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The use of geothermal energy for buildings refurbishment in Europe - technologies, success stories and perspectives*

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Abstract: *The paper presents a large overview on the different technologies available for the use of the geothermal energy, as well as their combination with classical technologies (CHP) in view of reaching the best possible primary energy efficiency for refurbished buildings. The case studies within the paper provide information on technical and economic aspects. The paper also highlights several important administration and financial issues that must be dealt with in order to facilitate a wider spread of the geothermal energy use.*

Key-words: geothermal energy, heat pumps, seasonal performance factor, buildings refurbishment, energy performance certificate.

1. Introduction

Currently, Geothermal energy sources provide more than 15 GW_{th} for heating and cooling in the European Union, equivalent to more than 4 Mtoe per year, whereby geothermal Heat Pump systems contribute to the largest part. The potential is huge. The geothermal resources can be used virtually anywhere for residential and tertiary sectors, but also in the industry providing high temperature heat (200-250°C).

Following the current trends, within EU-27, the 2020contribution will amount to around 40 GW_{th} installed capacity, corresponding to about 10 Mtoe.

The technological challenges are to develop innovative solutions for refurbishing the existing buildings, using system which are easier to install and more efficient at low temperatures.

The quantitative development of the European geothermal market in the next ten years is expected to be fuelled mainly through the introduction and consolidation of the shallow geothermal systems, with a quite mature market in Sweden and Switzerland and developing markets in Austria, Germany and France (Figure 1).

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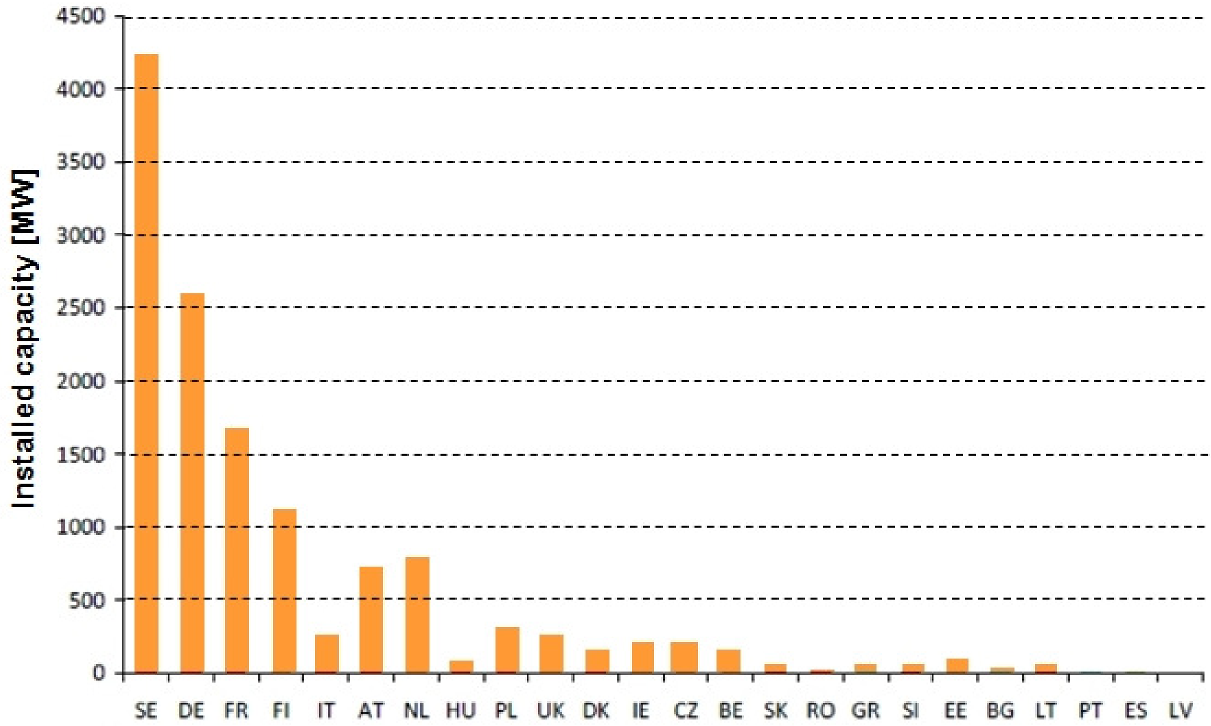

Figure 1 - Shallow geothermal heating capacity in Europe [1]

In other emerging European markets, a high growth is possible and it is expected over the next years (Italy, France, Spain, UK, Hungary, and Romania). Mature market countries (namely Sweden and Germany) will experience a steady increase, mainly stimulated by sales in the renovation segment, but all the other countries will experience a significant growth too.

The fast development for geothermal heat pumps illustrates how shallow geothermal energy resources, previously often neglected (before 2006), have become very significant, and should be taken into account in any energy development scenario until 2050 (Figure 2).

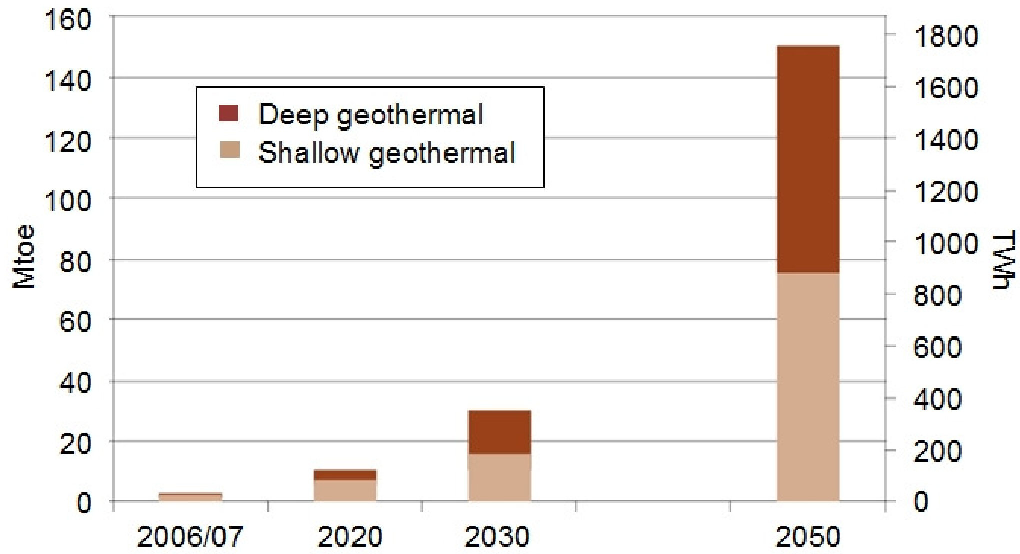

Figure 2 - Heating potential of geothermal energy in Europe [2]

The deep geothermal market is also increasing in Europe, summarising presently 216 systems of 4,900 MW_{th} capacity. Used mainly in district heating applications, it replaces successfully the old and inefficient equipment which runs on fossil fuels. Iceland has the most developed market among the European countries due to favourable hydro-geological conditions; with more than 2000 MW_{th} installed capacity (Figure 3).

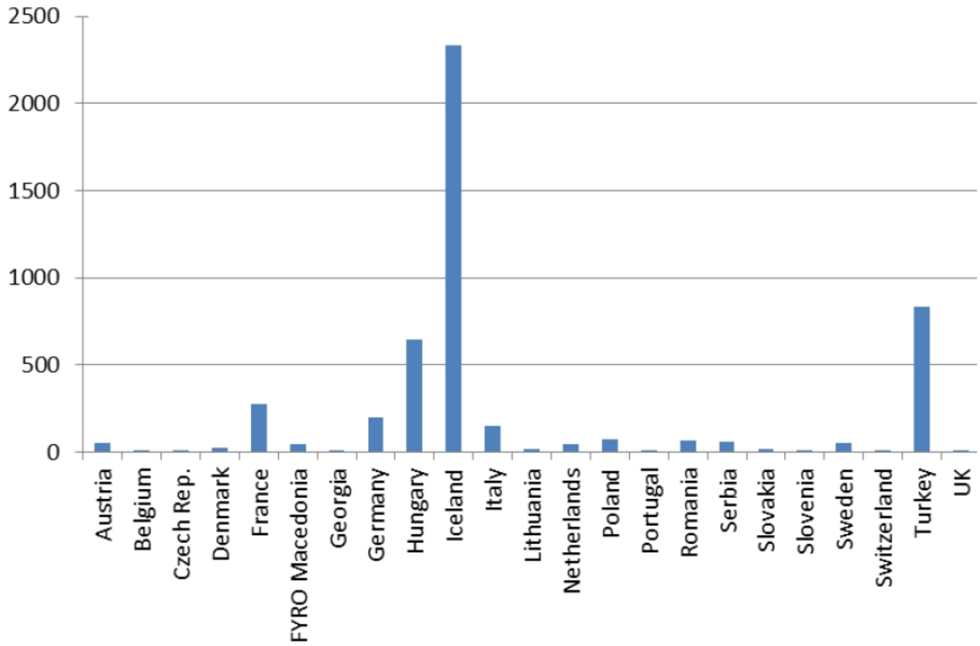

Figure 3 - Installed capacity [MW_{th}] of deep geothermal DH applications in Europe [3].

The ground source heat pump (GSHP) technology is suitable for small, individual houses as well as larger multi-family houses or groups of houses, with capacities ranging from under 10 kW_{th} to over 500 KW_{th}. The depths of geothermal heat exchange ranges from a few meters to more than 200 m, depending upon the used technology, the geological situation, the demand profile, and other design considerations. For space cooling, in certain regions with moderate climate, direct cooling from the ground via cooling surfaces (ceilings, walls, floors) or other equipment is possible, allowing space cooling with minimum energy input. In warmer regions with higher cooling demand, the heat pump can be used in cooling mode.

For well-insulated houses with a forced ventilation system, the geothermal energy can contribute to pre-heating or pre-cooling the fresh air while it passes through intake pipes buried in the ground.

Another geothermal technology useful for a broad domain of applications is the underground thermal energy storage (UTES). Heating and/or cooling can be provided by using underground (aquifers, boreholes, basins, caves, pits etc) as a seasonal storage. For thermal balanced applications (the excessive heat or cold produced in one season matches the demand plus losses in the next exploitation season) UTES proves to be highly efficient. When the heating and the cooling demand do not match, additional equipment has to be used, preferably RES. In most of the cases, UTES is used in combination with CHP or solar collectors for mainly heating applications and with surface water or cooling towers for mainly cooling applications. Temperatures vary from 7°C for cold storages up to 90°C [4] for warm storages. In particular UTES at 40-90 °C can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by periods of inactivity.

Whilst the number of geothermal heat pumps with a capacity below 50 kW crossed the threshold of 1 million units in 2010, the geothermal heat pumps are already used in Southern Europe (Figure 4).

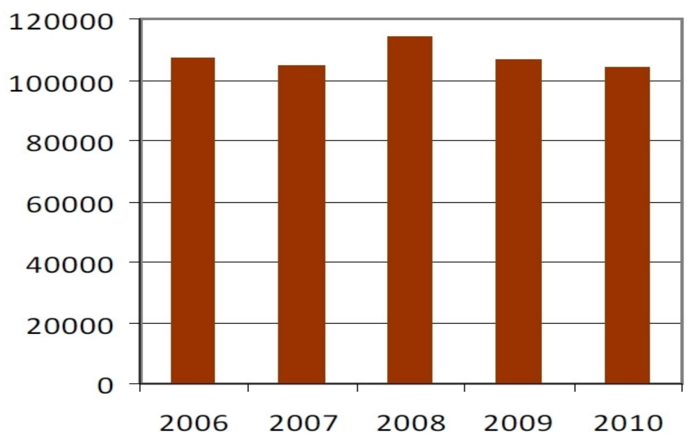

Figure 4 - Number of HP units sold per year according to HP Barometer (2011)

Further R&D and practical experience is crucial to fully exploit the advantages of geothermal heat pumps in warmer climates in supplying heat and cold from one single installation.

Success Stories

The year 2011 has shown a stable GSHP market at the European level. The economic and financial crisis had an impact on the GSHP market especially for the residential sector and in the most mature markets like Sweden, Germany and France. Losses here could be balanced by sales increase in emerging markets such as the UK and the Mediterranean countries. The increase there can be explained by the high potential for this technology and by the low number of installations already in place. The market is developing all over Europe and for all kinds of sectors: residential, tertiary and industrial (in the latter, in the form of UTES).

The hottest market

The highest number of units is still found in the Northern countries. Sweden has been dominating the market for over the last 30 years, and the growth is continuing, but at a lower rate. Finland and Denmark are also important markets for GSHP, as is the non-EU-country Norway.

It is also in the Nordic countries that the largest single installations can be found, with hundreds of borehole heat exchangers.

In Sweden, some signs of saturation can be seen, and a substantial share of new heat pumps (about one quarter) goes into the replacement of older units, and not in new installations. This follows the trend towards “re-powering”, as in other RES sectors. However, with increased efficiency of new heat pumps, existing ground coupling installations might have to supply a higher share of the useful energy, and thus need to be checked and adapted.

In Western Europe traditional, growing markets exist in France, Germany and Austria, and of course in Switzerland. In Germany, after a strong increase until 2008, the number for new GSHP is decreasing slightly; in France, the increase is still visible, and currently France, as the later starter, is on its way to overtake Germany in terms of total number and heat production. On the other hand, GSHP played a major role in the market for heating in new buildings in Germany over the last years. While the number of new constructions went down, the share of GSHP increased strongly, reaching a high of almost 14% of all new residential houses in 2009 and 2010.

Regarding UTES, Sweden and The Netherlands are the two main markets for these applications, with smaller numbers in other countries such as Belgium and Germany.

New entrants

The UK, The Netherlands, Belgium, Poland, Italy and Spain are today the fastest increasing markets for GSHP. Some specific problems hinder the success in UK: one reason is more technical, concerning the traditional construction methods and the lowduty electricity distribution in older districts. The other reason is purely political and has a name, Renewable Heat Incentive (RHI). The RHI was originally a good idea and very welcome, but was then postponed and potential GSHP owners waited for a decision. The RHI still is not in force for the residential sector, and the proposals being discussed today are not encouraging.

Beside the countries listed above, smaller, but interesting markets exist in the Baltic countries and in Central and South-eastern Europe. The plant with the largest number of borehole heat exchangers (BHE) in Europe will be constructed in 2013 in the framework of ELI, the European Extreme Light Infrastructure project. The ELI Nuclear Physics Facility under construction in Măgurele, Romania, will be cooled by more than 1000 BHE!

Figure 5 – ELI-NP Building in Magurele, Romania, supplied by more than 1000 BHE, impression of Hachiko (2011)

Shallow geothermal heating and cooling is no longer exotic. The number of GSHP has increased steadily over the years, and the technology is well understood.

For residential houses, GSHP are already a routine in a number of countries. However, in total only a small portion of the potential of shallow geothermal energy is as yet in use in Europe.

There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. In several countries a market-driven economy exists already, and might be boosted further by increasing fossil fuel prices. The use of GSHP for commercial applications can yield economic and environmental advantages. In particular, in cases where heating and cooling is required, the ground as heat source and sink can act as a kind of seasonal buffer storage.

The size of individual GSHP units ranges from about 5 kW_{th} for residential use to large units of over 500 kW_{th} for commercial, institutional and industrial installations. A number of huge plants in the MW_{th} range, typically using some UTES systems, highlight the technical opportunities of shallow geothermal. In Northern and Western Europe, most units are sized for the heating load and are often designed to provide the base load with peaks covered by fossil fuel in larger installations. With more new plants in Southern Europe, also the opposite appears: GSHP sized for meeting the (smaller) heating demand, and additional cooling machines for covering the peak cooling demand.

Some very interesting examples of larger installations in warm climate have been built in the last few years, among them a furniture retail building in Jerez de la Frontera in Spain, were the heat demand was only 1.8 % of the cooling demand. Using innovative approaches including seasonal and diurnal cold storage, a share of about 13% of the cooling demand could be met with the GSHP even under these imbalanced conditions.

Figure 6 - Furniture retail building in Jerez de la Frontera, Spain, using GSHP predominatly for cooling.

Also "water-loop" GSHP, consisting of a larger number of small heat pumps for heating and cooling working on a single water pipeline, coupled with a BHE or groundwater wells and air coolers have been constructed in the Mediterranean region; the largest example with 208 BHE is located in Istanbul.

In global terms, the EU is one of the main regions using GSHP technology. At the end of 2012, the number of units was estimated at nearly 1.1 Million, representing an installed capacity in the order of 13,000 MW_{th}.

Sweden alone has more than 380,000 units running by the end of 2012, with a capacity of almost 4,000 MW_{th}. Germany still ranks second in the EU, with about 260,000 units installed at the same time. In France, the GSHP market in 2012 is estimated at over 15,000 new units, bringing the total number of geothermal heat pumps installed to about 180,000. According to AFPG, the French Geothermal Association, with 118.5 MWth installed in 2011, the total installed capacity in the country is estimated to be 1,850 MWth, while the annual production from GSHPs amounts to 2,800 GWh. During the year 2012, the geothermal heat pump market in Europe exceeded the threshold of 100,000 units sold annually for the sixth consecutive time. Projections with regard to heat production are really positive.

If the sector for geothermal heat pumps keeps growing at the rate of about 15% per year until 2020, it could achieve a cumulative capacity of ca. 40,000 MWth.

Perspectives

Shallow geothermal systems consist mainly of the devices for exchanging heat with the underground and the components to make this heat available for use in the building, like the heat pump and conventional heating and HVAC (Heating, Ventilation & Air Conditioning) equipment. The heat pump as such is covered in the Cross Cutting research priorities. Any progress in HVAC components (better efficiency, lower cost, adaptation to temperatures delivered by geothermal systems) will also benefit the overall geothermal system. Specific R&D for geothermal heating and cooling in the residential sector thus mainly concerns ground-coupling technologies.

The performance of geothermal heat pump systems improved substantially since their introduction in Europe in the 1970's. The first plants were installed in Sweden, Germany, and Switzerland, used for heating only. In these regions the typical efficiency, expressed as Seasonal Performance Factor (SPF), increased from below 3 in the 1980's to well above 4 today, and with continued R&D, average values in the order of 5 seem feasible for 2020.

Component efficiency improvement: The most popular ground-coupling technology is the borehole heat exchanger (BHE); a good efficiency of a BHE results in a small temperature loss between the ground and the fluid inside the BHE. This temperature loss is controlled by the borehole thermal resistance which could be reduced by more than 40 % over the last ten years. The impact of his value to a defined shallow geothermal system is given by the Hellström-efficiency, which increased from below 60 % to about 70 % in state-of-the-art installations over the past 10 years. There is still room for improvement, so provided the technology progress is continued, efficiencies of about 80% in 2020 seem achievable.

The cost shows a steady reduction in the last decades. A study of the Swiss Heat Pump Association (Fördergemeinschaft Wärmepumpen Schweiz, FWS) calculated the cost for a BHE-system (drilling, heat exchanger, and heat pump) for a small house, and found a reduction of 27.5 % over 12 years, from 1992 to 2004. In fact, the situation concerning the first cost is a bit more complicated. Better efficiency results in a decrease in energy input for operating the geothermal heat pump system that is much more pronounced than the slight reduction in first cost. In recent years, the lifecycle cost of a fuel oil boiler has surpassed the price of an average shallow geothermal system.

Study case in Romania

In Romania, the RES market is dominated by far by electricity production, having already one of the biggest wind turbines plant in Europe (1100 MW_{el} capacity) and several PV power plants.

In most of the Romanian cities, heating has been provided from district power plants built back in the 1980's, based on co-generation, using coal, gas or oil as energy source. Since then, no major improvements were made, so the overall efficiency dropped significantly leading to increased heating costs. The final users could not bear the bills and switched to alternative heating systems, especially to individual gas boilers (microCT). Today, only 95 cities are still connected to district heating, compared to 315 in 1989 (Figure 7).

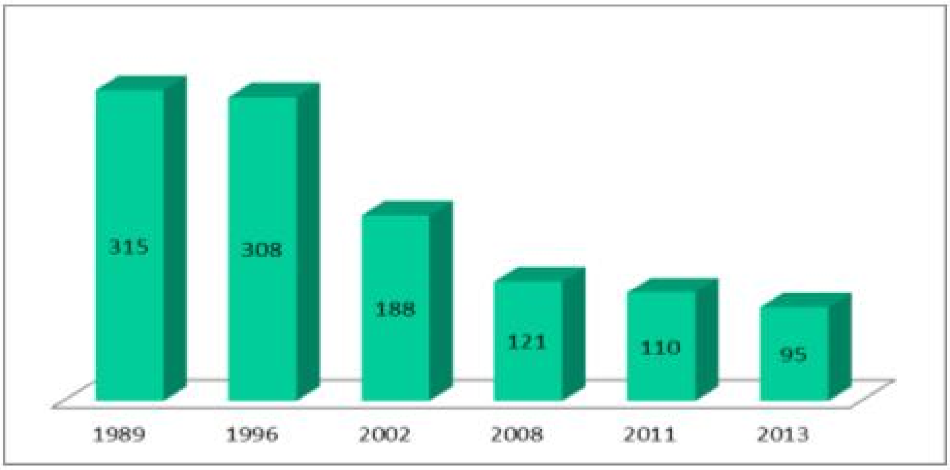

Figure 7 - Number of cities conected to District Heating system in Romania, from 1989

To keep the heating costs affordable, the government pays a lot of money, giving a general subsidy for district heating (around 45% of the full price). The National Authority for Energy Regulation (ANRE) states that 1 billion euro per year were spent for those 95 district plats which provide affordable heating and electricity for population. The actual share divided on fossil fuel types, used in those district power plants, is shown in (Figure 8).

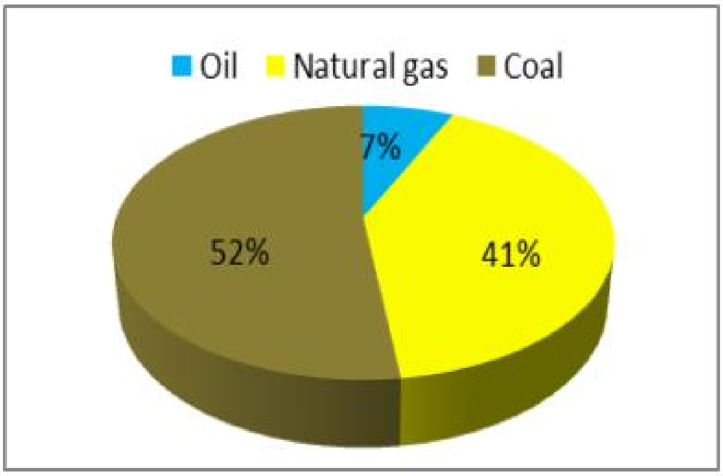

Figure 8 - Fuel source for District heating and electricity production (in old CHP) in Romania. Dates from 2008.

For the 2012-2013 winter, in Bucharest, the heating price was 61 Euro per MWh_{th} (one of the lowest princes compared to the other 94 cities). The price was subsidised by the municipality of Bucharest up to 48%, resulting a price of 31.7 Euro per MWh_{th} for the final user. For the upcoming years, the subsidy will not be paid any more, and the final user will have to support the full price for heating.

The National program of Building Refurbishment helps the situation by reducing the heating demand up to 40% but up to now, in Bucharest only 2% of the total amount of buildings was refurbished. The program initially established to share the investment costs as follows: 33% to be paid by the government, 33% by local authorities and 33% by owners (beneficiaries). It didn’t work this way and therefore the share for owners was lowered to 20% and the rest is further on covered by the local authorities (municipalities).

In a case study for Bucharest, Romania, we tackled the feasibility aspects of using district geothermal heating for a condominium. The reference case is based on a residential area, connected to a district heating system, supplied by old CHP plants, running on fossil fuels (mostly gas). The residential area is formed of multi-storey buildings and has a maximum heating demand of $1MW_{th}$. The total heated area equals to 240 conventional apartments of $50m^2$, which have an individual annual consumption of 8.14 MWh/yr. The calculation parameters were set according to Table 1.

Table 1

Calculation parameters

Calculation parameters	**Values**
Total heated area	12000m^2
Heated area of a conventional ap.	50m^2
Total number of conventional ap.	240
<u>Investment</u>	
Individual gas boiler (microCT)	1700 Eur
Shallow geothermal plant	4200 Eur/ap.
Deep geothermal plant	5000 Eur/ap.
<u>Estimation of energy costs increase evolution</u>	
Gas	5% per year
Electricity	2% per year

The investment costs for geothermal plants were set according to the European average costs indicating 0.65-2.0 Mil.Eur/MW_{th} for shallow systems and 1.5-2.2 Mil.Eur/MW_{th} for deep systems.

Evolution of gas price for the next 20 years was set to an average of 5% per year due to limited existing resources, early shale gas technologies and expensive biogas production.

Electricity price increase was set to 2% per year especially due to renewable electricity producing and smart grids developing. Even if at this moment, a part of the government incentives, given for implementing new technologies, are paid by the final users, on a long term, the evolution of costs will be in favour of electricity.

A simulation was made for a conventional apartment with an annual consumption of 8.14 MWh_{th}. Initially the apartment was considered connected to an old district heating network (old CHP), paying around 500 euro in the first winter for heating and hot water. The price per MWh_{th} increases with 5% per year, having gas as primary fuel.

The second option was to disconnect it from the old district heating network and to install an individual gas boiler (more than 140.000 gas boilers were installed in Bucharest). The entire effort costs around 1700 euro (money spent entirely by owners). The price per MWh_{th} is again influenced by the price of gas but avoiding this way the loss over the distribution network. In the first year, the price was 420 Euro and it increased by 5% per year. The yellow curve in Figure 9 represents the heating costs for individual gas boiler.

Every two years, the gas boiler needs to be checked by authorised personnel. The service is called "periodical technical verification" (VTP) and it costs 40 Euro-this is the reason why the curve is not straight.

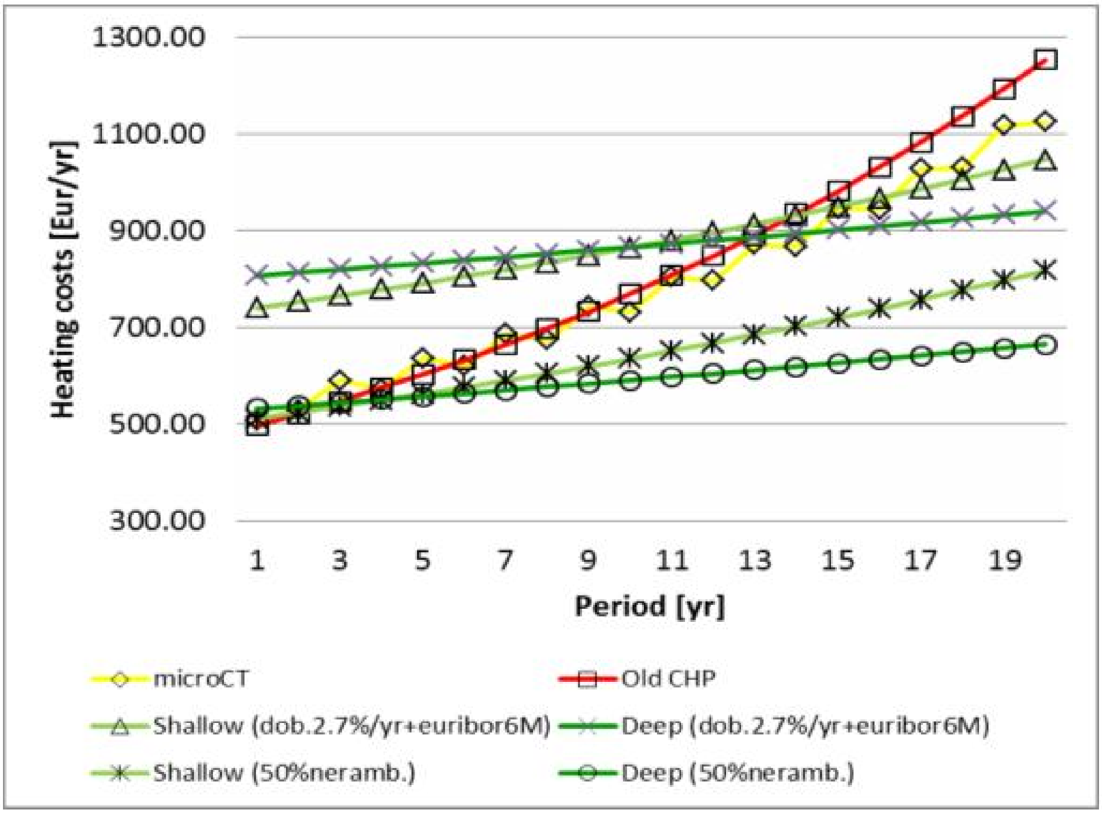

Figure 9 – Heating costs for a conventional apartment in Bucharest of 50 m^2 with an annual consumption of 8.14 MWh_{th}

Another approach was to change the destination of the thermal substation which provides heating and hot water for the entire condominium (240 apartments). There are 870 thermal substations in Bucharest and have enough space to turn them into geothermal power plants.

Under this case study, we considered two cases: a) shallow geothermal based on HP technology and b) deep geothermal based on CHP-HP-ATES technology.

The shallow geothermal is running with water from Fratesti aquifer in an open loop heat pump system. The investment costs were set to 1 mil.Euro. The system running costs were set at 30 Euro per MWh_{th} and the price for district heating will reach 50 euro per MWh_{th}[5].

The deep geothermal system uses a seasonal thermal storage (ATES), placed in a geothermal reservoir at approximately 1500 meters depth; a cogeneration gas turbine (CHP) which provides electricity for running the system, gives a temperature boost for heating, provides DHW and delivers the excess heat for ATES recovery during summer; and heat pumps (HP) to provide heating in a second stage (lower input temperatures from the storage). The investment costs for this application rises to 1.2 mil Euro considering that the same ATES is used by at least 4 other power plants, sharing the costs for drilling and exploitation. System running costs were set at 30 Euro per MWh_{th} and price for district heating will reach 50 euro per MWh_{th}.

Both geothermal investments were set according to the following scenarios:

1) Loan from the bank with 2.7% interest per year plus Euro Interbank Offered Rate (euribor 6M).

2) A share of 50% from local authorities who paid subsidies up to now and 50% non-refundable co-finance from the EU

The investment costs were divided over the 20 years of exploitation, according to the graph in Figure 9.

We notice that the individual gas boiler and both geothermal systems (with loan from the bank) recover the investment in less than 15 years. If 50% of the investment can be obtained from the EU as non-refundable co-financing, according to RES policies, than the geothermal systems will be able to provide heating at lower prices (than the old CHP) from the first years, giving the chance to authorities to recover the investment from the end users (the 50% share) over the next 20 years.

Another important aspect regarding heating systems refers to greenhouse gas (GHG) emissions. The CO_2 emission factors were set at the EU level and mentioned in NREAP for the common applications – they are specified in Table 2, and estimations are made for particular cases.

Table 2

CO_2 emission factors

Fuel type	Factor	Obs.
Natural gas in old CHP	0.300	Estimation
Natural gas in microCT	0.202	EU average
Electricity from NEG	0.701	EU average
Electricity from PV	0.000	Estimation
Electricity for HP (compressor+additional electrical heater)	0.120	Estimation

Emissions for geothermal systems were calculated according to the electricity consumption for pumping and heat pumps usage (compressor and additional electrical heating device). Results are shown in Figure 10. The total electrical consumptions are known as $E_{driving}$, important value to determine the performance of the HP system.

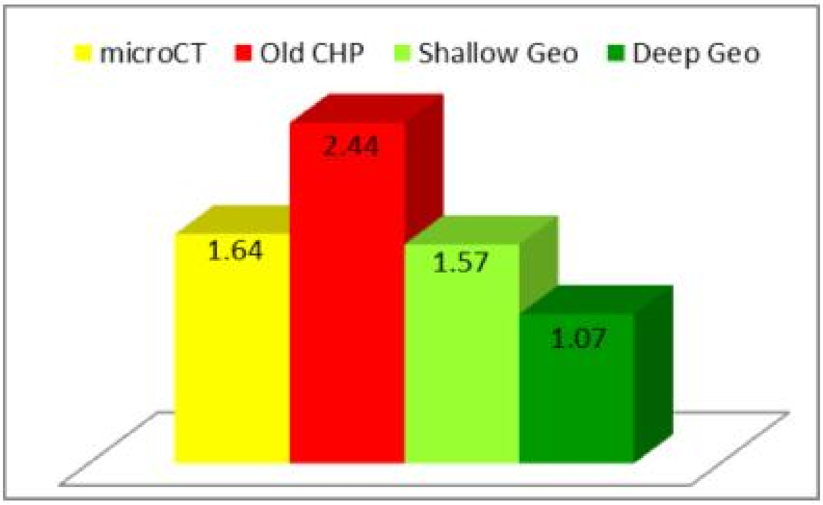

Figure 10 – CO_2 emissions [tons per year] for a conventional apartment in Bucharest of 50 m^2 with an annual consumption of 8.14 MWh_{th}

For the considered application, deep geothermal system reduces the CO_2 emissions with 56% and the shallow geothermal with 37%, comparing to the old district heating system.

Buildings certification procedure refers, according to EPBD Recast, to specific annual energy consumption, in terms of primary energy. Therefore we studied the EPB sensitivity due to refurbishment methods. On one hand we are talking about improving the buildings envelope by decreasing the overall U value - this process is running under the National Program of Thermal Refurbishment. On the other hand, at least equally important is refurbishing the technical system of the buildings by implementing renewable resources according to the RES Directive.

Two general cases were analyzed:

1) Refurbished buildings with a specific energy consumption of 100kWh/m^2yr, at final user, connected to the technical systems discussed previously and

2) Non-refurbished buildings with a specific energy consumption of 350kWh/m^2yr, at final user, connected with the same technical systems as at pt.1

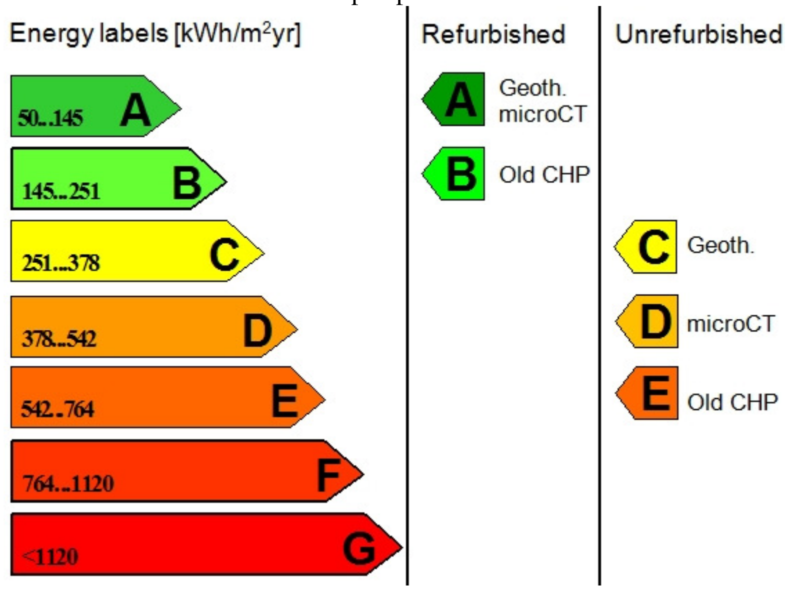

Figure 11 - Energy performance certification for refurbished / un-refurbished buildings, connected to several energy sources

The energy certificate in Figure 11 was made according to EPBD Recast, expressing the energy at final user in terms of primary energy. The calculus was made using the general conversion factors, mentioned in Table 3.

Table 3

Primary energy conversion factors

Energy source	Conversion Factor
Thermal energy from old CHP	2.0
Electricity from old CHP	2.5
Energy from microCT	1.1

The refurbishment process reduces significantly the energy demand of the buildings, ranking them at least 3 classes higher on the energy performance scale. In terms of CO_2 emissions, the rank is not yet reaching the 2020 targets and committed through NREAP.

We notice that after refurbishment, both sources (Geothermal and microCT) bring the buildings to class A. To get a clearer picture on which one is more efficient we need to split the A energy class in three subclasses (A1, A2, A3 or A, A+, A++). The top subclass will be attributed to very efficient buildings with the total specific energy (Heating, Cooling, Ventilation, DHW, and Lightning) smaller than 50kWh/m^{2}yr, called as nZEB. The other 2 subclasses will be set according to the Romanian particularities (climate and economic situation).

Conclusions

➢ A great future can be expected for the geothermal sector, with positive trends for the next ten years. Shallow geothermal is on track for reaching the targets for 2020 set forth in the NREAPs, with a total of about 2,500 ktoe actually produced in 2011. Deep geothermal is proper for district heating, especially in crowded cities and it is proved to be efficient next to CHP plants.

➢ New materials and technologies are developing, increasing the RES market and lowering the prices for the previous ones. Future markets are comprises of both: large systems in Germany, France and UK, and small and large systems for heating and cooling in Mediterranean countries, mainly Italy and Spain.

Investments in geothermal systems can be co-financed from non-refundable European funds, especial in developing member states.

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