Utilization of geothermal energy in Slovakia

***Henrieta Pavolová*[1], *Katarína Čulková*[1] *and Tomáš Bakalár*[1]**

Higher demand for energy consumption and the importance of environmental issues has encouraged researchers and policy makers to consider renewable energies more seriously. Energetic projects, resulting from orientation to energetic effectiveness are contributing to the increase of energetic safety and reduction of economic dependence on unstable prices of gas and petroleum during their import. The contribution studies possible ways of utilization of individual types of renewable energies by the analysis of utilization of geothermal energy through characteristics of individual areas of geothermal energy in Slovakia according to the intensity of heat flow. The results of the analysis prove that Slovakia has the vast potential of geothermal energy. There is, therefore, necessary to support business activities, orientated to the energy saving projects.

Key words: *geothermal energy, economic efficiency, intensity of heat flow, potential of thermal energy, Slovakia*

Introduction

Currently, research and science are dealing with the finding of new, clean sources of energy. Slovakia has an important potential for geothermal energy due to its natural conditions, which is preliminarily calculated to 5,538 MWt according to contemporary researches. It presents a renewable energy source, spread in the territory which utilization has the importance from the economic, as well as the ecological view. Therefore, the interest of the state is to create conditions for rapid using of its potential. Geothermal energy is using heat in the effective output of 142.75 MWt of geothermal water in 36 localities of Slovakia. Sources of geothermal energy in Slovakia are presented mainly by geothermal water, utilized in agriculture, heating and recreation.

Energetic projects, resulting from orientation to energetic effectiveness are contributing to the increasing energetic safety and reduction of economic dependence on unstable prices of gas and petroleum during their import. Saving of energy for companies and households means lower costs for providing energetic needs and by this way, a direct or indirect increase in competitiveness and quality of inhabitants' life.

The present state of problem

Higher demand for energy consumption and the importance of environmental issues has encouraged researchers and policy makers to consider renewable energies more seriously. The European Union has a leading role in the world due to its strong commitment to increasing renewable energy sources as for the energy system change. The success of such long-term project requires, first of all, a stable political framework, well-tailored support system of finances, technical background and administrative, and by this way, it can overcome the obstacles existing in distorted energy markets. Regardless their high potential, renewable energy resources are insufficiently exploited in Europe (Menegaki 2012). Geothermal resources represent a green energy source that can make a considerable contribution in some countries. For example, Japan has the third ranking geothermal energy potential, and its geothermal electricity production is currently eighth in the world (Jalilinasrabady and Itoi 2013). Countries must, therefore, have policies that give a legal basis for the geothermal energy to produce electricity. There are different scenarios to assess the attractiveness of geothermal investment to attract private investors to participate. (Nasution 2012).

Due to the rapidly increasing percentage of the population living in urban centers, there is a need to focus on the energy demand of these cities and the use of renewable energies instead of fossil fuels (Schiel et al. 2016). Around 50 % of the urban population currently lives in areas of medium aquifer thermal energy storage (ATES) suitability, a percentage that will remain constant. Demand for ATES is likely to exceed available subsurface space in a significant part of the urban area. Countries and regions, where regulation and stimulation measures may increase application of ATES technologies and thus help reduce CO_2-emissions, are identified. These two preconditions can be combined to identify where in the world ATES potential is present, or will be present as a consequence of climate change. (Bloemendal et al. 2015)

Schiel et al. (2016) developed a model to determine the potential per parcel for using shallow geothermal energy and calculated the percentage of the energy demand that could be supplied by geothermal energy. Due to

[1] *Henrieta Pavolová, MSc.,PhD., assoc.prof. Katarína Čulková,MSc. PhD., assoc.prof. Tomáš Bakalár, MSc.PhD.,* TU Košice, Faculty BERG, Letná 9, 040 01 Košice, henrieta.pavolova@tuke.sk, katarina.culkova@tuke.sk, tomas.bakalar@tuke.sk.

the geothermal energy usage, there is necessary to determine the requirements and parameters governing the development of shallow geothermal energy in an efficient and safe manner. Luo et al. (2015) mathematically quantified a geothermal heat exchange system and simulated and modeled it to understand heat transfixion and strata deformation taking into account the groundwater leakage and temperature fields, as well as land subsidence.

Ratlamwala and Dincer (2012) focused on a comparative assessment of multi-flash (single to quintuple) geothermal power generating systems integrated with electrolysis through three definitions of energy and exergy efficiencies. They varied operating parameters such as ambient temperature and geothermal source temperature to investigate their effects on the respective efficiencies of individual and integrated systems and finally studied the effect of increasing the number of flashing steps on the efficiencies.

The other parameters were investigated by Tomaszewska et al. (2014). In their study, they calculated an energy efficiency and an economic analysis, demonstrated that the cost-effectiveness of implementing the process in a geothermal system on an industrial scale largely depends on the factors related to its operation, without limitation the amount of geothermal water extracted, water salinity, the absorption parameters of the wells used to inject water back into the formation, the scale of problems related to the disposal of cooled water, local demand for drinking and household water, etc. The economic efficiency was also studied by Al-Ali and Dincer (2014), who created a new multigenerational integrated geothermal-solar system to produce electrical power, cooling, space heating, hot water and heat for industrial use. They also conducted a parametric study to investigate the effects of operating conditions and environment parameters on the system performance.

For research and utilization of geothermal source, it is necessary to estimate also deep groundwater temperature. Best thermal waters (temperatures from 130 °C to 160 °C) for the purpose are located in the spa, which presents another area of research of geothermal resource utilization (Stojković et al. 2013).

Methods

In order to summarize the characteristics of individual areas of geothermal energy in Slovakia, a classification of geothermal activity according to the intensity of heat flow was used (Tab. 1).

Tab. 1. Classification of geothermal activity, according to the intensity of heat flow (Franko et.al 1995).

Value of heat flow intensity [mW.m^{-3}]	**Geothermal activity**
< 10	very marginal
10-20	marginal
20-30	rather marginal
30-40	very low
40-50	low
50-60	rather low
60-70	average
70-80	rather increased
80-90	increased
90-100	very increased
100-110	rather high
110-120	high
> 120	very high

Classification of geothermal energy is also made by a complex of the country area. Triassic dolomite and limestone complexes are among spatially largest collectors of geothermal water in Slovakia in the internal part of Western Carpathian. Springs of geothermal waters originate from these carbonates. From the area view, neogene sand and clastics are in the second place, and andesite and pyroclastics are in the third place. From the view of the lithologic development of flysch and cliff area, there is practically no geothermal water in the area. Water beds are extended to 25 or 26 limited geothermal areas. Geothermal activity is given to the areas according to the value of heat flow intensity (Tab. 2).

According to the world trend geothermal water was divided into three groups:

1. high-temperature waters with surface temperature over 150 °C (reservoir water over 180 °C),
2. medium-temperature waters with surface temperature 100-150 ° C (reservoir water 130-180°C),
3. low-temperature waters with surface temperature under 100 °C (reservoir water under 130 °C)

Sources of geothermal energy were classified according to the criteria, regarding their physical and chemical characteristics or geological processes in connection with their origin. According to the type of temperature regimes in the frame of the Earth, they are divided by Wright and Culver (2000). Table 3 shows a review of classification according to various authors during geothermal energy classification by temperature.

Tab. 2. Classification of limited geothermal areas, according to the value of heat flow intensity.

Value of heat flow [mW.m^{-3}]	**Limited areas**
120-100	Beša – Čičarovce
110-80	Košice Basin
100-90	Central Slovakian neo vulcanite (southeast territory)
100-70	Central Slovakian neo vulcanite (northwest territory)
90-100	Levice block (Dubnice depression)
90-70	Central depression
80-70	Humenné Ridge, Hornostrhársko-Trenčská depression, Hornonitrianská Basin, Komjatice depression
80-60	Levoča Basin (west part) levoča Basin (north part)
70-60	Trnava, Piešťany Creeks, Trenčín, Ilava, Bánovce, Turiec, Rimava Basins, Komárno block
70-45	Vienna shell
approximately 60	Žilina Basin, Skorušiny Hill, Liptov Basin, Komárno block

Tab. 3. Review of classification of geothermal energy sources, according to a temperature of water in underground stocks.

Author	**Muffler-Cataldi** (1978)	**Hochstein** (1990)	**Benderitter-Cormy** (1990)	**Mavrickij et al**. (1997)	**Haenel et al**. (1988)
Low temperature	to 90	to 125	to 100	to 70	to 150
Medium temperature	90-150	125-225	100-200	70-100	
High temperature	over 150	over 225	over 200	over 100	over 150

Potential of geothermal water is calculated according to the temperature regime of the earth's crust, which influenced the depth of 1.5-40 m mainly by the intensity of solar radiation in various annual periods. This influence is decreasing with growing depth. The temperature of the ground in the depth H can be expressed by the following equation:

$$t_H = t_V + (H + g_t) \times h_t^{-1}, \qquad (1)$$

where

t_V – medium temperature of air in the area (K)
H – depth (m)
h_t – depth of the layer of fixed annual temperatures (m)
g_t – geothermic level (m.K^{-1})
t_H – temperature of ground in depth H (m)

The majority of data that were available for geothermal potential determination were obtained from unsuccessful experimental boreholes during the finding of earth gas and oil.

Results

Geothermal energy has a vast potential similar to hydropower, and it presents approximately 21,456 TJ in Slovakia annually. Slovakia has very good conditions for development and using of this RES (Pavolová et al. 2011). The performance of heat from geothermal waters is around 70 MW.m^{-3}. The geothermal gradient of Slovak sources achieves an average of 37 K.km^{-1}, which is more than the worldwide average of 30 K.km^{-1}. There are 26 localities in Slovakia with sources of geothermal waters, with temperature 25 – 150 °C. The temperature of the water is proper for cascade using during households heating, as well as for using in agriculture and industry. The total energetic thermal potential is around 5 538 MWt. At 40 % using of the potential, there should be produced 2 200 MWt of thermal energy. At present, only 5.4 % of the identified technically useful potential of geothermal energy is used, mainly in the area of heat. The technically useful potential for production of electricity represents only 0.06 TWh per year. Present using of the potential is only 44 kW in two small co-generation units, burning gas from a geothermal source in the city of Komárno with an annual production of 0.0035 TWh. Further potential from this RES is presented by the project in the Košice Basin with electrical performance of 5 MW and expected annual electricity production of 0.04 TWh, but this project was not realized due to the extremely high cost of geological research and mining. These are the basic limiting conditions for further use of the potential (Tab. 4).

Tab. 4. Potential of thermal energy from geothermal waters in Slovakia (MWt), regenerated and without regeneration.

Regenerated			**Without regeneration**		
Probable	**Verified**	**Predicted**	**Probable**	**Verified**	**Predicted**
321	147	85	4,511	29	445
The total potential of available geothermal energy is 5,538 MWt					

The total potential of energy from a renewable energy source that is possible to change to other forms of energy per one year, and its volume, is given by natural conditions. As for its characteristics, it is unchangeable from the short term and middle term view. Technically available potential, which can be used during establishment of available technology, is limited by administrative, legislative and environmental obstacles.

Division of various types of potential, according to the volume of produced energy in the form of heat and electricity, is illustrated in Table 5.

Tab. 5. Potential of geothermal energy, compared with other RES in Slovakia, in TJ (2012).

Source	Technically available potential	Present using	Available potential	Economic potential	Market potential
Geothermal energy	22,680	1,224	21,456	8,424	4,355
Wind energy	2,178	0	2,178	505	150
Solar energy	18,720	25	18,695	4,460	1,270
Small water power plants	3,722	727	2,995	749	299
Biomass	40,452	12,683	27,770	11,868	2,932
Total	87,754	14,659	73,094	26,006	9,006

According to Table, the value of available potential is currently used only in 20 %. It presents a value of the economic potential of approximately only 36 % from the total available potential of renewable energy sources in Slovakia. The position of current legislation against renewable energy sources expresses the last data in Table, which means the value of market potential that corresponds approximately to 12 % of the available potential at present prices of technologies, repurchase prices of energy and support tools for the use of renewable energy sources. Considering that geothermal energy and biomass generally have the highest energy potential, and they contribute to the production of heat energy, it is not amazing that heat potential is higher than electric. For all sources, there is the available potential of 17.5 % for electricity production from total available potential, while the market potential of electricity is 12.3 % of the total market potential.

While the economic potential of heat represents 36.9 % of available potential, it is only 27.6 % of electric energy. This trend is also approved by figures from the market potential that is 13.1 % of available potential of heat while it is only 8.9 % for electricity. This can be explained by the problematic realization of photovoltaic systems and wind power plants on a large scale. Extension of individual types of geothermal waters in limited areas is mentioned in Table 6.

After deduction of average annual air temperature of 7 °C in Slovakia from the temperature at the depth of 1,000 m, the remaining temperature approximately corresponds with an average geothermal gradient. Geothermal waters can be divided into basic types from the view of chemical structure (Puchala 2008):

- relict sea waters,
- highly mineralized geothermal waters,
- petrogenic geothermal waters with total mineralization up to 5 g per liter,
- geothermal waters of mixed genesis with complete chemical structure.

Tab. 6. Ranking of limited geothermal areas, according to the temperature at the depth of 1000 m.

Temperature in 1,000 m [ºC]	**Limited areas**
> 65	Beša – Čičarovce, Levice block (Dubnice depression)
65-45	Košice Basin
60-40	Central Slovakian neo vulcanite (southeast territory), Central Slovakian neo vulcanite (northwest territory), Komjatice depression
50-45	Humenné Ridge, central depression
50-40	Komárno block, Hornostrhársko-Trenčská depression
50-35	Vienna block, Trnava, Hornonitrianská, Piešťanská Basins,Turiec, Komárno blocks
45-30	Bánovce, Liptov, Levoča Basins, Levoča – west block, south and north part
40-30	Skorušiny block
35-30	Trenčín, Ilava, Žilina Basins
40-20	Komárno block

Geothermal water with a temperature of 15-90 °C, from the view of energy, is a very convenient source for heat pumps, but the basic disadvantages are very high investment cost for its obtaining (drilling hole to the depth of several km), and high level of corrosion and its availability at the place of appearance. The convenient solution would be the use of geothermal water with high temperature, first of all for obtaining of heat directly in heat converters "water-water" and consequently during its cooling to 15-25 °C, as a source for heat pumps. (Tometz and Dugáček 2010). Type of geothermal water according to the temperature is illustrated in Table 7.

Tab. 7. Depths of water beds of geothermal water in relation to their surface temperature.

Type of geothermal waters	**Limited areas**	**Depths water beds** [m]
High temperature (over 150 °C)	Humenné Rift	5,000-6,000
	Beša Čičarovce	3,500-5,000
	Ždiar Basin	5,000-6,000
	Vienna block	5,000-7,000
Medium temperature (100-150 °C)	Beša – Čičarovce	2,500-3,000
	Košice Basin	2,500-3,000
	Central depression of Dunaj block	3,000-4,000
	Humenné Rift, Levoča block	4,000-6,000
	Žilina, Ilava, Trenčín Basins	5,000-6,000
	Trnava and Piešťany creek	4,000-5,000
	Vienna block	4,000-6,000
Low temperature (under 100 °C)	Komárno block	100-3,500
	Central depression of Dunaj block	1,000-3,000
	Bánovce Basin	100-3,500
	Trnava and Piešťany creeks	1,000-4,000
	Central Slovakian neo vulcanite NW+SE	1,000-4,000
	Hornonitrianská Basin	1,500-2,500
	Turiec Basin	1,000-3,000
	Žilina Basin	1,000-5,000
	Skorušina Depression	100-25,000
	Liptov Basin	1,000-4,000
	Levoča Block (west and south part)	500-4,000
	Horná Nitra depression	500-600
	Rimava Basin	150-1,500
	Trenčín and Ilava Basins	1,000-5,000
	Block Levoča (north part)	1,000-2,000
	Komárno block	1,000-2,500
	Vienna block	2,000-4,000
	Komjatice depression	2,000-3,000
	Levoča block	1,500-4,000
	Beša – Čičarovce	1,000-2,500
	Košice Basin	1,000-2,500

Discussion

Geothermal sources present such part of the geothermal energy of solid, liquid or gas phase of the earth's crust that can be economically mined and utilized by currently available technologies for energetic, industrial, agricultural, balneal, technical, and recreation - rehabilitation purposes. The source of the energy is the recent heat of Earth, heat that is decreasing during the radioactive ground destruction and during movement of lithospheric plates, which is accompanied by volcanic activity and earthquake. From this view, geothermal energy is considered as a renewable energy source (NSK 2009).

In Slovakia the following division of geothermal sources of geothermal energy is used (Čulková and Teplická 2008):

- low temperature – of 20-100 °C,
- medium temperature – of 100 - 150 °C,
- high temperature – of over 150 °C.

Sources of geothermal energy generally appear in four main forms: hydrothermal system, geo-compressed zones, dry heat of the ground (hot, dry rock) and magmatic sources. Available geothermal sources are in places where there is relatively slight earth's crust, or where it is invaded by tectonic movements and volcanic activity during 10 million years also with its volcanic reflections and recent volcanic activity (Duleba and Lisoňová 2009).

From a total volume of energy that is annually consumed in Slovakia, almost half is falling into the industry, almost fifth into households, the next fifth into providing of agricultural production and services and residual into the transport. Average household needs probably 60 % of energy due to the heat supplement, around 30 % for heat water supplement and 10 % for the operation of appliances in the household. When considering family or community as an economic unit, there is the natural way how to deal with it - to decrease energy costs from short-term as well as the long-term view. Using of geothermal waters in Slovakia is illustrated by Fig. 1 and 2.

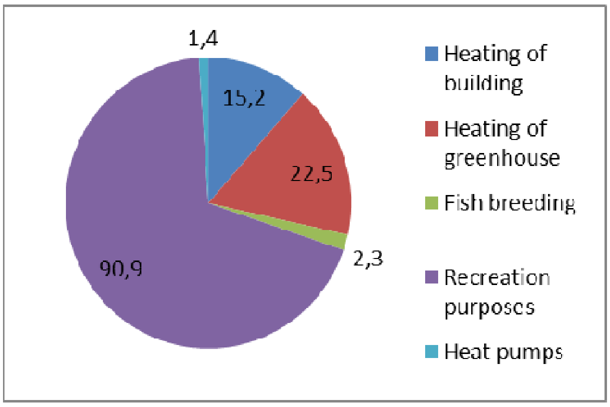

Fig.1. Using of geothermal water in Slovakia, according to the installed performance [MW].

Geothermal water is not always used only in heating, secondary use of water is in supply to other heating systems. In the case of swimming pools and spas, there is direct using of geothermal water, which means that geothermal water is filling into pools directly from the drill hole. The majority of localities with using of geothermal water is in Trnava District.

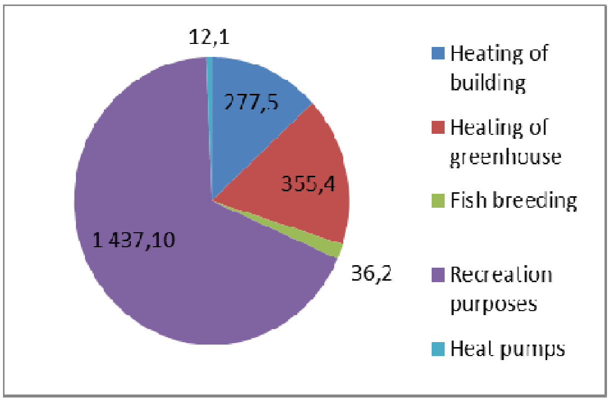

Fig.2. Using of geothermal water in Slovakia, according to the annual consumption of energy [TJ per year].

Except heating in the system, there is also possible to prepare heat service water for habitation and steam used for technological purposes in hospitals. By this installation, it is possible to provide heat for habitation and to improve the living environment in the city, where coal is not used. For example one of the localities, providing heat for whole habitation and a hospital with a health center, is in Galanta.

From the view of providing decreased energetic demand, presenting one of the main goals of energy policy in Slovakia, there is necessary to follow up possibilities how to support energy projects together with their personal, program and financial sustainability (Hakeľová et al. 2013).

As for the following of financial situation, it is necessary to orientate to support of business activities financing, orientated to the energy saving measurements, for example finding an effective way of financing.

At present, it is possible to use various operational programs in the form of structural funds for financing energy projects, various specialized donations financed from the state´s budget, or international programs and funds.

Geothermal energy is used through its bearers – geothermal waters and steams. Most known external and clear reflection of this energy means volcanic activity, connected with seismic territories – most active zones in the earth's crust. The second best visible manifestation of geothermal energy means springs of steam and hot waters, which are also connected to these zones.

Using of geothermal energy has several advantages (Duleba and Lisoňová 2009):

- presents domestic source,
- is rather cheaper than fossil fuels,
- decreases the danger of living environment threatening by reduction of transport, elaboration and using of fossil fuels (accidents during construction, service of gas and gas product stocks, stock economy, emissions,
- enables managing of energy prices,
- service of geothermal energy is secure with minimal impact to living environment and soil occupation.

Conclusion

One of the priorities of the state´s policy is the support of business, orientated to increasing of energetic effectiveness, production, and consumption of energy. By this way, business is more and more orientated rather to environmental appeal, as the quality of the air, climatic changes and management of sources with opportunity for regional development through investing in regions and communities, the opportunity for a job, decreasing of production cost, the growth of competition advantages, etc.

However, it is not possible to achieve this goal without a necessary financial mechanism, supporting effective and environmental business with energy sources. Energetic projects that result from orientation to energetic effectiveness contribute to the increase of energetic safety, and they decrease dependence on unstable prices of gas and oil during import.

As for the companies, services, and households, a saving of energy means lower costs for providing of energy needs and by this way direct or indirect increasing of competitiveness, as well as the quality of inhabitants' life.

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