

Barriers against and actions towards renewable energy technologies diffusion: A Principal Component Analysis for residential ground source heat pump (GSHP) systems

Spyridon Karytsas*, Ioannis Choropanitis

Centre for Renewable Energy Sources and Saving (CRES), Geothermal Energy Department, 19th km Marathonos Av., Pikermi 19009, Athens, Greece



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ABSTRACT

The residential sector is responsible for 20% of the total energy consumption worldwide, with fossil fuels being its main energy source. Ground Source Heat Pump (GSHP) systems are an alternative option for heating, cooling and Domestic Hot Water (DHW) production in the residential sector, offering several advantages compared to conventional systems. Through a survey, this paper examines the views of people involved in the Greek GSHP sector, regarding existing and future adoption level of residential GSHP systems, dissemination barriers and actions that can contribute to their adoption. The conducted Categorical Principal Components Analysis (CatPCA) indicates that diffusion barriers can be classified to market and information barriers, regulatory and financial barriers, installation barriers and siting barriers, with a) lack of public awareness on the GSHP technology and its benefits, b) economic recession, c) lack of adequate subsidies or tax exemptions for the installation and d) installation cost being considered as the most significant ones. In accordance, diffusion actions that can contribute to the penetration of the technology can be categorized to regulatory and technology improvements, financial incentives and awareness activities, with tax reductions suited for GSHPs, public awareness activities on the technology and its benefits and training activities for installers being considered as the most important ones.

1. Introduction

The residential sector is responsible for 20% of the total energy consumption on a worldwide basis [1], while the corresponding figure for EU-28 is 25% [2]. In addition, global residential energy consumption is projected to increase significantly over the forthcoming decades, primarily due to increased demand from countries outside the Organization for Economic Co-operation and Development (OECD) [3]. The main needs covered by the energy consumed by the residential sector are heating, cooling, lighting and Domestic Hot Water (DHW) production [3]. In developed nations, in which Greece is included, household heating dominates the energy consumption of the sector [4]. Worldwide, fossil fuels and electricity are the main energy sources used by the residential sector for heating and hot water production.

The current widespread use of fossil fuels is characterized by unreliability and insecurity, as energy resources come from limited reserves that are concentrated in politically vulnerable areas, while also having a negative impact on the environment, thus leading to an increase in health and global climate change risks [5,6]. This also applies to Greek households, which mainly use fossil fuels for the

operation of residential heating systems. In addition, more than 50% of Greek households use air-conditioning units for cooling, and almost ¾ use electric heaters for production of DHW [4].

The use of renewable energy sources, which are considered viable energy resources regarding current and future economic and social needs of the society, can be a key factor in achieving sustainable development [7–11]. Ground Source Heat Pump (GSHP) systems are a renewable energy technology that can help meeting the heating, cooling and hot water needs of buildings, thus contributing to independence from fossil fuels and sustainability.

The present study attempts to identify the barriers that hinder the diffusion of GSHP systems in the Greek residential sector, as well as the actions that can contribute to the adoption of the technology by households. Specifically, the study examines the views of people (industry representatives, academics, researchers) involved in the Greek GSHP sector and classifies their opinions through the use of Categorical Principal Components Analysis (CatPCA). In parallel, the main attributes of GSHP technology are presented.

* Corresponding author.

E-mail addresses: spkary@cres.gr (S. Karytsas), jchoro@cres.gr (I. Choropanitis).

2. GSHP systems

2.1. GSHP systems technology

Geothermal energy is the heat that is found inside the earth and consists of a) the energy flow through the earth's crust, in the form of material transfer, b) the heat flow due to the thermal conductivity of rocks and c) the energy stored in rocks and fluids in the earth's crust [12]. Geothermal resources can be considered as renewable in the time scale of technological/ social systems, as they do not require the renewal time scale that fossil fuels (such as coal, oil and gas) need [13]. Therefore, geothermal energy is a renewable energy source that can provide electricity, heating and cooling in domestic, commercial and industrial buildings, as well as in other facilities [14–18]. Geothermal energy is distinguished depending on temperature fluids in a) high temperature ($> 90\text{ }^{\circ}\text{C}$), b) low temperature ($25\text{--}90\text{ }^{\circ}\text{C}$) and c) shallow geothermal ($< 25\text{ }^{\circ}\text{C}$), according to Greek Law 3175/2003 [Government Gazette (GG) 207 A']. The exploitation of shallow geothermal energy is realized through the use of GSHPs.

GSHP technology utilizes the relatively constant temperature of the soil or water to provide heating and cooling of buildings and DHW throughout the year [19–27]. Specifically, a GSHP system, depending on the season, uses the ground or groundwater for heat absorption in order to provide heating and for heat rejection in order to provide cooling. During the winter, a GSHP carries thermal energy from the ground or groundwater to provide space heating. During the summer, the energy transfer is reversed, with the ground or groundwater absorbing thermal energy from the building, in order to cool it. GSHPs are the key to the exploitation of the unlimited shallow geothermal energy resources, as they can be used almost anywhere, since they do not require the existence of geothermal resources (existence of hot water or steam) [28–34]. GSHP systems can be used from small residential buildings up to large individual buildings or complexes (offices, hotels, schools, shopping centers, etc.) [35,36].

GSHP systems comprise of three main elements [37,38] (Fig. 1):

- A mean for the absorption or rejection of heat from the ground, groundwater or surface water;
- A heat pump, which converts this heat to a suitable temperature level;
- A system inside the building for the distribution of heating and

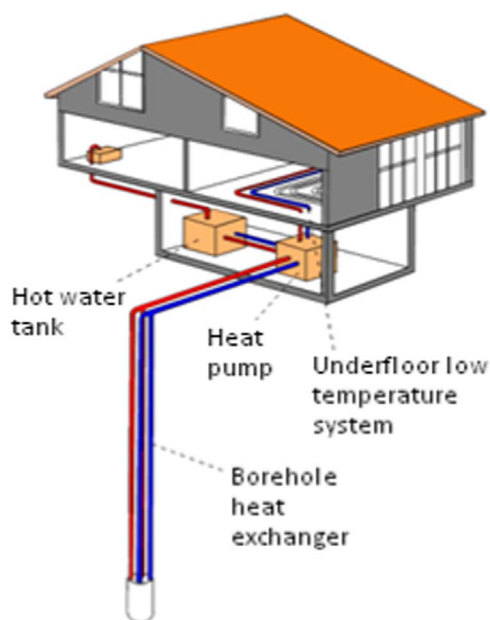


Fig. 1. Typical GSHP system (vertical closed loop system) [20].

cooling provided by the heat pump. In addition, in the case that DHW is provided, the system includes a hot water tank.

2.1.1. Mean for heat exchange

A heat exchange system is used for the efficient exploitation of the heat capacity of the ground. Heat exchange with the ground is achieved either through the circulation of a heat carrier fluid (closed system) or, if possible, through the use of groundwater (open system) [32,39].

During the heating mode, fluid circulates through pipes which are placed in trenches, boreholes or building foundations. Heat contained in the circulating fluid is extracted by a heat pump and is used to heat the building. The cooled circulating fluid is reintroduced into the ground, where it absorbs heat, thus completing the cycle. In cooling mode the system is reversed, with the heat being removed from the building and transferred to the ground through the heat pump and the circulating fluid (Fig. 2) [30].

2.1.2. Heat pump

The heat pump is the device that increases the temperature which is introduced through the ground or groundwater at a level which is suitable for the heating system (hydraulic or air) located in the building, since the temperatures encountered in shallow geothermal energy are usually too low for direct use [30,39]. The heat pump is not a new technology; Lord Kelvin developed the idea in 1852, leading to the creation of the GSHP by Robert Webber in the 1940s [20,30]. The heat pump is nothing more than a refrigeration unit, and includes the same main components with a refrigerator or an air-condition unit. It is a device that forces heat to flow from a lower to a higher temperature; i.e. exactly what an inverted cooling unit does [34,36,40]. Fig. 3 presents the typical operation of a heat pump of a GSHP system in heating mode. Reversing this cycle corresponds to operation in cooling mode.

In order to achieve the required temperature increase, the heat pump needs additional power [27]. This energy is usually electrical (rarely, thermal energy is used) and is required for the compressor's operation [34,41]. The energy input required is less than the attributed heat; the less the energy needed, the more environmentally and economically attractive the heat pump is [30,35]. In the residential sector, typical heat pumps used have a thermal capacity between 5 and 20 kW [35].

2.1.3. Heating/ cooling distribution system

The distribution system that delivers heating in the winter and cooling in the summer is also part of the GSHP system. The distribution system is located inside the building, while usually an underfloor, in-wall, air handling unit (fan coil), duct system or low temperature radiator is used [25,26,29,34,35,37].

Existing GSHP technology can be applied only through the use of low temperature heating systems (maximum $55\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$), which limits their application mainly to new buildings. The systems installed in existing buildings are often of high temperatures ($80\text{ }^{\circ}\text{C}$ to $90\text{ }^{\circ}\text{C}$), which means that the installation of GSHPs in these buildings requires the replacement of the high temperature heating system with advanced systems (e.g. fan coil or low temperature radiator), as well as the replacement of building pipes with ones' with larger diameter. The development of heat pumps that deliver higher temperatures is the step required to solve the problem of necessary modifications/ replacements in existing buildings [32,43].

2.1.4. GSHP system design

The proper design of a GSHP system is necessary in order to ensure its long-term sustainability [33]. Factors that must be considered when designing a system are local climate [36,44], layout and use of the building [30,36], heating and cooling requirements of the building [44,45] and soil characteristics (composition, morphology, moisture, thermal properties, hydrogeological conditions) [43,44,46,47].

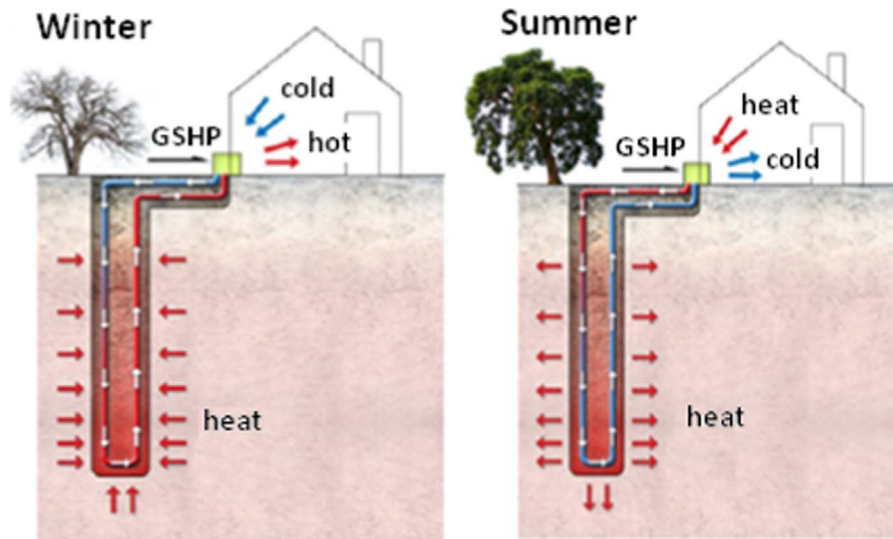


Fig. 2. Heat exchange with the ground: Vertical closed loop GSHP system [30].

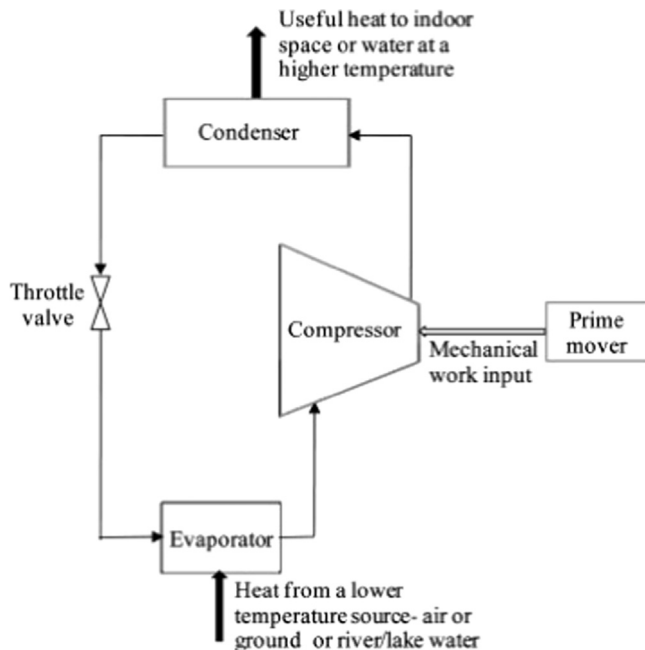


Fig. 3. Heat pump theoretical operation cycle in heating mode [42].

Through the examination and identification of system characteristics, over-sizing or under-sizing is avoided, thus maximizing economic and environmental benefits [48–51].

One of the most important processes during design of vertical systems is the identification of the thermal properties of the soil where the system will be installed. This procedure can be accomplished through the Thermal Response Test (TRT) during the early stages of the project. Through the information collected during this test and in combination with data concerning the heating and cooling loads of the building, the number of boreholes, their diameter, their depth, the size of the pipes, the grouting material, etc. are calculated in detail [52–55].

2.1.5. GSHP systems performance

The unit which is used for the performance measurement of a GSHP system is the Coefficient of Performance (COP). COP is defined as the ratio of output energy to the electrical energy consumed, and refers to a specific time or specific conditions [56–59]. The electrical energy taken into account concerns the total energy consumed by the

heat pump, the circulators, the borehole pump, etc. [26,27,30,57].

More specifically, in Europe the system performance is usually described for the heating mode with COP_h and for cooling with COP_c [20]. The corresponding units used in the United States, as well as in other markets outside Europe, are COP and EER (Energy Efficiency Ratio), which is measured in Btu/ watt * h [45,56]. In practice, the performance of a system is best expressed by the SPF (Seasonal Performance Factor) which is the mean COP during the heating/cooling period (with the SPF of each system having a lower value compared to its COP) [58–61]. Measures corresponding to SPF, which are used mainly outside Europe, are the Heating Seasonal Performance Factor (HSPF) for the heating operation and the Seasonal Energy Efficiency Ratio (SEER) for cooling operation [62–64].

The COP and SPF depend on local climate, temperature of water imported from the underground circuit, geological conditions, technical parameters, heating/ cooling load, operation mode (heating/ cooling), and by residence's characteristics such as the heating system type [65–69]. Typical COP and SPF values range between 3.5 and 6.0 [20,29,32,38,43,58,59,70–77]; through technological developments the COP and SPF of GSHP systems are constantly improving [39].

2.2. GSHP system types

There are several different options regarding the GSHP systems types; the initial categorization is whether the system is open or closed loop, and whether it is installed in a horizontal or vertical arrangement [43,44,56,78,79]. Apart from the more common system types, many subcategories and variations exist, such as closed loop systems with inclined loops [80,81], standing column wells [44,79], direct expansion systems [82,83], systems with a helical heat exchanger [84–86], systems using water from tunnels or mines [87,88] and hybrid systems [28,34,89,90].

The system type selected each time depends on the available land surface [91], the soil type [27,35], whether water drilling is possible in the area [20,27,35] and the heating and cooling characteristics of the building/s [35]. These factors determine the most economical option for installation [35,92].

2.2.1. Open loop system

Open loop systems use water from a water well (Fig. 4), a body of surface water (e.g. lake) (Fig. 5) or even waste water from community sources (e.g. sewage, rainwater, water from processing units) as means to exchange heat with the ground, i.e. absorb and reject heat. Main technical components of open loop systems are the water wells, which

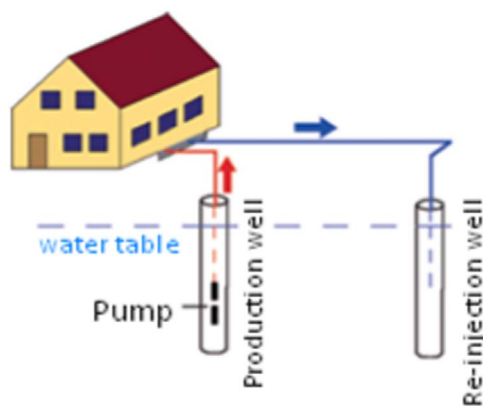


Fig. 4. Open loop system with injection – reinjection wells [35].



Fig. 5. Open loop system using surface water (redesign) [56].

serve the extraction or deposition of water to/ from the underground water bodies. Most systems use a productive well to provide water to the heat exchanger and a reinjection well in order to return the water to its source [93,94]. In open loop systems, the supply of the fluid is ensured by the hydrological cycle, with heat coming either from above (atmosphere) or from below (thermal flow of the earth) [95].

Open systems are cost efficient, so in case their use is feasible, these systems are preferred [26,35]. An advantage of open loop systems is the possibility of offering free cooling; this is feasible when the water source temperatures allow it (generally if they are between 7 and 15° C), and always in combination to the cooling needs and weather conditions [96]. In case of free cooling, significant reductions to the operating cost can be achieved, thus reducing the overall payback period of the system.

On the other hand, the installation of open loop systems is limited to locations with a suitable groundwater table [29,34,35] and with the existence of an appropriate reinjection space [19,29]. In addition, these systems require an adequate water flow rate [26,29,35] and good chemical composition of water (e.g. low content in Fe) [29,35], while it is also important to properly maintain them [34,35].

Regarding systems using water from surface bodies, their application is largely limited by environmental legislation; in addition, because the temperature of surface waters depends on the climate, it makes them having similar characteristics to air source heat pumps. However, if conditions are appropriate, these systems are very attractive from an economic view [92].

2.2.2. Closed loop system

In closed loop systems, the heat concentrated in the ground serves as an energy source. In these systems a closed loop pipe (typically high density polyethylene, with lifetime over 50 years) is placed horizontally or vertically in the ground, with water or a mixture of water and antifreeze circulating in the pipes in order either to collect heat from the ground during the heating mode, or to reject heat to the ground during the cooling mode [46,93,97]. Closed loop systems can be used almost anywhere, as unlike to open systems they do not require the existence of specific resources, while the circulating fluid never comes into direct contact with the ground [30,36]; on the other hand, these systems have a higher installation cost [36,98]. Concerning the residential sector, a small residence requires one or two vertical heat exchangers or a horizontal collector [35].

It should be noted that apart from the ground, closed loop systems can be installed within a body of surface water (e.g. lake), if available. These systems are efficient and have a relatively low installation cost [19,28,36]. In addition, recently emphasis has been given to closed systems using subsurface components (energy piles, foundations, basement walls, ground slabs, tunnels and ground anchors) which can accommodate the pipes. The advantage of these systems is that installation costs for new construction can be significantly lower, since no additional drilling or excavation is required [99–107].

2.2.2.1. Horizontal systems. Horizontal systems are usually used for small installations, where the required space is available [35,48]. The installation of horizontal systems is easier and has a lower installation cost [24,29,35] with the pipes being buried in trenches with depth of 1–2 m [37,97]. Typically, the pipes are arranged in parallel or in series (Fig. 6); more "compact" types are also available, with the arrangement being spiral or in trench [30,35] (Fig. 7). The "compact" types achieve the placement of larger pipe length into smaller trenches, thus requiring less surface area [29,35]. A typical horizontal system has a length of 35–60 m per kW of heating or cooling capacity [24].

For the installation of geothermal heat exchangers in a horizontal arrangement, usually a layer of soil is completely removed, the pipes are placed, and the soil is placed over the pipes [29,35]. Furthermore, new drilling methods allow the installation of horizontal systems without creating a large disturbance in existing residences [24,108]. In horizontal systems, and especially in those operating only for heating, the main thermal recharging is supplied by solar radiation absorbed by the ground. This is why it is important not to cover the surface above the heat collectors [40,95].

Horizontal systems are not suitable in most urban areas because of space restrictions [29,30]. The efficiency of these systems can be also influenced by differentiation of ambient temperatures. However, lower installation cost and ease of installation makes these systems attractive under certain conditions [29,92].

2.2.2.2. Vertical systems. Vertical systems exploit the constant temperature of soil below a certain depth (about 15–20 m) throughout the year [24,35]. In a typical vertical GSHP system, plastic pipes are placed within wells with a depth of 50–150 m [37,40,49,97] and a diameter of 10–20 cm [25,30,40]. To achieve maximum efficiency, the space between the pipe and the borehole wall is filled with a thermally conductive material (usually a mixture of



Fig. 6. Horizontal closed loop systems a) in parallel and b) in series arrangement [35].

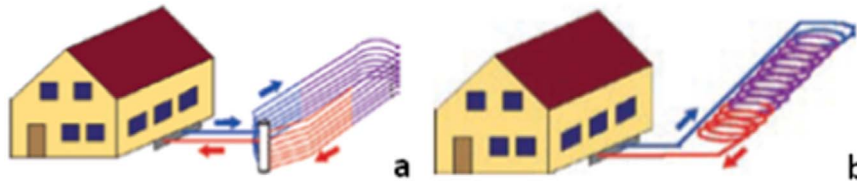


Fig. 7. Horizontal closed loop systems a) in trench and b) in spiral arrangement [35].

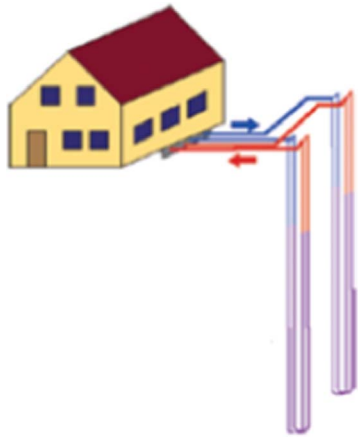


Fig. 8. Vertical closed loop system with two boreholes [35].

bentonite and sand) [36,43,109]; for the enhancement of the thermal conductivity new materials are tested, containing graphite components [110,111] or recycled materials such as limestone sand and silica sand [112]. In most cases more than one boreholes are required, with tubes being usually joined in parallel or in series; 5 m is considered a proper distance between the boreholes [29,35] (Fig. 8).

There is a number of different types of loops for vertical systems, with the two main categories being [35,113] (Fig. 9):

- U-shaped pipes, i.e. a pair of rectilinear pipes which are connected together at their edge with a U-shaped (180°) pipe. Due to the low cost of the pipes, two or even three of them can be installed in a single borehole.
- Concentric or coaxial pipes connected either in a very simple way, i.e. with one pipe placed inside another pipe of larger diameter, or connected in a more complex arrangement.

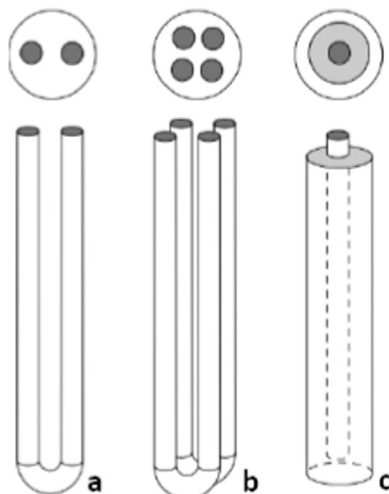


Fig. 9. Loop types for vertical systems: a) single U-shaped, b) double U-shaped and c) coaxial pipe [52].

In vertical systems, the heat source for heat recovery is solar energy (in the upper part) and geothermal flow (in the lower part), with a small influence of the flow of groundwater or filtered water [35,114]. This applies particularly for systems that operate only for heating, while in systems operating both in heating/ cooling, the recovery is achieved during the annual cycle [40,95].

Vertical systems have the advantage of requiring much less area than the horizontal systems, so they are preferred in locations with little space available [40,48]. In addition, they minimize disturbance to the existing landscape [24,92], while they are preferred over horizontal systems in cases where the ground near the surface is very rocky [18,24]. On the other hand, they have a higher installation cost due to the high cost of drilling [48,98].

2.2.3. Combination of GSHPs with other RES technologies

2.2.3.1. GSHPs and solar PVs. The combination of a high efficiency technology such as GSHP systems with a solar PV system installed on buildings' roofs or terraces is an ideal arrangement that can lead to zero-emission and zero-power consumption buildings [115–117]. The combined installation of the two RES technologies balances the electricity consumption need of the GSHP system; practically, the electrical energy required by the GSHP system is produced by the solar PV system. This way the user is at the same time the producer of almost the whole amount of energy required for the heating/ cooling and DHW production of the household. This combination is an investment that can minimize the cost of heating/ cooling and DHW, thus significantly reducing the total energy expenditures of a building.

2.2.3.2. GSHPs and solar thermal. The combination of GSHPs with solar thermal panels for heating/cooling and DHW production improves the total efficiency of the system, thus reducing its electrical energy needs [118–120]. The temperature in the ground closed loop system increases due to the contribution of the solar panels leading to the increase of the input temperature of the fluid in the GSHP's evaporator, thus achieving an increase of the efficiency of the GSHP system and a reduction of the required electrical energy. The benefits from the combined use of GSHPs and solar panels are various, and they depend on the design and the selection of a suitable automation system. For example, during the summer the solar thermal panels can cover the DHW production requirements thus saving electrical energy from the reduced use of the GSHP; this way the operating hours of the GSHP's compressor are reduced, its lifetime is increased, while contributing to the achievement of the ground's temperature equilibrium. To sum up, the use of solar thermal panels in combination with a GSHP system can lead to a) the direct production of DHW, b) the pre-heating of the DHW, c) the direct production of thermal energy for the heating system or d) the temperature increase of the water introduced in the GSHP's evaporator.

2.2.3.3. GSHPs, solar PVs and solar thermal. The combination of GSHPs, solar PVs and solar thermal panels can lead to a maximum energy savings system offering heating/ cooling and DHW production

with zero electrical energy needs and zero CO₂ emissions. The electrical energy needs are minimized through the combined use of GSHPs and solar thermal panels; in this case, the user can also employ solar PVs for the production of the energy consumed by the combined GSHP/solar thermal system [121,122].

2.3. GSHP systems costs

In order to make a comparison between GSHP systems and alternative heating/cooling systems, a direct comparison should be made between installation cost, operating cost and maintenance cost [123–125]. On this basis, the payback period of the installation of a GSHP system compared to an alternative system is estimated [123]; this information plays a very important role in the final decision on selecting a heating/cooling system.

The installation cost of a GSHP system depends on the type of system to be installed (open/closed, horizontal/vertical), the type and dimensioning of the collectors, the heating and cooling load of the residence, the soil characteristics, the system functions (heating, cooling, DHW) and the GSHP market (availability of equipment, installers etc.) [18,35,48,92,123,126]. It is estimated that a 10 kW residential closed loop system in Europe requires 1100–2100 € per kW for its installation [127]; it should be noted that in a vertical closed loop system it is likely that half of the cost involves drilling, and the remaining half the heat pump system [49]. Table 1 presents the installation costs, concerning the Greek market, for systems with different characteristics [128].

The operating cost of a system (GSHP or conventional) is mainly affected by the price of electricity, fuel prices, the performance of the system, the climate of the region, the system use (heating or heating/cooling) and habits of the dwelling's occupants [18,29,35,79,105,123,125,126]. However, GSHP systems are particularly attractive in areas where the energy cost of traditional systems is high and the cost of electricity is low [38,79,129,130].

The maintenance cost of GSHP systems is low compared to most alternative options. This is due to the fact that GSHP systems a) do not require a boiler or a stove for their operation, b) their equipment is not located outdoors, c) the system's design is simple, d) the fluid leaks are rare and e) the pumps, compressors and pipes have a long lifespan [18,79].

Table 1
GSHP system installation cost.
Source: [128]

	Open system	Closed horizontal system	Closed vertical system
Borehole / heat exchanger	50–60 €/m (drilling) Performance depending on ground	8–12 €/m ² (one layer at 30 cm) Performance 18–25 W/m	40–50 €/m (heat exchanger) Performance depending on ground
Heat pump	Small systems (0–50 kW): 300–400 €/ kW Large systems (> 50 kW): < 300 €/ kW		
Heating / cooling distribution	Fan-coils: 150–200 €/kW Underfloor: 60–80 €/kW In-wall: around 60–80 €/kW		
Engineering cost (materials & labor)	For 10 kW: 1500 €		
For heating: COP=5–6 / SPF _{th} =4.5–5.5 – For cooling EER=4.5–5.5 / SPF _c =4–5			

2.4. Advantages and potential negative impacts of GSHPs use

2.4.1. GSHP advantages

The use of GSHP systems can offer benefits to consumers, as well as to a local, national and international level. The benefits can be divided into three main categories: technological, environmental and socio-economic.

Technological benefits:

- System that provides heating, cooling and DHW [29,35,59,92,98].
- Technology adjustable to the available resources, the size and the type of the equipment and needs that have to be covered [32,35,59].
- Use of ground or groundwater, which are means more stable than ambient air [131].
- One of the most energy efficient heating and cooling systems that exist today, thus contributing to energy saving [131–142].
- Highly reliable technology [19,29,40,46,59,79,92].
- System with a long lifespan [19,20,35,92].
- Provides evenly distributed temperature within the residence, thus offering comfort to its users [37,59,79,92,98].
- Lack of an outdoor unit, which can be unattractive and noisy. Also, the lack of an outdoor unit results to a longer lifespan and reduced maintenance costs [19,29,35,37,40,48,59,79,92,131,143].
- Secure technology, as there is no combustion, flammable materials or potentially dangerous fuel storage tanks [19,27,35,59,92,98,143].
- Technology that is not affected by the change of seasons, climatic conditions and the time of day (day/night) [35,59,93].
- Relatively wide option for installation siting, beside or beneath the building; small requirement for space inside the building [20,59].
- Decentralized installation, depending on the needs. Costly heat distribution, which is required in district heating, is avoided [20].
- Reduction of peak power requirements [144].

Environmental benefits:

- Environmental friendly system that does not produce pollutants and contributes to the reduction of greenhouse gases, such as CO₂, SO₂ and NO_x [59,76,79,98,133,135,139,144,145]. The savings –compared to conventional heating technologies which use fossil fuels– vary depending on the source used for the production of electricity and the technology with which the comparison is made [138–140,142,143,146–151]. Of course, actual reduction in emissions is achieved only when units operating with fossil fuels are replaced; with the installation of new GSHP systems only the additional pollutants that would be produced are avoided [27].
- Contributes to fossil fuel saving [27,35,40,92].
- No risk during transport, storage and operation (as for example with heating oil) [20].
- No risk of groundwater contamination (as for example with oil tanks) [20,59,92].
- Reduction of thermal radiation in urban areas [144].

Socioeconomic benefits:

- Low operating costs compared to other heating systems [79,123,136,138,141,152,153].
- Low maintenance cost, due to the fact that combustion is not required and that the equipment is located indoors [131,136,154,155].
- Payback of investment in just a few years [59,92,147]. The payback period depends on the type of system under consideration, energy costs, and the type of system with which the comparison is made, thus presenting significant differences between each different case.
- In a long term it increases the value of the building in which it is installed [59].
- An economically viable solution, as it is a local energy source

independent from external effects on supply/ demand and from changes in exchange rates [35].

- Contributes to employment growth, as increases in GSHP installations lead to increased demand for specialized drillers, installers and maintainers. Also, small and medium-sized enterprises operating in this industry strengthen local and regional economies [19,35].
- The growth in the GSHP industry increases sales of the corresponding equipment, which is an advantage for the countries that produce it [19].
- The use of GSHPs leads to reduced use of fossil fuels, which in many cases are imported. Through the reduction of imports, trade balance is improved [19,92].
- Increased competitiveness, since the adoption of GSHP systems leads to cost savings for users. These savings contribute to reduced overheads, increased operating efficiency and lower prices for consumers [19,35,137].

2.4.2. Comparison between GSHPs and conventional systems

In order to better understand the economic, energy and environmental benefits of GSHPs compared to conventional heating/ cooling systems, a theoretical comparison has been performed for a 10 kW heating/ cooling system in the four different Greek climate zones (zones A to D, Fig. 10). In all four zones different comparisons have been conducted concerning a) an open loop GSHP system and b) a vertical closed loop GSHP system in relation to c) a heating oil boiler and a conventional cooling system and d) a natural gas boiler and a conventional cooling system. The comparisons concern the installation of new systems (either conventional or GSHP) and not the replacement of existing systems. The results are indicative on how GSHPs installation can provide benefits in different cases; a comparative view on the expected benefits of GSHP application in various situations, on a basis of different climate zones, GSHP types and conventional systems is offered. In order to perform the calculations, the values presented in the work of CRES (2014) [156] were used (Table 2). The heating/ cooling operation hours for each zone were calculated based on data from the Technical Directive TCG T.O.E.E 20701-3/2010 "Greek

Table 2

Values used in systems' comparative analysis.

	Value
Building heating/ cooling load	10 kW
Mean heating operation time - zone A	1003 hrs
Mean cooling operation time - zone A	800 hrs
Mean heating operation time - zone B	1262 hrs
Mean cooling operation time - zone B	700 hrs
Mean heating operation time - zone C	2150 hrs
Mean cooling operation time - zone C	500 hrs
Mean heating operation time - zone D	2600 hrs
Mean cooling operation time - zone D	300 hrs
Open loop GSHP SPF _h	5.2
Open loop GSHP SPF _c	4.5
Closed loop GSHP SPF _h	4.5
Closed loop GSHP SPF _c	4.2
Heating oil boiler efficiency	0.8
Natural gas boiler efficiency	0.85
Cooling system efficiency	2
Electricity price ^a [159]	0.1495 €/kWh _e
Heating oil price ^b [160]	0.968 €/lt
Natural gas (NG) price ^c [161]	0.05492 €/kWh _t
NG conversion coefficient [161]	11.5882 kWh/Nm ³
Open loop GSHP installation cost	1100 €/kW
Closed loop GSHP installation cost	1270 €/kW
Heating oil system installation cost	150 €/kW
Natural gas system installation cost	150 €/kW
Cooling system installation cost	450 €/kW

^a March 2017; 2/3 regular tariff, 1/3 night tariff

^b March 2017

^c December 2016

regional Climate Data" [157], while the values concerning systems' efficiencies, energy costs and installation costs were updated to the present status.

For each case the primary energy savings, the emission reductions and the simple payback period are estimated (Table 3). GSHP systems present better results (in financial, environmental and energy terms) when compared to heating oil boilers in relation to their comparison

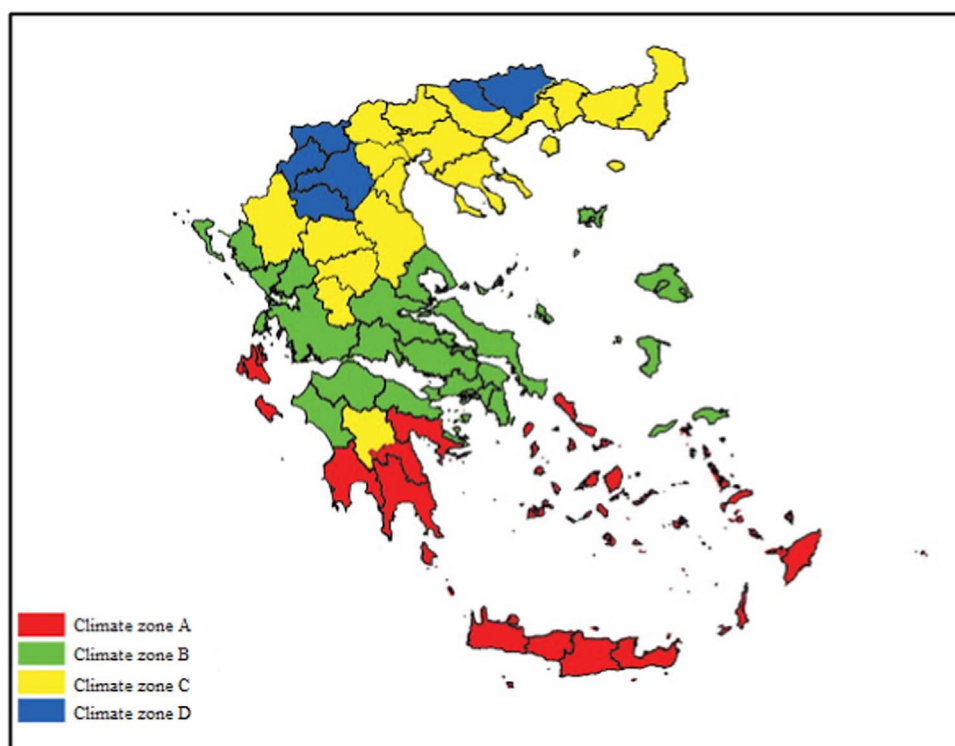


Fig. 10. Map of Greek climate zones [158].

Table 3
Comparison of GSHPs to conventional heating/ cooling systems in different climate zones.

GSHP type	Conventional system	Comparison of GSHP to conventional system	Climate zone			
			Zone A	Zone B	Zone C	Zone D
Open loop	Heating oil & ASHP	Primary energy savings (%)	54.45%	54.25%	53.86%	53.65%
		Emission reduction (TCO ₂ /yr)	4.11	4.38	5.67	6.08
		Simple payback period (yrs)	3.48	2.98	1.94	1.68
Closed loop	Heating oil & ASHP	Primary energy savings (%)	49.75%	48.64%	47.50%	46.90%
		Emission reduction (TCO ₂ /yr)	3.75	3.92	5.00	5.31
		Simple payback period (yrs)	4.86	4.17	2.72	2.34
Open loop	Natural gas & ASHP	Primary energy savings (%)	48.42%	46.96%	43.77%	41.93%
		Emission reduction (TCO ₂ /yr)	2.34	2.37	2.74	2.75
		Simple payback period (yrs)	7.23	6.73	5.11	4.73
Closed loop	Natural gas & ASHP	Primary energy savings (%)	42.48%	40.45%	36.03%	33.47%
		Emission reduction (TCO ₂ /yr)	2.05	2.04	2.26	2.19
		Simple payback period (yrs)	10.67	10.00	7.70	7.18

with natural gas systems. In addition, open loop systems have a lower payback period and higher savings compared to closed loop systems, due to their higher efficiency. In all cases, primary energy savings are higher in zone A due to the relatively equal distribution between heating and cooling hours. On the other hand, emissions reduction and payback period present their best results in zone D. This is due to the higher number of heating hours, meaning higher consumption of heating oil or natural gas by the conventional systems, in comparison to electrical energy used by the GSHPs.

Regarding on how different input factors can affect the comparison results, it should be mentioned that an increase of heating/ cooling hours, higher SPF, higher heating oil/ natural gas prices (these prices change frequently throughout the year, thus affecting the payback period calculation) or lower electricity prices and lower installation cost of the GSHP systems or higher installation costs of the conventional systems lead to better comparative results for the GSHPs (installation costs affect only the payback period). Obviously, respective opposite alterations of the input factors lead to comparatively worse results for the GSHP systems. Additionally, it should be mentioned that in case that the comparison examines the replacement of an existing conventional system, then the payback period is higher, since the installation cost of the existing system is not taken into account.

2.4.3. Potential negative impacts from GSHP operation

Any technology (conventional or alternative) that is not properly installed or operated may lead to the creation of negative impacts. This also applies for GSHPs, whose operation can potentially create negative impacts, especially to the local environment; the proper design, installation and use of materials can prevent any potential negative effects from their use. Specifically:

- In the case of a closed system, due to improper installation methods and use of non-certified material there is a minimal possibility that the heat exchanger's operation may fail, or there is a leakage of anti-freezing fluids in the underground [162,163]. The use of certified material equipment and installers eliminates the possibility of this happening.
- The improper design and sizing of the ground heat exchanger may lead a) in the case of an open loop system to the reduction of the underwater supply (due to oversizing of the system) and b) in the case of a closed system to the disturbance of the thermal balance of the soil (due to under-sizing of the system) [30,164]. These issues can be treated through the suitable design of each system.
- GSHPs are one of the most energy efficient systems, between all conventional and RES systems that offer space heating and cooling. However, their operation still relies on electrical energy [96], with

all the impacts that this implies (production of CO₂ emissions, vulnerability to energy supply). The combination of GSHPs with other RES technologies -as described in Section 2.2.3- can lead to the creation of zero energy consumption/ emission heating and cooling systems.

2.5. GSHP market

2.5.1. Global GSHP market

The first installations of GSHP systems took place more than 60 years ago in the United States [20,32,43], while in Europe countries leading the systematic adoption of the technology were Switzerland, Sweden, Germany and Austria [20,60]. During the last 15 years the countries with the largest markets are the United States and Canada in America; Germany, Switzerland, Austria, all the Scandinavian countries and France in Europe [165–172], while in Asia the markets presenting significant growth are Japan, China, South Korea and Turkey [23,56,133,172–174].

According to 2015 data, GSHPs hold world's highest percentage of produced energy and installed capacity among all direct uses of geothermal energy, with 70.95% and 55.3% of global installed capacity and energy consumption respectively [172]. Over time, GSHPs present globally continuous development; the worldwide installed capacity in 1995 was 1854 MWt and had reached 49,898 MWt in 2015 (Table 4) [172]. The number of countries with GSHP installations increased from 26 in 2000, to 33 in 2005, 43 in 2010 and 48 in 2015. The installed capacity corresponds to 4.16 million units of 12 kW (the most common size for American and European households), representing an increase of 50% compared to 2010 [172].

2.5.2. European GSHP market

The latest available report of EHPA states that in 2012, 14% of total heat pump sales corresponded to GSHPs, while between 2006 and 2012 sales of GSHPs in Europe surpassed 100,000 units per year [175]. In addition, according to the most recent reports of EGEC, at the end of 2013 there were 1.3 million GSHP systems installed, corresponding to

Table 4
Data on worldwide use of GSHPs.
Source: [172]

	1995	2000	2005	2010	2015
Installed capacity (MWt)	1854	5275	15,384	33,134	49,898
Produced energy (TJ/yr)	14,617	23,275	87,503	200,149	325,028
Capacity factor	0.25	0.14	0.18	0.19	0.21

17,700 MWt [170,171]. According to EurObserv'ER data [176–180], the overall European GSHP sector has shown a decline during the last years. Some of the largest markets, such as Sweden, Germany, Austria and France, as well as smaller markets such as Denmark, the United Kingdom and Ireland, present a decline in their annual sales. On the other hand, smaller and newer markets such as Finland, Poland and Estonia present a remarkable year to year growth.

The recession of the European GSHP market has specific causes. It is caused due to the general economic recession of recent years and the fact that the GSHP market is connected to the construction of new buildings, which in many European countries is currently at its lowest level [176–181]. Furthermore, the low prices of fossil fuels, which are competitive to GSHP systems lead consumers to choose solutions that are cost effective only in a short term [176,177]. The fact that not all European markets have a common trend –others are developing, others are stagnating and others are declining– is due to the status in each country regarding a) the construction sector, b) the price levels of electricity compared to those of fossil fuels, c) financial incentives and d) legislative and regulatory framework [170,171,179].

2.5.3. Greek GSHP market

Through a study concerning the Greek consumers, it has been found that about 40% of the public knows what geothermal energy is, while about 24% knows that GSHPs can be used for residential heating and cooling [182]. In addition, 8.5% has stated that they had the intention of installing such a heating/ cooling system [182]. Based on another survey, using a sample with higher education and more related to environmental/ technological issues, the knowledge of geothermal energy was found to be approximately 70% [183].

The first pilot residential GSHP vertical closed system in Greece was installed in 1993 [184]. Since then, hundreds of systems have been installed throughout the country. Since there is no official body recording the installed units, aggregated data regarding the status of GSHP installations in Greece are available only through reports presented at the World and European Geothermal Conferences [185–190]. The available information concerning the installed capacity and annual energy output of GSHPs are summarized in Table 5, while it should be noted that in many cases the information presented in these reports is an estimate based on available data.

The Greek GSHP sector presented a remarkable growth in the mid-2000s, with the installation of open and closed loop systems; in addition, seaside hotels operating only during the summer showed interest in cooling their facilities through the use of seawater [187]. According to the latest data, 61% of installed capacity concerns open systems, 30% vertical closed loop systems and 9% horizontal closed loop systems (Fig. 11) [190].

Factors contributing to the industry's increase were a) the increase of oil prices compared to the price of electricity, b) awareness of public and installers of heating/ cooling systems and c) improvement of the licensing process for installation of the systems [187,188].

The development path that the industry followed during the mid-2000s peaked around 2010. Since then, the sector shows a decline due to the economic recession and the stagnation of the construction industry. However, GSHPs are the main contributor to low enthalpy installed capacity, as all other low enthalpy uses show stagnation [188–190]. Moreover, strong competition by natural gas and air source heat

Table 5

Data on Greek GSHP market.
Source: [185–190]

	1999	2004	2007	2009	2012	2014
Installed capacity (MWt)	0.4	4	14	50	100	135
Produced energy (TJ/yr)	3.1	39.1	80	270	486	648
Capacity factor	0.25	0.31	0.18	0.17	0.15	0.15

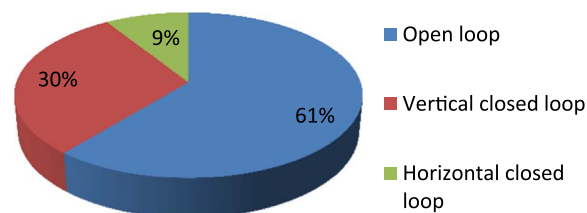


Fig. 11. Types of systems in Greece in 2014, based on installed capacity [190].

pumps is a reason for the sector's recession [189,190]. GSHP market is largely dependent on the construction of new buildings, while air source heat pumps can be installed during a simple renovation of a dwelling [191], have a lower installation cost and require less free space for the installation [96,192]. On the other hand, air source heat pumps are designed in the worst case ambient temperatures, thus having a higher installed capacity compared to GSHPs. Additionally in extreme environmental conditions (either hot or cold) their efficiency is reduced, while in these cases their operation could be also paused. These characteristics lead air source heat pumps to higher electricity consumptions, meaning higher operation cost and CO₂ emissions than GSHPs. Therefore, the factor that provides an advantage to GSHPs compared to air source heat pumps is that they utilize the relatively constant temperature of the soil or water, while air source heat pumps base their operation on the ambient air which presents high temperature fluctuations throughout the year [70,192].

A very interesting aspect presented in the relevant reports is the available financial incentives offered during different time periods for the installation of GSHP systems in Greece. As presented in Table 6, during 2004 and 2009 there was no incentive provided. In recent years (2012 and 2014) the "Energy efficiency at household buildings" program was available for households; very few installations have been materialized through this program, as GSHP installations in existing buildings is relatively complex [190].

2.6. Legislative framework for GSHP systems in Greece

The first mention of shallow geothermal energy was made in the Greek legislation in Law 3175/2003 (GG 207 A') "Exploitation of geothermal potential, district heating and other provisions" [193]. According to this law, the installation of space heating/ cooling energy systems through the exploitation of the heat of geological formations and water (surface water and groundwater), which are not classified as geothermal potential (i.e. do not exceed 25° C) according to the provisions of this law, is allowed through a license issued by the relevant regional administration.

The required documentation and the procedure for issuing a license are described in Ministerial Decree Δ9B,Δ/Φ166/οικ13068/

Table 6

Available financial incentives for GSHP installation.
Sources: [186–190]

Year	Incentives
2004	The state provides no financial incentive for GSHP installation
2007	There is no subsidy for households, but a tax exemption of 200 € is offered. VAT for GSHP equipment is 9%, while for natural gas systems it is 19%
2009	The state provides no financial incentive for GSHP installation
2012	Direct subsidy up to 10,500 € and an interest-free loan or subsidized loan rate up to 4500 € for residential and commercial buildings ("Energy efficiency at household buildings" program), direct grant up to 40% of the investment in hotels ("Green tourism" program), reductions of prices offered by installers ("Building the future" program)
2014	Subsidized loan interest up to 100%, subsidy of the final eligible expenditure, minimum cost coverage for energy inspectors through the "Energy efficiency at household buildings" program

Table 7
GSHP diffusion barriers.

Category	Barriers
Financial	High initial investment cost [18,28,30,36,38,40,48,92,96,98,130,133,136,164,191,195–197,199,201,203,204] Long or uncertain payback period [191,197,201] Inadequate or unclear financing options [196,199,201] The value of the investment is not reflected in the value of the property [201] Landlord-tenant dilemma (who will make the investment?) [199] Due to the long lifespan of the installation (exchanger) it is likely that not only the person that invested in the system will benefit from it (presence of externalities) [28,201]
Technical	Lack of qualified personnel to install and promote systems [43,48,98,133,164,191,196,199,201,203,205] Lack of certification, guidelines and standards for the design, installation and reference data [164,191,199,201,202] Lack of infrastructure for the design and installation of GSHP systems [28,164,196,198] Limited space for installation in urban areas [92,164,191,197,203] Difficult and expensive installation in cases of existing buildings [43,48,164,191]
Institutional, legislative and policy	Regulatory barriers and unsuitable regulatory frameworks [133,191,195,198,200] Unclear requirements in order to receive a grant [199]
Information	Low awareness level of consumers, industry, government agencies and policy and legislation makers on GSHP and/ or their benefits [28,92,96,136,164,191,195,196,199,201,203] Limited availability of objective information about the technology, its costs and benefits [199,201]
Market	Competition with fossil fuels [198] Operating costs depend on the price of electricity [191] Difficulty for consumers accessing technology [201] Due to small market, installation cost may be high [98]

Table 8
GSHP diffusion actions.

Category	Actions
Financial	Providing financial incentives (loans with favorable rates, grants, subsidies, tax reductions, leasing, shared savings, end-use pricing) [19,22,96,98,144,206] Removal of financial barriers [201] Development of financial models through which the installation of geothermal exchangers will be realized by public utility companies (as it is done for example with the electricity poles or gas pipelines), in order to reduce the initial installation cost for the consumer and to take into account that the system may have more than one users during its whole lifetime [28,98,164,201]
Institutional and policy	Development of appropriate regulatory and legal framework (for companies, technology, installation) [131,195,203,206] Creation of a strategic development plan [206] Existence of an institutional body responsible for the overall completion of the licensing process [195] Lower price of electricity when used by GSHP systems [195] Cooperation between public and private actors [191] Development of partnerships in order to create new business models which will reduce the cost of drilling/ trenching [191] Reduction of the necessary documents for licensing to the minimum required [200]
Technological	Establishment of certifications, standards and guidelines for installers, equipment suppliers, maintainers and equipment [29,33,75,92,191,200,206,207] Development and standardization of performance factors (e.g. COP, SPF) [96,144] Development of research and technology [96,144,164] Training of designers, installers and policy makers [19,44,98,191,200,201] Development of infrastructure for design and installation of GSHP systems [28,164] Coordination between installers, designers and other stakeholders, in order to develop efficient and economical systems [201] Planning system installation in entire communities, not just in individual buildings [191] Improvement of technology and installation process in order to reduce the installation cost [19,98,144]
Information	Awareness and information programs on GSHP systems and their benefits [19,92,96,191,201] Collection and evaluation of objective data of the GSHP systems [28,164,191,201] Demonstration/ pilot applications [195] Publication of best practice guides [164] Mapping of GSHP installations [144]

ΓΔΦΠ2488 of 2009 (GG 1249 B') [194]. The decree aims to define the terms, conditions, required documentation and procedure for issuing a license for own use of space heating/ cooling energy systems through the exploitation of the heat of geological formations and water, surface water and groundwater, which are not classified as geothermal potential. In addition, the restrictions which must be taken into consideration regarding the installation and operation of the system are defined. The restrictions concern the borehole drilling or trench opening, the use of surface water or groundwater and the certification

of the pumps and systems.

2.7. Barriers against and actions towards GSHPs diffusion

2.7.1. GSHP diffusion barriers

There are studies that aim specifically on the GSHP sector, regarding factors that hinder the development of the market, as well as the actions that can be performed to encourage the adoption of residential GSHP systems. These studies have been carried out mainly

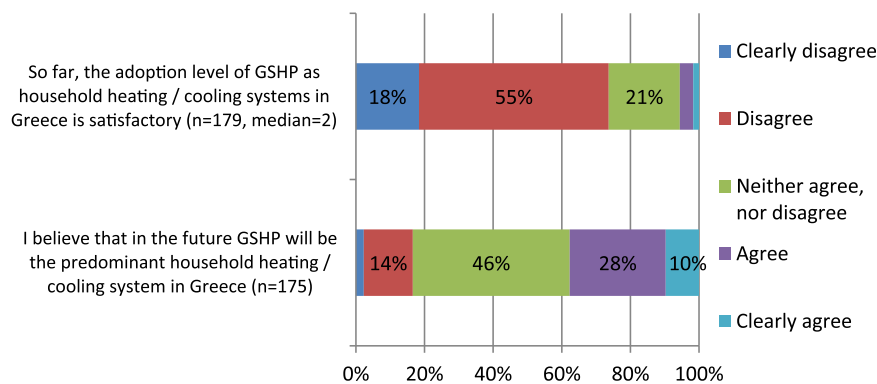


Fig. 12. Perceptions on GSHP systems diffusion levels in Greek residential sector.

for the United States [28,164,191,195–198] and for European countries [131,199,200]. The theoretical classification of identified barriers is presented in Table 7.

Other technical barriers are also reported, which are not met so often in the relevant literature; specifically: a) there is no standard design for the system [196], b) the need for a exchanger significantly increases the complexity, cost and risk of the investment (cost and difficulty in assessing the suitability of each individual installation) [191], c) seasonal variations in the soil's temperature near the exchanger may limit performance [191], d) installers without experience may increase costs in order to take account of the "unknown" costs that the installation process may include [201], e) engineers without experience and specific training tend to oversize systems, thus increasing the cost and reducing the efficiency and effectiveness of the systems [201] and f) lack of new technologies and techniques in order to improve the cost and efficiency of GSHPs [28,202].

2.7.2. GSHP diffusion actions

The actions proposed through the relevant studies for the adoption of GSHP systems can be classified into four categories; financial actions, institutional and policy actions, technology actions and information actions (Table 8).

3. Methodology

In order to study the diffusion barriers and the actions that can increase adoption of GSHP systems, a survey was conducted to collect the views of people specifically involved in the GSHP sector. The collected sample comprised of people whose profession/ interests include GSHP systems; it included individuals that were either working in technical companies that install GSHPs or similar systems, or people that work in academic or research institutions related to the subject.

A questionnaire entitled "Domestic use of Ground Source Heat Pumps in Greece" was developed in order to gather the views of the people active in the GSHP sector regarding diffusion barriers and actions that can encourage the adoption of the technology. The questionnaire consisted of the following five sections:

- Identification details (company/ organization, name, job position)
- Perceptions on GSHP systems diffusion
- Diffusion barriers of residential GSHP systems
- Actions that can boost the adoption of residential GSHP systems
- Criteria for the residential heating system selection

In order to have a representative sample, an analysis of the stakeholders (industry, academia, researchers) involved in the specific sector was performed prior to the conduction of the survey. Having identified the relevant stakeholders, two different methods were applied to achieve the best possible participation in the survey: distribution of a hardcopy questionnaire and electronic distribution

through a mailing list. The distribution of the hardcopy questionnaires was conducted during two scientific workshops relevant to the technology, carried out by the Centre for Renewable Energy Sources and Saving (CRESS). Specifically, it was distributed during the two "Local Forums for stakeholders and MAS" within the GEO.POWER project, which took place in January and May 2012. The electronic distribution of the questionnaire was performed during July and August 2012 through an electronic mailing list created to include individuals and companies of the GSHP sector. In total, 181 questionnaires were collected; during the first workshop 69 questionnaires were collected, during the second one 45, while through the mailing list 67 more questionnaires were gathered.

A database was created from the data collected through the survey. In order to analyze the data, descriptive statistics and Principal Component Analysis were applied. The statistical package SPSS 20 was used in order to perform these analyses.

4. Results

4.1. Descriptive statistics

The participants of the survey were mainly executives from private companies, public bodies and research institutions, as well as freelancers. Regarding the specialties of the respondents, there was representation from a range of scientific disciplines, with the majority being Mechanical and Electrical Engineers. About ¾ (73.7%) of the respondents disagree and clearly disagree that so far, the adoption level of GSHP as household heating/ cooling systems in Greece is satisfactory. On the other hand, 37.7% believe (agree and clearly agree) that in the future GSHPs will be the predominant heating/ cooling system for Greek households (Fig. 12).

Fig. 13 presents the main factors that may hinder the implementation of GSHP systems in households. Based on the results, the majority of the respondents support (agree and clearly agree) that economic factors and awareness issues are the main determinants that affect negatively the diffusion of GSHPs in Greece, namely being: a) inadequate public awareness about the GSHP technology and its benefits (87.8% agrees or clearly agrees), b) economic recession (84.8% agrees or clearly agrees), c) the installation grants/ tax exemptions are insufficient (78.8% agrees or clearly agrees) and d) installation cost (78.8% agrees or clearly agrees).

The actions that are mainly proposed (agree and clearly agree) by the respondents in order to promote the adoption of GSHP systems by Greek households are presented in Fig. 14. It has been identified that the actions that could enhance the installation of GSHP systems in Greek households are the establishment of funding incentives and the organization of awareness and training activities. Specifically, the most widely accepted actions are a) tax exemptions tailored for GSHPs (91.7% agrees or clearly agrees), b) public awareness activities on the technology and its benefits (91.6% agrees or clearly agrees), c)

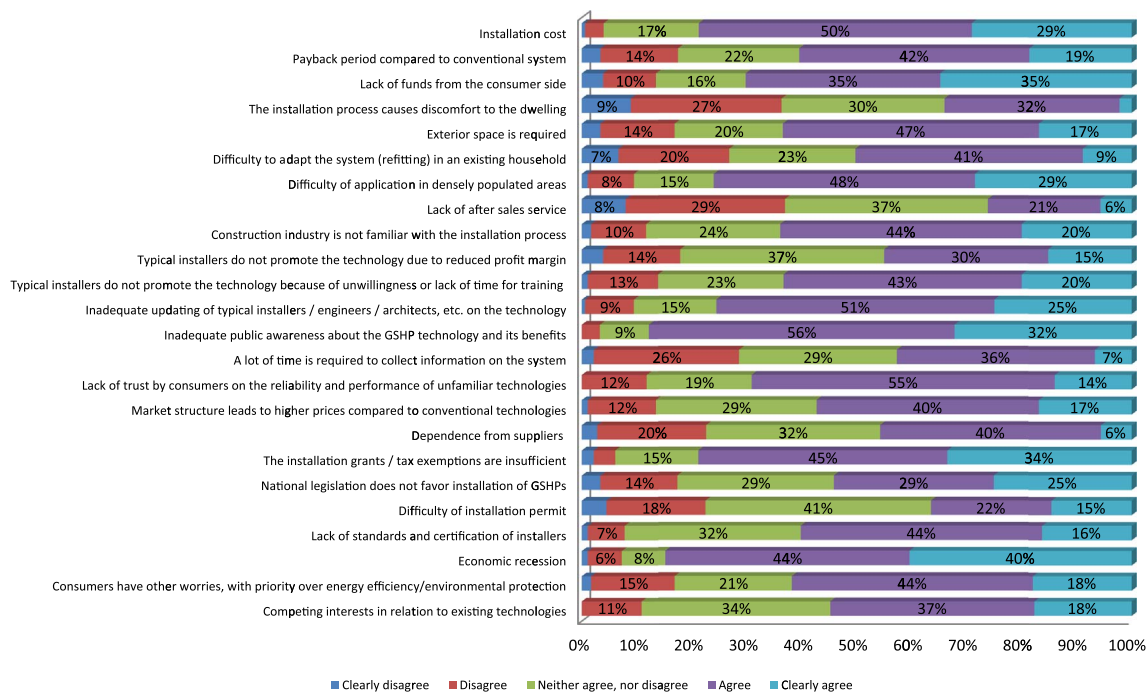


Fig. 13. Diffusion barriers of GSHPs as residential heating/ cooling systems (n=175–180).

organization of educational activities for installers (91.6% agrees or clearly agrees), d) more installations of demo sites in governmental buildings (90.5% agrees or clearly agrees) and e) legislation and policies that will accelerate the use of RES by residential users (90.5% agrees or clearly agrees). It should be mentioned that the agreement level on the possible actions is so high, due to the fact that the respondents are people involved in the GSHP technology sector.

4.2. Principal Component Analysis

4.2.1. Theoretical framework

Principal Component Analysis (PCA) is used in order to categorize the main diffusion barriers of GSHP systems in the Greek domestic sector, as well as actions that can contribute to their adoption. At first, the methodology used for the analysis concerning the diffusion barriers is presented in detail, followed by the presentation of the analysis concerning the actions that can contribute to the adoption of GSHP systems.

PCA is a data reduction technique which uses basic mathematical

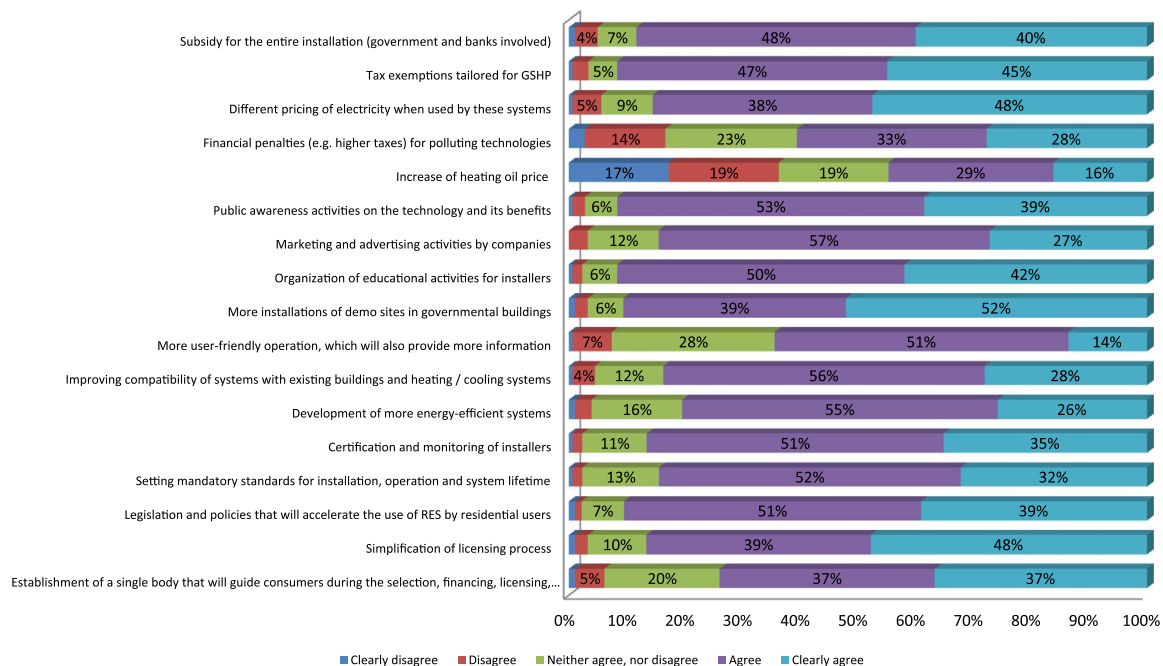


Fig. 14. Actions proposed to remove the diffusion barriers of GSHPs as residential heating/ cooling systems (n=177–180).

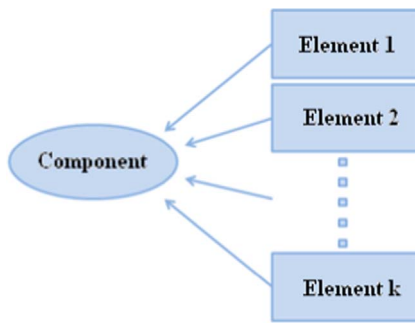


Fig. 15. Conceptual illustration of PCA. Based on [211].

principles in order to reduce the number of observed variables to a smaller number of principal components which include the largest portion of the variance of the observed variables [208–210]. A conceptual illustration of PCA is presented in Fig. 15, where a) the oval shape represents a non-observed factor at the population level, b) the rectangles represent observed variables in the sample level and c) arrows represent causal paths [211]. Objectives of a PCA is to a) extract the most important information from the data, b) compress the size of the data keeping only the essential information, c) simplify the description of the data set, and d) analyze the structure of the observations and the variables [212,213].

The basic mathematical expression of PCA is $Y=XB$ [210], where:

- Y is the observed variables matrix;
- X is the components scores matrix;
- B is the eigenvalues matrix.

In many cases the PCA is mistakenly considered as a subcategory of Exploratory Factor Analysis (EFA), as they often give similar results. The conceptual difference between PCA and EFA is that the first analyzes variance, while the second analyzes covariance [214]. Whether someone chooses PCA or EFA should be decided before the conduction of statistical analysis, as it is inappropriate to perform PCA and EFA on the same data [210]. Practically, this means that when someone wants to analyze variables arising from a theoretical framework that has been based on previous research regarding relations between the variables, EFA must be used (thus examining only covariance, and excluding variances). On the other hand, when the aim is to investigate whether there are patterns in the data, without relying on a previous theory it is more logical to perform a PCA (thus, taking into account variances) [215]. This is why PCA has been selected in this case.

4.2.2. Analysis steps

While conducting a PCA, important decisions must be taken regarding the suitability of the sample, the fitness of the variables included in the model, the number of components that will be accepted in the model, the method of rotation used and the interpretation of the results [216–223]. The steps required for the conduction of a PCA are

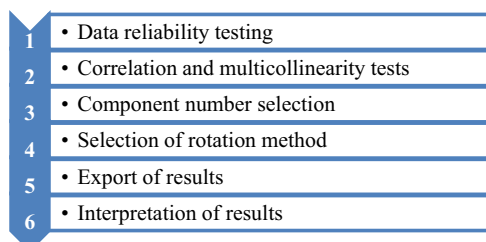


Fig. 16. Overview of the steps of a PCA.

presented in Fig. 16. It should be noted that the development of a model is not a linear process. This means that some of the steps of the analysis may be repeated, in order to conclude to a model that meets all the required criteria. For example, correlation and multicollinearity tests may reveal that some variables are problematic for the developed model. This means that the analysis should be repeated, with the problematic variables being removed.

4.2.3. Model for variables concerning diffusion barriers of GSHPs

4.2.3.1. Sample size and reliability of sample. Variables included in a PCA must a) be at least interval [224], b) follow, generally, a normal distribution [225,226] and c) not have outliers [226]. In this study the variables are ordinal; although PCA is commonly -but improperly- performed on ordinal data, the appropriate method that should be applied in these cases is Categorical PCA (CatPCA), which is the non-linear equivalent of PCA [227]. In CatPCA variables are analyzed using the principal components model, and at the same time the ordinal categorical data are transformed into quantitative data by the technique of optimal scaling [228]. In the present study, the numeric valued transformed variables (transformed by assigning optimal scale values to the categories) [227] produced through the CatPCAs (spline transformations) were used as input to the PCAs in order to perform the appropriate rotation methods (rotation is not available in SPSS for CatPCA).

When conducting a PCA, the sample size must be taken into consideration as the correlations are not resistant [229], meaning that the reliability of the analysis can be significantly affected [226,230]. The rule of thumb regarding the sufficiency of the sample size suggests that the ratio of observations to variables should be 5:1 or higher [219], with the number of variables taken into consideration being the initial number of variables of the study, and not the number of variables included in the model [214]. In this study the sample size is $n=162$, while the selected method to treat missing values was "exclude cases listwise". This method may lead to the reduction of the sample on the one hand [231], but on the other hand it helps to avoid any over-estimation of the data [214]. In addition, the study includes 27 variables, leading to a 6:1 ratio which is within the limits set by the rule of thumb.

A choice provided by SPSS in order to control the sample size is the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy. The sample is satisfactory when the KMO value is higher than 0.50 [224,226,232,233]. In the analysis of the variables concerning diffusion barriers of GSHP, the value of KMO is $0.737 > 0.50$ (Table 9).

The next step is to test the correlation and multicollinearity that may exist between the variables. The variables should correlate, but not on a very high level, as this would create difficulties in determining the contribution of the variables in each component [226]. The correlation is examined through the Bartlett's test of sphericity, with values lower than 0.05 [226] being accepted in order for the model to present patterned relationships [233]. In order to examine the existence of multicollinearity in the model, the determinant of correlation matrix is used. Values of the determinant of correlation matrix higher than 0.00001 indicate absence of multicollinearity in the model [226,233].

Table 9
KMO and Bartlett's tests.

	Diffusion barriers of GSHPs	Diffusion actions for GSHPs
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.737	0.751
Bartlett's Test of Sphericity	0.000	0.000

Table 10

Diffusion barriers of GSHPs: Part of the SPSS results regarding the Anti-image correlation, derived from the "Anti-images" table.

Exterior space is required	0.546 ^a	−0.174	−0.379	0.018	0.191	−0.046	−0.113
Difficulty to adapt the system (refitting) in an existing household	−0.174	0.669 ^a	−0.085	−0.249	−0.097	−0.047	0.178
Difficulty of application in densely populated areas	−0.379	−0.085	0.691 ^a	0.024	−0.117	0.144	−0.061
Lack of after sales service	0.018	−0.249	0.024	0.775 ^a	−0.131	−0.251	−0.121
Construction industry is not familiar with the installation process	0.191	−0.097	−0.117	−0.131	0.775 ^a	−0.304	−0.272
Typical installers do not promote the technology due to reduced profit margin	−0.046	−0.047	0.144	−0.251	−0.304	0.795 ^a	−0.153
Typical installers do not promote the technology because of unwillingness or lack of time for training on new systems	−0.113	0.178	−0.061	−0.121	−0.272	−0.153	0.814 ^a

In addition, in order to check whether the sample is appropriate, all diagonal elements (with the exponent "a") of the Anti-Correlation matrix should have values greater than 0.50 [224,226,233].

Indeed, after removing from the present analysis some variables that created multicollinearity issues, the Bartlett's test indicated that there are patterned relationships between the variables ($p < 0.001$) (Table 9), the determinant of the R-matrix > 0.00001 that there is no multicollinearity problem, while all elements of the Anti-Correlation matrix have values over 0.50, with the majority of the values being higher than 0.70 (Table 10).

4.2.3.2. Component number selection. An important step in conducting a PCA is the selection of the number of components comprising the final model. Criteria for this choice are the following [219,226,231,234–236]:

- Kaiser Criterion, according to which all components with eigenvalue over 1.00 are included in the model;
- The Scree Plot;
- The selected components should explain 60–70% [209] of the variance;
- The values of the communalities should not be too low;
- The fact that a component with less than three variables may be considered weak and unstable;
- The components should be interpretable.

After some testing, the model that combined in the most appropriate way the above criteria was selected for the interpretation of the variables concerning the diffusion barriers of GSHPs. The model comprises of four components and is presented in Table 11.

4.2.3.3. Selection of rotation method. The next step is to check whether the selected rotation method is the most appropriate one. Rotation in PCA is a process in which the dimensions (axes) of the components originally exported are rotated in order to simplify and clarify the structure of the data, thus improving the interpretation of the results [219,224,237–239]. In other words, the purpose of selecting the appropriate rotation method is to achieve "simple structure" [240]. This concept has been summarized by Bryant and Yarnold [238] as: "the situation in which a variable load is close to 1 (in absolute value) or close to 0 in one factor. Variables with a load close to 1 are clearly important for the interpretation of the factor, and variables with load close to 0 are clearly insignificant. Thus, simple structure simplifies the interpretation of the factors".

The orthogonal rotation methods (SPSS 20: varimax, equamax, quartimax) assume that the components are uncorrelated, while the oblique methods (SPSS 20: direct oblimin, promax) that they are correlated [219,239]. In social sciences it is expected to have a certain relationship between the components (as variables based on behavior rarely function independently), therefore oblique rotation theoretically

gives more accurate results [211,219,226]. Moreover, even if the theory indicates that the components are independent, this should be confirmed on an empirical level, through the use of oblique rotation [211]. This is why this analysis uses oblique rotation, and specifically the "direct oblimin" method. It should be noted that all oblique rotation methods tend to produce similar results [218], while in the cases that the components are actually uncorrelated, orthogonal and oblique rotation give identical results [219].

On a practical level, in order to control whether the chosen rotation method is appropriate, the produced factor transformation matrix is used. Specifically, if using an orthogonal rotation method leads to data that are outside the diagonal of the table that are not almost symmetric, then an oblique rotation method should be used [233]. Since this is the case in the specific analysis, the oblique rotation method is selected as the most appropriate one.

4.2.3.4. Extraction and interpretation of results. The absolute value below which the load factors in each component are not being accepted, which in relevant literature is defined as "cut-off point", plays a significant role for the results' interpretation. In order to have findings with practical value, for a sample size of 150 observations an acceptable cut-off point is equal to 0.45, while for a sample with 200 observations the cut-off should be equal to 0.50 [241]. In the specific analysis a cut-off point of 0.45 is selected, as the sample has 162 observations (taking also into consideration the "missing values" management method).

Through this analysis, and based on the methodology described above, diffusion barriers can be classified into four components: "market and information barriers", "regulatory and financial barriers", "installation barriers" and "siting barriers" (Table 11). Each variable has an absolute value greater than 0.50; it is also important that each variable has a value within these limits in only one component (with the exception of "lack of after sales service" variable), thus contributing to the achievement of the "simple structure" [240].

The last column of Table 11 presents the communalities values (h^2). Each one of these values shows the percentage of variation explained by the four components for each specific variable [215]. For example, 72.3% of the variance of the variable "typical installers do not promote the technology because of unwillingness or lack of time for training on new systems" is represented by the four components of the analysis. In social sciences, typical values for communalities are between 0.40 and 0.70, as it is difficult to achieve values greater than 0.80 in analysis of real data [219].

The last line of Table 11 displays the percentage of variance that each component represents [215]. This last value indicates the total percentage of variation that is interpreted by the specific model. This means that this model represents 55.67% of the variance. The total variance explained indicates how much of the variability of the data is described by the exported components. An acceptable limit of variation explained by a model is in a range between 60–70% [209].

Table 11
Classification of diffusion barriers.

	Component				h ²
	1	2	3	4	
MARKET & INFORMATION BARRIERS					
Typical installers do not promote the technology because of unwillingness or lack of time for training on new systems	0.797				0.723
Construction industry is not familiar with the installation process	0.790				0.646
Typical installers do not promote the technology due to reduced profit margin	0.752				0.629
Inadequate updating of typical installers/ engineers/ architects, etc. on the technology	0.728				0.660
Inadequate public awareness about the GSHP technology and its benefits	0.538				0.605
Lack of after sales service	0.501		0.586		0.637
REGULATORY & FINANCIAL BARRIERS					
The installation grants/ tax exemptions are insufficient		0.774			0.606
National legislation does not favor installation of GSHPs		0.720			0.591
Installation cost		0.637			0.443
Lack of standards and certification of installers		0.552			0.442
Payback period compared to conventional system		0.539			0.346
Economic recession		0.523			0.394
Difficulty of installation licensing		0.505			0.379
INSTALLATION BARRIERS					
Difficulty to adapt the system (refitting) in an existing household			0.723		0.563
The installation process causes discomfort to the dwelling			0.664		0.464
SITING BARRIERS					
Exterior space is required				-0.774	0.736
Difficulty of application in densely populated areas				-0.721	0.599
% of variance explained by each component	22.57	13.87	11.15	8.08	55.67

4.2.4. Model for variables concerning diffusion actions of GSHP

The same procedure -conduction of Categorical PCA and use of produced numeric valued transformed variables as input for rotation through PCA- was also used for the analysis of the variables concerning diffusion actions of GSHPs. In this analysis there are $n = 171$ observations, while the number of variables is 17, leading to a ratio of 10:1, with the value of KMO being $0.751 > 0.50$ (Table 9). In addition, after removing some variables that were found to create multicollinearity issues, Bartlett's test indicates a pattern relationship between the variables ($p < 0.001$) (Table 9), the determinant of the R-matrix > 0.00001 shows that there is no multicollinearity issue, while all the elements of the Anti-Correlation table have values over 0.60 with the majority of the values being higher than 0.75 (Table 12). The rotation method selected was again "direct oblmin", while the cut-off point for load factors was 0.45.

Based on this analysis, the actions for the diffusion of GSHP systems in Greek households can be categorized to: "regulatory and technology improvements", "financial incentives" and "awareness activities" (Table 13). Each component includes at least three variables, with each variable having an absolute value greater than 0.54. It is also important that each variable has a value within these limits in only one component, which contributes to the achievement of "simple structure". As indicated in the last row of Table 13 this model represents 80.85% of variance.

5. Discussion

The use of GSHP systems in the Greek residential sector can clearly offer financial and environmental benefits. The environmental benefits are applicable immediately, through the reduced CO₂ emissions of GSHPs. Economic benefits are achieved through low operation cost, due to the payback of the installation cost in a short/ medium time period. Based on the comparison performed in the present study, it is indicated that a GSHP system needs 1.5–5 years to cover the higher installation cost compared to a heating oil/ conventional cooling system and 4.5–10.5 years compared to a natural gas/ conventional cooling system. After reaching the break-even point, the use of GSHPs leads to clear economic profits. The application of open loop systems leads to higher environmental benefits and lower payback periods; however, the installation of this type of GSHP system depends on availability of resources and regulation restrictions. In addition, the comparative analysis shows that the installation of GSHPs in the colder areas of Greece (with more heating requirements) presents the highest environmental benefits and lowest payback periods. Still, the differences with the hotter areas are not so great, as these areas balance the total energy needs due to higher cooling requirements.

The abovementioned economic benefits are related to the end-user of the system. However, the installation process and equipment manufacturing of GSHPs can contribute to wider economic and social benefits on a national level, such as employment creation, industry development, increased competitiveness and reduction of imports (as presented in Section 2.4.1). These impacts are especially important for

Table 12
Diffusion actions for GSHPs: Part of the SPSS results regarding the Anti-image correlation, derived from the "Anti-images" table.

Subsidy for the entire installation (government and banks involved)	0.672 ^a	0.036	−0.143	0.191	0.298	0.007	0.031
Tax exemptions tailored for GSHPs	0.036	0.610 ^a	−0.987	−0.020	0.016	−0.011	0.228
Different pricing of electricity when used by these systems	−0.143	−0.987	0.605 ^a	0.008	−0.056	0.013	−0.229
Marketing and advertising activities by companies	0.191	−0.020	0.008	0.751 ^a	0.014	−0.020	0.040
Organization of educational activities for installers	0.298	0.016	−0.056	0.014	0.609 ^a	−0.216	0.017
More installations of demo sites in governmental buildings	0.007	−0.011	0.013	−0.020	−0.216	0.920 ^a	0.003
Development of more energy-efficient systems	0.031	0.228	−0.229	0.040	0.017	0.003	0.933 ^a

Table 13
Classification of diffusion actions.

	Component			h ²
	1	2	3	
REGULATORY & TECHNOLOGY IMPROVEMENTS				
Setting mandatory standards for installation, operation and system lifetime	0.990			0.976
Certification and monitoring of installers	0.990			0.976
Improving compatibility of systems with existing buildings and heating / cooling systems	0.990			0.976
Development of more energy-efficient systems	0.801			0.639
Legislation and policies that will accelerate the use of RES by residential users	0.691			0.918
FINANCIAL INCENTIVES				
Different pricing of electricity when used by these systems		0.949		0.889
Tax exemptions tailored for GSHPs		0.946		0.885
Subsidy for the entire installation (government and banks involved)		0.896		0.803
AWARENESS ACTIVITIES				
Public awareness activities on the technology and its benefits			0.537	0.683
Organization of educational activities for installers			0.913	0.833
More installations of demo sites in governmental buildings			0.807	0.642
Marketing and advertising activities by companies			0.699	0.482
% variance explained by each component	34.76	26.39	19.70	80.85

Greece, due to the recent years' financial situation. Thus, in order to maximize the potential benefits that the GSHP sector can offer, emphasis should be given on the development of the sector dealing with the manufacturing of equipment used in a GSHP system. The financial support of research and development of the relevant sector can contribute to this direction.

Despite the several advantages that GSHPs can offer - thus compensating any potential negative impacts, their adoption level in the Greek residential sector is still low level. However, opportunities for their further diffusion are available, thus contributing to the achievement of the final goal of sustainable development. The identification and classification of the most significant barriers that hinder the technology's adoption can contribute to their lifting, through the selection and implementation of the appropriate diffusion actions.

According to the opinion of people involved in the Greek GSHP sector, financial barriers are the main reason for the low penetration of GSHP systems. Specifically, high investment cost compared to conventional heating/ cooling and DHW technologies is the most significant obstacle for GSHP adoption by consumers; this finding is consistent with results of several previous studies in different countries (Table 7). At the same time, the recent years' financial recession creates a further difficulty of fund raising by consumers, thus adding to the problem of high initial installation cost; besides, the specific barrier has been pointed out as one of the main factors of the GSHPs market stagnation during the last years [176–181]. The above barriers act in combination with the absence of financial incentives (subsidies, tax exemptions etc.) in Greece concerning the installation of GSHP systems, as recorder in Table 6. The development of financial-oriented actions is the key to the diffusion of this technology in the residential sector. The creation of a funding scheme (state and banks involved) in order to subsidize the installation as well as the development and establishment of a tax exemption system tailored to GSHPs can mitigate the effect created by the high installation cost of the system and the difficulty that consumers have to raise funds.

The payback period of the system is directly related to installation and operation costs of the GSHP and the conventional systems. The differentiation of electricity pricing (e.g. use of reduced night-tariff through the whole operation time of the system) for GSHP systems can also reduce the negative effect of the high installation cost, through the reduction of the payback period of the system.

According to the findings of the present study, major obstacles against the diffusion of the technology are the low awareness level of installers/ engineers/ architects, etc. and the lack of public awareness of the technology and its benefits. In order to contribute to the removal of the aforementioned barriers, actions focusing on public awareness and awareness of the installers, engineers etc. should be performed. In this context, appropriate actions are the organization of public awareness activities on the technology and its benefits (by public bodies, research centers, dissemination projects etc.), educational activities for installers and creation of more demo sites mainly in governmental buildings. The education and proper information of heating/ cooling system installers and sellers is critical on this aspect, as they can influence the decision of consumers during the heating/ cooling system selection process.

Another category of barriers involves the installation process, and specifically the difficulty to adapt the system in an existing household, as well as the discomfort that the installation process causes to the dwelling. Improvements are made in order to make easier the installation of such systems in already constructed buildings, for example through the development of new drilling methods. In addition, technological progresses (e.g. improvement of heat pumps) are made in order to increase the compatibility of GSHPs with the existing heating distribution systems, thus dealing with the disadvantage of GSHPs of not being easily installed in existing buildings.

The regulatory framework concerning GSHPs in Greece has been improved during the last years. However, further modifications can be made that will enhance the diffusion of the technology. For example, changes on the installation specifications (reduction of distance from elements such as neighboring buildings of different ownership, underground main pipelines etc.) of the system can contribute to the removal of the barrier concerning the difficulty of applying the GSHP technology in densely populated areas. In addition, regulatory improvements that can lead to the further market diffusion of the technology are the clear separation of the licensing procedure of open and closed systems, the simplification of the license issuing of the installation of closed loop systems and the expansion of the possibility of exploiting surface water through GSHP systems.

6. Conclusion

The aim of this study was to investigate the barriers that hinder the diffusion of GSHP systems in the Greek residential sector, as well as the actions that can stimulate their adoption. In order to achieve this, the views of people activated in the specific sector were examined. The diffusion barriers of GSHP systems were classified into four categories through the use of Categorical PCA, namely market and information barriers, regulatory and financial barriers, installation barriers and siting barriers. In addition, diffusion actions required for disseminating GSHPs were grouped into regulatory and technology improvements, financial incentives and awareness activities. The appropriate actions are required in order to overcome the diffusion barriers of the technology, thus improving its competitiveness and market penetration and therefore benefiting on an economical and environmental level from their use.

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