Geothermal Energy Use, Country Update for Greece

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ABSTRACT

Geothermal exploitation in Greece comprises 43 MW_{th} of low enthalpy geothermal energy use for greenhouse heating and other agricultural applications, 43 MW_{th} of thermal spas and 191 MW_{th} of ground source heat pumps (GSHP). All three sectors are expected to enjoy high growth during the next years. Furthermore, new district heating systems are under development and the first geothermal pilot power plants exploiting high enthalpy resources are under investigation.

1. INTRODUCTION

Greece is characterized by considerable availability of geothermal resources. They are divided in three main groups: (a) low temperature (30-99 °C) identified in most cases in the vicinity of the numerous thermal springs found all over the country, (b) medium-high temperature (100-300 °C) inferred by geothermometers at the depths of basins/grabens of high heat flow and in formations of Miocene or more recent volcanism and (c) high temperature (>300 °C) identified by drilling exploration or active volcanism in the islands of the Aegean Volcanic Arc Nisyros, Santorini, and Milos (Mendrinos et al 2010, Papachristou et al 2014).

Geothermal activities during the years 2019-2022 are characterized by intensive exploration seeking low temperature resources, mainly by the Hellenic Survey of Geology & Mineral Exploration (HSGME), development of the large corporate geothermally heating greenhouses of SELECTA HELLAS and THRACE GREENHOUSES and further expansion of the GSHPs market. Investments for low enthalpy applications (excluding GSHP) amounted at around 6 million euro annually. In addition, the geothermal legislation has been streamlined removing some of the legal barriers of the previous framework. The new legislation effectively facilitates GSHPs development, as the temperature threshold below which no concessions are required has been increased to 30 °C. Other market segments, namely the small family-owned agricultural units, aquaculture and thermal spas remained stagnant at previous levels due to the financial crisis affecting the country and the COVID-19 pandemic, while there was no geothermal power generation (Papachristou et al 2020).

2. RECENT DEVELOPMENT

2.1 Power generation

The national plan for energy and climate foresees 100 MWe of install capacity of geothermal power plants in 2030. In this direction, PPC-R the subsidiary of Public Power Corporation of Greece focusing on renewable energy has shown renewed interest in geothermal development. PPC-R proceeded with strategic cooperation with ELECTOR SA for the development of geothermal power plants in the areas that PPC-R has acquired high enthalpy geothermal concessions, namely Milos-Kimolos isl., Lesvos isl., Methana peninsula and Nisyros isl. In each one of them a 5 MWe power plant is planned.

The cooperation will be implemented through the joint subsidiary "Geothermal Objective II" owned by 51% ELECTOR, and 49% PPC-R. PPC-R will complete the exploration for the identification and characterization of geothermal potential in these areas. The total investment plan amounts at 120 million euro, 70 million of which will be geothermal exploration and the other 50 million geothermal field and power plants development.

The national legislation has been completed by two Ministerial decrees, as follows. The first one is Ministerial decree No ΥΠΕΝ/ΔΑΠ/42138/552 published at government gazette 1960B on 21 May 2021, which regulates onsite geothermal works. The second one is Ministerial decree No ΥΠΕΝ/ΔΑΠ/25257/126, published at government

gazette 1460B on 28.03.2022, which defines the terms and procedure for allocating concession rights for exploration, management and exploitation of geothermal resources of national interest (resource temperature above 90 °C), as well as geothermal exploration rights in unexplored areas.

2.2 Agricultural applications

The utilization of geothermal fields for agricultural applications in northern Greece is largely due to the positive attitude of local government and local communities, and the general perception that geothermal energy can be a source of economic and environmental benefits.

THRACE GREENHOUSES

Thrace Greenhouses is the flagship of low enthalpy geothermal development in Greece with a turnover of 8 million euro annually employing 210 persons. It exploits the geothermal resource of Neo Erasmio, in order to heat 18.5 hectares of hydroponic greenhouses producing 6000 tons of tomatoes plus 10000 tons of cucumbers for the Greek market. It utilizes 14.64 MW_{th} of geothermal fluids of 60-70 °C delivering 45.8 GWh_{th} annually of heat from 8 production wells, 210-330 m deep each. Additional wells and piping network are planned to be constructed in order to reach 36.7 MW_{th} of geothermal heat utilization. For this purpose, additional 13 hectares of greenhouses are under construction in Neo Erasmio, increasing production by 6000 tons and creating another 70 jobs. An investment of 14.66 million euro is foreseen for this purpose.

The company has also secured the concession of the northern part of the nearby geothermal field of Nea Kessani, in order to produce 12 MW_{th} of 73°C of geothermal fluids from 400-450 m deep wells, which will heat 13 ha greenhouses producing 10 thousand tons of vegetables (tomatoes and cucumber). The corresponding investment amounts at 12.6 million euro and will generate 90 job positions.

SELECTA HELLAS

Selecta Hellas is the second corporate-owned geothermal greenhouse complex in Greece, producing flowers for the export markets. It is located at the geothermal field of Eratino-Chrysoupoli, near Kavala airport. The greenhouses cover an area of 3.5 hectares (ha) and employ 120 persons. In collaboration with the Municipal Water Supply and Sewerage Company of Nestos, it exploits 2.38 MW_{th} of geothermal fluid produced at 69-77 °C from two 750 m deep well doublets. Company development plans are to expand the greenhouse area by 2.1 ha in the next years, and to drill 2 additional wells (doublet) 700 m deep, in order to reach 9.8 MW_{th} of installed geothermal capacity.

FAMILY-OWNED GREENHOUSES

Having been the backbone of geothermal development in Greece until 2010, approximately 20 small family-owned geothermal agricultural businesses remain operational today. It has been a declining market during the past 10 years, mainly due to the financial crisis prevailing in the country and the COVID-19 pandemic. They are located in the geothermal fields of northern Greece, namely Nea Apollonia, Nigrita, Sidirokastro, Neo Erasmio and Myrodato, but also on the islands of Lesvos (Polychnitos) and Milos. They comprise greenhouses, soil heating and drying facilities, with small space heating applications in a few cases. Soil heating, space heating and aquaculture concern very limited applications, both in terms of installed capacity and number of facilities. Fish farming units do not operate any more. Estimated total geothermal utilization is around 24 MW_{th}.

2.3 District heating

During the last few years, the Municipality of Alexandroupolis started a new geothermal venture, in order to provide heat from the nearby geothermal field of Aristino to existing and new thermal energy users. Co-financed by regional structural funds, after 8 years of preparations and bureaucracy, in April 2020, a contract of 6.2 million € was signed for the construction of a 12 km long heat transfer and piping network. Its capacity is 10 MW_{th}, 9 MW_{th} of which will be utilized for agricultural use, namely heating 2 existing greenhouses of 1.5 ha total, plus new greenhouses totalling 3 ha, and 1 MW_{th} for district heating of nearby social housing complex of 5 buildings hosting children, plus 11 municipal buildings. The district heating network will be supplied by two geothermal doublets, 500 m deep. An additional amount of circa 1.2 million € was allocated recently for this purpose.

The project is now in its final phase and, according to the contractor, it is expected to be delivered by the end of August. At the time of writing of this paper (April 2022), drilling of the first re-injection borehole is under way, while drilling of the second one is expected to commence in May 2022. Next, consumers will be connected to the district heating network.

Future plans include expansion of the district heating network by additional wells and 6 more km piping to nearby villages, plus heating of a pellet-producing plant under construction. Allocated budget amounts at 14.7 million €. In April 2021, the Municipality expanded its geothermal concession rights to exploit fluids up to 99 °C, which are suitable for large scale district heating plus a small geothermal power plant. The Municipality initiated the necessary prefeasibility studies in this direction.

2.4 Thermal spas

In Greece there are more than 70 spa therapy centres and spa facilities as well as circa 25 outdoor pools operating with geothermal water. There are 100+ hot springs across the country, 80 of which are officially characterized as thermal, see Figure 1. The temperature of the hot springs ranges from 25 to 92+ °C, while the temperature of the hot waters in the spa treatment facilities does not exceed 39 ° C. Almost all traditional spa towns are open from June to October, while only a

few remain open all year round. Geothermal fluids in these facilities are for thermal use only and are not used for heating of the spa areas or the hospitality of the guests, except in the case of the baths of Traianoupolis, located near Aristino geothermal field. The use of geothermal energy in spa units in Greece cannot be accurately calculated, as there is no systematic recording of the necessary data. A conservative estimation of installed capacity and energy use is 43 MW_{th} and 72 GWh_{th}/yr respectively.

In order to further develop the spa market in Greece, the Ministry of Tourism is setting up the public limited company "Thermal Springs of Greece" with initial share capital of 5 million €, in order to identify, manage and utilize the country's thermal springs according to existing investment plans. The "Thermal Springs of Greece" will utilize the natural thermal resources, their facilities and the surrounding area within a radius of 500 meters, which is the property of the State or local Authorities.

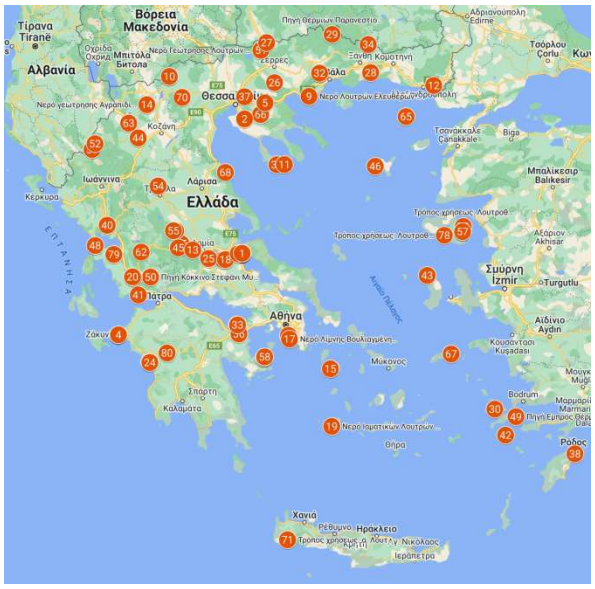

Figure 1: Map of thermal springs in Greece.

2.5 Ground Source Heat Pumps

The GSHP sector remains the most dynamic in the domestic geothermal market, for reasons that could summed up in the mature technology, their attractive financial performance, the simplified licensing procedures and most important the National commitment towards decarbonising the building sector, by incorporating the corresponding EU legislation towards nearly zero energy buildings in the national legal framework. They provide heating and cooling to residential, commercial, industrial and public buildings, also including one greenhouse heating application in Chrysoupoli. Although no exact figures are available, it is estimated that every year around 180 new installations take place of total capacity around 6.7 MW_{th}, corresponding to 2 % of new buildings. They are mainly large units of circa 47 kW_{th} installed capacity on average. Overall installed capacity of GSHPs exceeded 180 MW_{th} at the end of 2021, corresponding to circa 320 GWh_{th} of heating plus circa 160 GWh_c of cooling.

2.6 Dehydration of Agricultural Products

As has been described in previous updates and in Andritsos et al. (2003), a novel dehydration plant of agricultural products operates in Neo Erasmio (Xanthi, northern Greece) since 2001. The unit uses geothermal water of 60°C to heat atmospheric air to 55-58°C, which then is directed to series of drying channels. Although initially the plant was designed and constructed to dehydrate only tomatoes, in recent years the plant is used to dehydrate several other agricultural products, and the plant actually operates almost all year around. In 2021 the quantities of dehydrated products are as follows: tomatoes 6 tn (lower quantities than in early 2010s due to unavailability of fresh produce), citrus fruits (lemons, oranges, limes) 9 tn, peppers (yellow, green, chili) 8.5 tn, olives 4 tn and garlic 1 tn. Smaller quantities of several other products, such as apples, onions, mushrooms and zucchinis, have been also dehydrated during 2021.

3. ONGOING PROJECTS AND FUTURE PLANS

In addition to the above developments, the most important geothermal exploration and utilization projects in progress concern the following low enthalpy geothermal areas:

Akropotamos geothermal field: The Municipality of Paggaio has acquired the exploitation rights and field management and plans to invest around € 10 million in district heating networks and the distribution of thermal energy in semi-urban areas, greenhouses and spa facilities. The project is still in the early stages of prefeasibility studies.

Lithotopos geothermal field: The geothermal exploration rights of the field have been leased to the Municipality of Irakleia. The geothermal exploration assigned to I.G.M.E. (now HSGME, Hellenic Survey of Geology and Mining Exploration) was completed in 2019 and had relatively good results. The new production wells, 352.5-519.5 m deep, yield waters of 37.5-74.5 ºC. The flow rates range between 5 and 80 m³/h depending on lithology, aquifer properties and screen depths. The total installed thermal capacity from the existing production wells is estimated to be 4.47 MW_{th} (Arvanitis et al., 2021). The Municipality has decided to utilize the geothermal energy in the area and is in the process of submitting feasibility studies for the development of the field in order to obtain the right to exploit and manage the geothermal potential.

Nigrita geothermal field: the Municipality of Visaltia extended their concession rights to exploit the geothermal field of Therma Nigritas for an additional 20 years. They own a production well delivering 2.5 MW_{th} of geothermal heat, which will be distributed to local farmers for greenhouse and soil heating.

Sidirokastro geothermal field: An ongoing geothermal drilling project is being performed by

HSGME (Hellenic Survey of Geology and Mineral Exploration) in the northern part of the Sidirokastro geothermal field. This project is included in the "Actions for the Rational and Sustainable Utilization of Geothermal Energy - GEOTHERM" and is funded by the Operational Program "Competitiveness, Entrepreneurship & Innovation" (EPAnEK) which is one of the Programs of the Partnership and Cooperation Agreement (NSRF) for the period 2014-2020. The first large diameter exploration well (Sd-18P) was completed in October 2021 and identified 75 °C fluid at 200 m depth. Geothermal exploration is ongoing in the area.

Eratino-Chrysoupoli geothermal field: The Municipality of Nestos, which owns the concession of the Eratino geothermal field and supplies geothermal fluid to Selecta Hellas via a small district heating network, also plans to further expand the district heating network towards heating the elementary school of Eratino and constructing a small farm heated by geothermal energy for agricultural research purposes in an area of 0.4 ha. The farm will comprise a pilot greenhouse growing hydroponic crops of vegetables and floating leafy vegetables, along with underfloor heating applications for asparagus, melons and watermelons. The greenhouse will be connected to existing district heating network. The project has already been designed and is in the final phase of funding.

Aristino geothermal field: A company named "THRACIAN ENERGY" plans to explore a part of the Aristino geothermal field covering an area of 7 km^2 and submitted binding investment proposal to the Decentralized Administration of Macedonia and Thrace in November 2021 in the frame of an open invitation. The proposed exploration program includes detailed geological and structural study, geoelectric surveys and drilling of two (2) exploration wells (500-600 m deep) aiming to find geothermal fluids of 90 ºC with a flow rate of 200 m^3/h.

Polichnitos geothermal field: The Municipality of Western Lesvos has been interested in the exploitation of the Polichnitos geothermal field where temperatures of 30-90 ºC are encountered at depths of 50-200 m and submitted binding investment proposal to the Decentralized Administration of the Aegean in November 2021 during an open tendering procedure for granting of exploitation and management rights.

Except for the exploration in the above-mentioned low enthalpy fields, some additional geothermal works and projects are currently carried out by the Hellenic Survey of Geology and Mineral Exploration (HSGME):

Diachronic (periodic and continuous) monitoring of selected low enthalpy geothermal fields and hot springs for their optimal use and ensuring their sustainability: Based on the new geothermal law (Law 4602/2019, article 21), the monitoring of the geothermal fields of the country is carried out by HSGME. For this purpose, the first geothermal telemetry stations for monitoring, recording and data transmission have been installed since October 2020 in the following geothermal areas: Neo Erasmio-Magana geothermal field, Nisyros island and Santorini island. Each geothermal telemetry station consists of the following main components: (a) temperature and hydraulic pressure sensors installed at specific depths in monitoring boreholes and contact thermometers at wellheads of production wells for water temperature measurements, (b) a box for collecting, recording and transmitting data containing the necessary equipment (data logger unit, radio modem, battery, charge controller) and (c) protected cables connecting sensors to the box. A telemetry station can be supplied either by photovoltaic panel or electricity grid. The installed telemetry stations use the "LoggerNet" support software for real-time access to data. All data is transmitted to the server of HSGME.

Management Plans of Low Temperature Geothermal Fields in Greece: This project has started since February 2020 and is funded by the Operational Program "Competitiveness, Entrepreneurship & Innovation" (EPAnEK) in the frame of NSRF 2014-2020. The aim of the Project is the creation of a pilot and synthetic study of management plans for geothermal fields of local interest (fluid temperature lower than 90 ºC) and its pilot application in 2 selected geothermal fields (Neo Erasmio-Magana and Nea Apollonia). The first two technical reports entitled "Management plan specifications of low temperature geothermal field" and "Standard pilot implementation of a management plan in the Neo Erasmio-Magana geothermal field, Xanthi area" were completed and submitted to the Hellenic Ministry of Environment and Energy in November 2020 and August 2021 respectively.

Reconnaissance geothermal exploration in the Myrodato area: The geothermal exploration in the Myrodato area (Xanthi Regional Unit) included in the "Actions for the Rational and Sustainable Utilization of Geothermal Energy - GEOTHERM" (EPAneK, NSFR 2014-2020) aims at the probable identification of a new low temperature geothermal field. Collection and critical review of the existing geological, structural, and drilling data, registration of existing irrigation and drinking water wells, borehole and wellhead temperature measurements, water sample collection and chemical analyses have already been carried out.

Compilation and publication of a Guide on Geothermal Energy, in Greek and English - A Guide on Geothermal Energy: The aim of the Project funded by the Public Investment Program (National Funding) is to compile an investment guide for the use of geothermal energy in Greece, which will provide useful information on the geothermal situation, the fields and potential of the country, the existing legal framework and the available financial tools for investment projects.

Long-term monitoring, supervision and restoration of geothermal wells drilled by IGME (now HSGME) which have not been assigned to third parties: A large number of geothermal wells have been drilled by IGME (now HSGME) for exploration, identification and evaluation of the country's low enthalpy fields. Some of them have not been assigned to third parties. This project funded by the Public Investment Program (National Funding) includes the following activities: (a) registration of existing geothermal wells (location, history, lithology, geothermal and construction characteristics) which have not been assigned to third parties and their current condition, (b) systematic in situ supervision and monitoring of these wells, (c) preparation of emergency response plans in case of leak detection, well-construction failures etc and (d) problem management in collaboration with the Decentralized Administrations of Greece. At the end of this project, the usable wells will be assigned to the Decentralized Administrations.

Creation of a National Register for the Registration and Monitoring of Geothermal Points: This project has started in January 2022 and is included in the Act entitled “Reinforcing Entrepreneurship in the Domain of the Hellenic Survey of Geology and Mineral Exploration (H.S.G.M.E.)”. The implementation of the National Register for the Registration and Monitoring of Geothermal Points is provided for by article 17 of the new Geothermal Law (Law 4602/2019). This project is accompanied by Legal Implementation Support and Publicity of the Act.

4. CONCLUSIONS

The Greek geothermal market is divided in three main segments, as follows.

The first one corresponds to direct low enthalpy heat use for heating agricultural units, which is transforming from small, family-owned agricultural enterprises to large corporate owned greenhouse units. The market is based on the exploration performed by the state-owned Hellenic Survey of Geological and Mining Exploration (HSGME) and infrastructure developed by local Authorities utilizing regional structural funds. This market segment is expected to grow in the next years by the expansion of existing and the addition of new geothermally heated greenhouses.

The second one is the thermal spa market, which is fragmented but has been stable during the past few decades, and is currently under reform by the Ministry of Tourism, in order to stimulate further growth materializing existing investment plans.

The third and the healthiest market segment corresponds to ground source heat pumps, which during the past 15 years enjoys steady growth, aided by favourable legal framework and national policy towards decarbonization of the building stock.

In the next years, two new market segments will be developed, namely space heating, as soon as the Municipal district heating systems under construction and planned are completed, and geothermal power, when the first pilot plants are constructed.

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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 2021	0	0	21846	53815	0	0
Under construction end of 2021	0	0	2630	-	0	0
Total projected by 2023	0	0	23160	55800	0	0
Total expected by 2028	23	160	28240	58900	0.1 %	0.3 %
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 0	
					Under investigation: 5	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Greece.

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

	Geothermal DH plants(1)		Geothermal heat in agriculture and industry(2)		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 2021	17	52	24	76	2	5	43	72
Under construction end 2021	65	198	-	-	-	-	-	-
Total projected by 2023	62	189	24	76	2	5	43	72
Total expected by 2028	90	275	29	89	2	5	43	72

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

(1) Includes stand-alone large Greenhouse complexes of Table D2 plus future district heating plants

(2) Small family-owned units

Table D1: Existing geothermal district heating (DH) plants, individual sites

No geothermal district heating plants currently in Greece.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021pro duc-tion (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Erateino - Chryssoupolis	SELECTA HELLAS	2017	N	2.38	2.38	6.7	100%	SELECTA HELLAS
Neo Erasmio - Maggana	THRACE GREENHOUSES	2014	N	14.64	14.64	45.8	100%	THRACE GREENHOUSES
total				17.02	17.02	52.5	100%	-

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g., by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production[(1)] (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021	3878	182	478	178	6.7	2
Of which networks **	0	0	0	0	0	0
Projected total by 2023	4234	195	513			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

(1) includes cooling

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES installations currently in Greece.

Table F: Investment and Employment in geothermal energy

	in 2021		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	3	23	20
Geothermal direct uses	7	85	7	90
Shallow geothermal	16	65	16	65
total	**23**	**153**	**46**	**175**

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	no	no	no
Financial Incentives – Investment	no	DIS	DIS, LIL
Financial Incentives – Operation/Production	FIT	no	no
Information activities – promotion for the public	no	no	no
Information activities – geological information	no	no	no
Education/Training – Academic	no	yes	yes
Education/Training – Vocational	no	no	no

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)