermal, aerothermal, hydrothermal)	206.7	238.6
TOTAL	**1485.1**	**1120.5**

The overall penetration of RES in gross final energy consumption remained relatively stable between 2015 and 2016 (Ministry of Environment and Energy: Fourth Progress Report on the Promotion and Use of Energy from Renewable Sources in Greece, 2018- Table 3).

Table 3: The sectoral and overall shares (%) of energy from RES (source: www.ypeka.gr)

	2015	2016
Heating and Cooling	25.61	24.24
Electricity	22.09	23.80
Transport	1.08	1.68
Overall share	**15.33**	**15.23**

3. NATIONAL TARGETS FOR RES

The national energy policy is regulated by the National Action Plan 20-20-20, defined by the Law 3851/2010 on "Accelerating the development of RES to deal with climate change and other regulations". In 2010, Greece endorsed the National Renewable Energy Action Plan (NREAP), which has set the following targets for RES shares in gross final consumption:

→ *Electricity*: 40%
→ *Heating & Cooling*: 20%
→ *Transport*: 10%

As regards geothermal energy, the target for electricity, heating and GSHPs was set to 120 MW, 51 ktoe, and 50 ktoe, respectively.

The share of RES for heating has already surpassed the 20% target for 2020, whereas their contribution in transport is significantly deviated from the desired target, although an increase between the years 2014 and 2016 has been observed.

It should be mentioned however, that these targets will soon be revised, in the framework of the upcoming national energy roadmap to 2030 and the assessment of the national energy mix.

4. REGULATORY FRAMEWORK

The main law that regulates all geothermal activities is L. 3175/2003 "Exploitation of geothermal capacity, district heating and other provisions", as it has been modified by the L. 3734/2009, L. 3737/2009, etc. The concession procedures, contracts, terms, royalties, etc. are determined in various Ministerial Decisions and secondary legislation. The exploitation of shallow geothermal resources (T<25°C) is mentioned in L. 3175/2006 and is further regulated by the Ministerial Decision Δ9Β,Δ/Φ166/οικ13068/ΓΔΦΠ2488 (Government Gazette Β΄ 1249/2009).

The geothermal fields are classified as '*low*' (T=25-90°C) or '*high*' (T>90 °C) temperature fields. Depending on the level of knowledge on their qualitative, quantitative and geometric characteristics, they are also characterized as '*proven'* or '*probable*'.

The *exploration rights* are leased for unexplored areas or probable geothermal fields, for a period of 5+2+1 years. The *exploitation/management rights* are leased for proven geothermal fields and for 25+10 years.

The *royalties and minimum fees* for each field are set by the competent authority, according to the legislation in force, the exploration findings, the characteristics of

the field, and the provisions of the submitted technical - economic study. In the case of low temperature fields, an additional fee (10% of royalties) must be paid to the local authority of the area that the project is established.

The necessary *permits and authorizations* depend on the size and type of the geothermal project/plant. Electricity generation and/or thermal energy distribution permits, energy sale contracts, connection (system or grid) agreement, environmental assessment approval, construction/installation/operation permits, etc., are usually required.

The special provisions for *environmental issues* mostly concern: (i) geothermal projects inside protected areas (RAMSAR, NATURA 2000 or other), and (ii) the re-injection of the geothermal sub-products.

The licensing procedure for the installation of *shallow geothermal systems* is significantly simpler and requires only the involvement of the Regional authorities.

It should be mentioned, however, that the main geothermal legislation (L. 3175/2003) is expected to be revised soon. The most important proposed modifications are the following:

- The threshold temperature for classifying a resource as geothermal will be 30°C instead of 25°C.
- The geothermal fields will be classified as of "local" (T=30-90°C) or "national" (T>90°C) interest, instead of "low" or "high temperature" fields.
- The concessions will concern exploration, exploitation or exploitation/management rights.
- The concession period for the exploitation or exploitation/management rights will become 30 + 20 years, instead of 35 years.

Since January 1st 2016, Greece has a new RES support scheme, described in Law 4414/2016 on "New Support Scheme for Renewable Energy Power Plants and High Efficiency Combined Heat and Power Plants"). The feed-in tariff-based (FiT) scheme has been replaced by a technology-specific sliding scale *Feed-in Premium* (FiP). The detailed provisions of the new RES support scheme are determined in several Ministerial Decisions (ΑΠΕΗΛ/Α/Φ1/οικ.187701-187706) adopted in December 2016.

According to the new scheme, RES support is granted in a competitive 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). 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 ≤ 5MW and 108 €/MWh for plants > 5MW*.

In January 2018, the Greek Parliament voted the Law 4513/2018 on "Energy Communities and other provisions". In the spirit of the European guidelines, this law introduces the establishment and operation of Energy Communities, which can be active in the fields of Renewable Energy Sources, Combined Heat and Power, Rational Energy Use, Energy Efficiency, Sustainable Transport, Management of demand and production, Distribution and Supply of energy at local and regional level (www.ypeka.gr). Members of Energy Communities may be individuals, public or private legal entities and/or local authorities. The general idea is for citizens to get directly and actively involved in energy projects, as producers and consumers at the same time. The Energy Communities are, as a rule, non-profit organizations, with the basic principle to diffuse the benefits to their members and to the local community.

5. GEOTHERMAL EXPLORATION

The most important areas of geothermal interest are located in several Aegean islands (e.g. Milos, Nisyros, Lesvos, Lemnos, Chios etc.), as well as in the grabens and post-orogenic sedimentary basins of Northern Greece (Delta Evros, Delta Nestos, Akropotamos, Strymon Basin, etc.). The geology and characteristics of the Greek geothermal fields and resources have been thoroughly described by several authors, such as Fytikas, 1988; Koutroupis, 1992; Kolios et al. 2005; 2007; Mendrinos et al., 2010 etc.), as well as in previous country update papers (Fytikas et al., 2005; Andritsos et al, 2010; 2013; 2015, Papachristou et al., 2016).

All geothermal exploration projects that have been carried out since 2016 regard additional exploration activities in known low enthalpy geothermal areas in Northern Greece, such as:

<u>*Strymon Basin*</u>: A new well was drilled in the low-temperature field of **Nigrita**, reaching the depth of 215m. The well produces 240-250 m^3/h of 61°C fluids. It is not yet decided whether it will be used as a production or injection well, as it was initially planned.

Four (4) new production wells, with depths ranging between 353 and 520m, were constructed in the low-temperature field of **Lithotopos**. The wells produce waters of 37.5-74.5°C, with low flow rates, ranging from 5 to 80 m^3/h.

<u>*Strymonikos Gulf*</u>: The extensive geothermal exploration conducted by IGME during the past decade, identified the existence of an important geothermal anomaly, which was confirmed after the drilling of six (6) boreholes along the coastal zone of Strymonikos Gulf (**Akroporamos** geothermal field). The top of the geothermal reservoirs were found at depths of 130, 230 and 515m, providing waters of 46, 85 and 90°C, respectively. In the frame of the new geothermal exploitation project, long-term production tests were performed in two (2) of the existing wells, with the following results:

- *Well AKR-1*: flow rate (artesian) = 220-230 m^3/h, T=84°C, wellhead pressure=1.4-1.5 bar
- *Well AKR-3*: flow rate (artesian) = 150-160m^3/h, T=90°C, wellhead pressure=0.5 bar
  flow rate = 130m^3/h with wellhead pressure = 1 bar (use of choke valve)

Nestos Delta Basin: Two new production wells were drilled in the low-temperature field of **Neo Erasmio**, in order to satisfy the increased heat demands of the local greenhouse unit (17 ha). The wells are cased to depths of 246 and 234m and each produce more than 120 m^3/h (required operational flow rate). Geothermal water temperature ranges between 57 and 59°C.

Evros Delta Basin: A new 415m deep production well was drilled in the north-western part of the **Aristino** low-temperature field**.** The maximum measured wellhead temperature was 97°C, indicating the high thermal potential of the reservoir. The initial production tests were not conclusive, due to serious technical complications that affected the performance of the pumping equipment. New pumping tests are scheduled for the next months.

6. GEOTHERMAL EXPLOITATION

6.1 Power Production

Geothermal energy is not being used for electricity production in Greece. All past attempts to develop this sectorfailed, for various reasons: technical complications, strong opposition from the local communities (e.g. Milos case), financing or bureaucratic obstacles, etc.

In 2017,the Public Power Corporation-Renewables S.A. (PPC-R), which will probably be absorbed by the mother company "PPC", announced an international call of interest to select a strategic partner for the financing, development and management of small (5-8MW_e) power plants in four fields leased by PPC-R (Milos-Kimolos island complex, Nisyros island and Lesvos island and Methana peninsula in NE Peloponnese). The selection process was concluded successfully in July 2018, with the company "HELECTOR S.A." declared as the highest bidder that will hold a 51% stake in its joint venture with PPC-R.The first power plants will be installed in Lesvos and Methana, hoping that the success of the project will ease the reaction of the locals in Milos and Nisyros against the exploitation of the high enthalpy resources.

6.2 Direct Uses

Geothermal energy in Greece is directly used for balneotherapy, space/soil/greenhouse heating, aquaculture, and vegetable drying. The total installed capacity from these applications is ~97 MW_{th} (Table 4).

No further development has been recorded since 2016 in the sectors of balneotherapy, soil & space heating, dehydration and aquaculture.

Table 4: Installed capacity and annual energy use of direct applications in Greece (March 2019).

Use	Installed Capacity (MW_{th})	Annual Energy Use (10^{12} J)
Direct Uses	**96.73**	**512.50**
Balneotherapy	42	251.00
Greenhouse Heating	46.74	221.10
Soil heating	4.5	21.29
Dehydration	0.58	2.74
Space Heating	1.65	10.41
Aquaculture	1.26	5.96
GSHP*	**175**	**1380.00**
TOTAL	**271.73**	**1892.50**

** estimated*

On the contrary, significant investments have been made for greenhouse heating in two low-temperature fields of Northern Greece:

Neo Erasmio (Xanthi, N. Greece): The geothermal greenhouses (hydroponic cultivation of tomatoes and cucumbers) that were constructed in 2014 (4 ha) by the company "THRACE Plastic Co S.A." have been gradually expanded to 17 ha (2018) and will reach 20 ha in 2020.

The heating requirements of the plantation units are covered by five (5) production wells (max total flow rate 500 m^3/h, T=60-65°C). The installed heating capacity and the annual energy use are 17 MW_{th} and 316.56 TJ, respectively. More than €20 million have been invested so far in this agriculture enterprise, which offers 120-150 job positions, improving significantly the local employment market.

Information on the heating system and geothermal installations can be found in Dalabakis et al., 2015 and Papachristou et al., 2016.

Eratino-Chrysoupolis (Kavala, N. Greece): The management rights of the "proven" Eratino field are leased to the Municipality of Nestos, which invested more than €10 million for the construction of the necessary district heating infrastructure for providing geothermal heat (up to 8 MW_{th}) to the end users, mostly for agricultural purposes. This project was completed in 2015.

In 2016, the company "SELECTA Hellas" implemented the first private investment in the Eratino field, with the construction and operation of a geothermal greenhouse unit (3.5 ha) for breeding, producing and marketing rooted cuttings of ornamental plants. The heat demands are entirely covered by geothermal energy. The maximum required flow rate is 50m^3/h. The temperature of the fluids is 75°C. The capacity and annual thermal energy in use are 2.3 MW_{th} and 43 TJ, respectively.

So far, the invested amount is about €7 million but it is expected to reach €10 million with the construction of additional units (2.5 ha) in the following years. In full

operation, the annual production will be 65 million plants.

6.3 Ground Source Heat Pumps

The Ground Source Heat Pump market in Greece has seenconsiderable growth after the mid-2000s (Figure 1). Despite the severe economic crisis of the past decade, the development of this sector remained positive.

According to the official statistics (Ministry of Energy and Environment) the total installed capacity of GSHPs installations in 2017 was 148 MW_{th}. It is very difficult to find the exact number of the installed shallow geothermal systems, especially of those in individual dwellings; however, it can be reasonably estimated that over 3300 GSHP units were operating in the country at the end of 2018, with a total installed capacity of approximately 175 MW_{th} (Table 4).

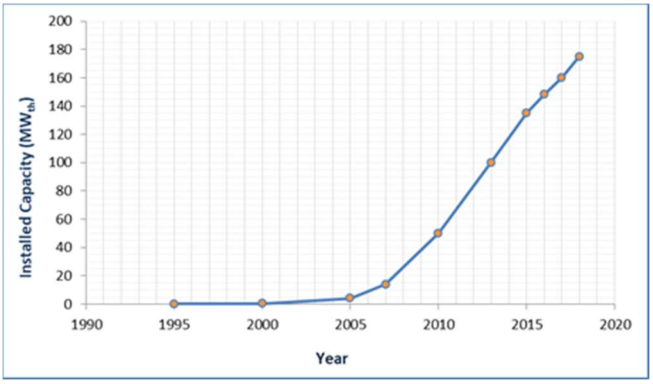

Figure 1: GSHP market development in Greece (1995-2019)

The GSHPs are commonly used in Greece for both space heating and cooling, as well as for domestic water heating. Many installations regard residential systems; however, their use is becoming increasingly widespread in publicor private office buildings, hotels, department stores, swimming pools, school complexes, etc. According to the Centre for Research & Technology Hellas (CERTH), 10 hotels in Greece use geothermal systems for cooling during summer months. The total installed capacity is approximately 6.7 MW for heating and 9.4 MW for cooling.

The installation of shallow geothermal systems for the soil heating of asparagus plantations (19 ha) in Chrysoupolis (Kavala, N. Greece) is the most important case of GSHPs in the agricultural sector. The system has been operating effectively since 2006, providing, at low cost, the required heat for early asparagus production. GSHPs were used for the first time in Greece for heating a greenhouse in Thessaly (Central Greece), achieving 50-75% annual energy savings. This was a demonstration project developed by the Department of Agricultural Engineering Technologists (TEI of Thessaly), in the frame of the *LIFE-Adapt2Change Program*.

Other notable applications regard the de-icing of pavements in a small mountain town of Central Greece and the use of GSHPs in wineries.

Several new GSHP systems have been installed in public buildings, under the obligation for significant energy savings in the public sector (Energy Performance of Buildings Regulation, 2010). Such a project is currently in progress at the 6500 m^2 administration building of the Kilkis Regional Unit (N. Greece). The heating/cooling requirements will be covered by a 230 kW heat pump and (30) vertical heat exchangers (100m deep each). The installation cost is estimated at €300000.

Data from indicative GSHP installationsthat have been operating continuously for more than a decadein Northern Greece, show that the mean annual savings for heating and cooling exceed 65% (>70% for heating and ~50-55% for cooling) in comparison to conventional systems (oil boiler coupled to split air-conditioning units). The payback time ranges between (3) and (9) years, depending on the building size and type.

During the past few years, a progressively increasing number of local and regional Authorities have installed GSHPs for the heating and cooling of the buildings they manage. For example, the Municipality of Nea Ionia (Attiki, Central Greece) recently completed an 1800m long district heating system supplied by GSHPs and solar panels for the heating and cooling of 9 municipal buildings. The total installed capacity is 1350 kW_{th} from GSHPs and 100 kW_{th} from solar panels (source: CRES, internal information)

Another important, and most probably the largest, GSHP project in the country was completed in 2016 and regards the installation of an innovative hybrid shallow geothermal system in the new building of the Central Macedonia Regional Authority in Thessaloniki (Figure 2).

Figure 2: The new buildingof Central Macedonia Regional Authority (Thessaloniki, N. Greece)

The total installed capacity is 850 kW, covering the heating and cooling requirements of 22000 m^2. The annual savings of heating and cooling during the first year of operation reached 70%. The obtained C.O.P. is 4.2. The installation cost for the heat exchangers reached €1 million.

The system consists of two heat pumps (2×425 kW) and three, different type, ground heat exchangers (Figure 3) that operate simultaneously:

i) a horizontal (slinky) heat exchanger (total length = 42000m)
ii) (4) coaxial geoexchangers (each 150 m deep)
iii) an open loop system (doublet) that provides the system with 45^3/h of water.

Figure 3: Shallow geothermal system in the building of Central Macedonia Region: a) horizontal heat exchanger, b) co-axial exchanger, c) open-loop manifold, d) geothermal heat pumps (courtesy of "AM Constructions")

According to "AM Constructions" (the designer of the vertical coaxial geo-exchanger, its innovative design and geometry (tube in tube) can guarantee much higher output and top performance, reducing the installation and operational cost of the geothermal system.

7. ON-GOING GEOTHERMAL ACTIVITIES

The most important on-going geothermal projects are briefly discussed in the following paragraphs:

(1) *Geothermal Power Production Project:* As it was aforementioned, PPC Renewables S.A., in joint venture with HELECTOR S.A., plans to install an 8 MW_e geothermal power station on Lesvos and 5 MW_e geothermal facilities in each of Methana, Milos-Kimolos complex and Nisyros. The first two fields that will be developed are Lesvos and Methana. Currently, the project is going through a series of approvals and conditions.

(2) *Geothermal field of Aristino* (Alexandroupolis, N. Greece): The Municipality of Alexandroupolis is carrying out an ambitious geothermal project that includes the drilling of new deep production and injection wells, the operation of the first geothermal district heating system in Greece, and the distribution of heat for agricultural purposes. In April 2017, the Municipality was granted the permission to distribute 9.8 MW_{th} of geothermal heat. The first production well (500m deep) has been already constructed, whereas the rest of the infrastructure works (wells, networks, thermal stations, in-building equipment) are scheduled to begin later this year. The total investment will be €6.2 million. The foreseen expansion of the district heating system is up to 20 MW_{th}.

(3) *Geothermal field of Nea Kessani* (Xanthi-Komotini Basin, N. Greece): The first investment in the low temperature (T_{max} = 82°C) field of Nea Kessani pertains to 5 ha of hydroponic geothermal greenhouses for cluster tomatoes, by the company "AGRITEX Energy". According to the investment plan, the greenhouse units will gradually reach 10 ha, providing 50 permanent and 100 seasonal job positions. Geothermal energy (12 MW_{th}) will cover almost entirely the annual heating demands of the facilities. The total investment is estimated at €7 million. This project is still under consideration.

(4) *Geothermal field of Akropotamos* (Strymonikos Gulf, N. Greece): The Municipality of Paggaio plans to invest €10 million in total for the exploitation of the low enthalpy resources (T_{max}=90°C) for district heating/cooling and the distribution of heat energy to semi-urban settlements, greenhouses and spa resorts. The project is still in the early implementation phase; however, the production tests that were recently performed to the existing (since 2000-2005) wells and the evaluation of their current status, suggest their replacement by new, larger diameter, production wells that will operate optimally and will ensure reliability and proper performance.

(5) *Geothermal field of Lithotopos* (Strymon Basin): In 2010, the Municipality of Iraklia was granted the exploration rights of the probable low temperature field. During the period 2016-2018 four (4) geothermal boreholes were drilled, producing fluids with temperatures up to 74.5°C. As it was indicated by the exploration/drilling results, part of the probable field will be officially characterized as "proven", following the relative procedure determined in legislation. The Municipality of Iraklia will soon submit the feasibility study with the proposed investments for the development of the field.

(6) *Geothermal field of Nymfopetra* (Mygdonia Basin, Thessaloniki)*:* The exploration project in the probable low temperature (25-40°C) geothermal field regards the drilling of three (3) new exploration boreholes, as well as the rehabilitation and development of the two existing geothermal wells, constructed some years ago by IGME.

8. GEOTHERMAL CONCESSIONS

According to the Greek legislation, the State is the owner of the geothermal resources with temperatures above 25°C. The exploration and management rights for the probable or proven geothermal potential may be leased to public or private legal entities through public tenders (highest bidding competitions).

As of February 2019, the following geothermal concessions have been granted, most of them under the Law 3175/2003:

Milos-Kimolos-Polyegos complex: The exclusive rights for the exploration and management of the high temperature potential (T>100°C) have been leased to PPC-R since 1985.

Milos island: The management rights for part of the proven low temperature field (Vounalia area - central Milos) have been leased to the Municipality of Milos since 2003.

Nisyros island: The exclusive exploration and management rights for the high temperature (T>100°C) potential are leased to PPC-R since 1986.

Lesvos island: PPC-R has been granted the rights to explore and develop the high temperature potential of the island. A few older concessions have been issued for small parts of the Polichnitos low temperature geothermal field (SE Lesvos).

Aristino (Delta Evros Basin): The management rights of the low temperature field have been leased to the Municipality of Alexandroupolis since 2013.

Neo Erasmio (Nestos Delta Basin): The exploitation and management rights of the proven low temperature field have been leased to the company "Thrace Greenhouses S.A." since 2014. An older concession (since 2000), regards the exploitation of a single geothermal well by Geothermica Hellas Ltd, which is used for the operation of the dehydration plant and the soil heating of the asparagus plantations.

Eratino(Nestos Delta Basin): The management rights of the low temperature field have been leased to the Municipality of Nestos since 2007.

Akropotamos (Strymonikos Gulf): The management rights for the proven low temperature field of Akropotamos were granted in March 2018 to the Municipal Water and Sewerage Company of Paggaio.

Nea Kessani (Xanthi, N. Greece): The southern part of the proven geothermal field was leased in April 2017 to "AGRITEX Energy S.A.".

Myrodato (Xanthi, N. Greece): Myrodato is officially characterized as an unexplored geothermal area. There is an old concession (since 2002) to a private company that has drilled a production well and uses the geothermal fluids (T=52°C) for soil heating of asparagus plantations (3.5 ha).

Lithotopos-Iraklia (Strymon Basin): The rights to explore the low temperature geothermal field are leased to the Municipality of Iraklia.

Sidirokastro (Strymon Basin): There are two concessions of the exploitation/management rights for the proven low temperature field. One part of the field is leased to the Municipality of Sintiki and the other one to the company "Geotherm Sidirokastrou S.A." Both concessions regard the use of geothermal resources for greenhouse heating.

Nigrita (Strymon Basin): There are currently five (5) concessions of the proven low temperature field (exploitation/management rights). Geothermal energy is being utilized for greenhouse heating and aquaculture (Spirulina).

Angistro (Strymon Basin): The rights to exploit the proven low temperature geothermal potential were leased in 2018 to a private company. The thermal water will be used in a balneotherapy center.

Nea Apollonia (Mygdonia Basin, Thessaloniki): There are currently three (3) concessions for the management of the proven low temperature potential, which is used for greenhouse heating.

Nymfopetra (Mygdonia Basin, Thessaloniki): The exploration rights for the probable low temperature potential have been leased to a private company since 2016.

Sani-Afytos (Chalkidiki peninsula): The exploitation rights for the proven low temperature potential and the exploration rights for the probable potential are leased to a private company that plans to invest in agribusiness.

9. DISCUSSION - CONCLUSIONS

Greece is currently undergoing significant energy reforms, which aim at promoting the use of renewable energy sources and, thus, achieving the 20% share of energy from RES in 2020. Geothermal energy could contribute considerably to the accomplishment of the above targets, however only a small fraction of the proven geothermal resources has been exploited so far. The total installed capacity from geothermal uses (GSHPs included) is approximately 272 MW_{th}, which does not correspond to the much more significant untapped potential. The specific NREAP targets for geothermal energy can only be met by the GSHP sector, which will probably reach 50 ktoe (final consumption) by 2020. The initial (set in 2010) target for 120 MW from geothermal electricity was totally unrealistic, whereas the use of geothermal energy (other than shallow) for heating and cooling should double in the next couple of years in order to achieve the NREAP target.

Nonetheless, the Greek geothermal energy sector has enormous prospective and could offer great opportunities for investors, as well as for the local or national economy. Yet, the confirmed *high enthalpy resources* in Milos and Nisyros islands remain unexploited, almost four decades after the shutdown of the pilot power plant in Milos.

Medium enthalpy resources, suitable for power generation, have been identified but not yet thoroughly explored in several areas of Northern and Central Greece, as well as in Aegean islands.

After a stagnation period of almost thirty years, important investments were made for the exploitation of the *low enthalpy potential*, mostly for greenhouse heating in the regions of Macedonia and Thrace. During the past decade, the use of geothermal energy in the primary sector has been established as a very attractive option that provides low cost energy. Depending on the characteristics of the geothermal reservoir, the cost of 1 MWh ranges from €10 (continuous energy use) to €30 (partial energy use). The investment cost per MW_{th} generally varies between €150000 and €300000 for simple schemes (production well – plant-injection well). The corresponding cost for heat distribution (base load ~10-15 MW_{th}) is €400000 to €700000. The experience that has been gained from the operation of the new hydroponic greenhouses in Northern Greece show that 1 MW_{th} is enough to cover more than 90% of the annual heating requirements of a 7-10 ha unit.

Apart from the primary sector, the first geothermal district heating project in Greece is under way in the geothermal field of Aristino (N. Greece). The construction works are expected to begin within the following months.

Moreover, the use of *GSHPs* is steadily increasing, with several new projects in progressacross the country, including the installation of shallow geothermal systems in existing or new public buildings. However, their use in agricultural applications is extremely limited and should be better and further promoted.

Public acceptance of geothermal energy has played a rather dramatic role in the growth of the geothermal sector in Greece and should not be underestimated. Social opposition in Milos and Nisyros during the early stages of geothermal development in the country has had a tremendously negative impact during the following decades. Unfortunately, the public view in these islands towards the new plans of PPC for geothermal power production has not change. For this reason, the realization of such projects would first and foremost, entailan extensive, sincere and thorough social dialogue.

Unlike Milos and Nisyros, the public attitude in other geothermal regions is very positive. Geothermal energy is considered by the local communities as an opportunity for social benefits, as well as for financial and environmental profit. In many cases, the local authorities have been actively and successfully involved in geothermal projects, mostly as managers or distributors of heat.

The anticipated reform of the main geothermal legislation, certain financial incentives under the new Development Law, the efforts to speed-up the licensing procedures, and, last but not least, the increasing interest and positive approach of the media, constitute positive steps towards the development of a better social and investment environment that will hopefully boost the domestic geothermal market.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2018	0		19588 *	52000 **	0	0
Under construction end of 2018	0					
Total projected by 2020	0	0	20600	50144	0	0
Total expected by 2025	10 ***	63	23800	51781	0.042	0.122
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2018 (indicate exploration/exploitation if applicable):					4 exploration	
					4 exploitation	

* *September 2018 (source: NECP, 2018)*

** *2017 (source: NECP, 2018)*

*** *source: PPC (personal communication)*

Table B: Existing geothermal power plants, individual sites

There are no geothermal power plants in Greece today.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2018	0	0	53.08	69.75	1.65	2.89	42	69.72
Under construction end 2018	0	0	0	0	0	0	1	1.66
Total projected by 2020	9.2	12.96	63.08	82.89	1.65	2.89	43	71.38
Total expected by 2025	41.2	59.39	71.08	96.04	1.65	2.89	43	71.38

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018	~3300 (*estimated*)	175	383	300	9	?
Projected total by 2020	~3500	195	450			

Table F: Investment and Employment in geothermal energy

	in 2018		Expected in 2020	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power	0	0	3	50
Geothermal direct uses	2.5	280 *	22	380
Shallow geothermal	22	300	20	350
total				

* Personnel working in geothermal spas are not included

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	DIS	DIS by national research projects, LIL	DIS
Financial Incentives – Investment	DIS	DIS, LIL	DIS, LIL from EU structural funds
Financial Incentives – Operation/Production	FIT, FIP-A		
Information activities – promotion for the public	YES	Workshops, seminars, conferences, short courses	Workshops, conferences, distribution of brochures
Information activities – geological information	YES	Legislation, papers, books	Geologic maps
Education/Training – Academic	YES, Lectures and courses for students	YES, Lectures and courses for students	YES, Lectures and courses for students, etc
Education/Training – Vocational	YES	YES	YES

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