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RESEARCH ARTICLE

The environmental evaluation of utilising geothermal energy with the life-cycle method

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Abstract

The aim of the present work is to demonstrate and compare the environmental effects of long-distance heating and hot water supplying systems, based upon the already existing geothermal energy in Hungary and comparing it with the non-renewable energy carrier (natural gas). We rely on the evaluations of the SimaPro 7.1 Life Cycle Assessment program.

Keywords

geothermal energy · life cycle assessment · environmmental effects · natural gas fired · geothermal district heating

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1 Introduction

In preliminary it can be shortly described that the energy constitutes an essential part of our everyday life. Nowadays our present way of life and civilization, is based on it too. However, nowadays considerable problems arise that most used energy sources (fossil energy carriers) pollute the environment and they are at disposal only in limited quantities and the reserves are worked out.

In consequence of using fossil energy carriers the natural green house effect has increased. The possible results of the rising temperature are the - global climate change, the displacement of the distribution of rainfall and the zones of the vegetation, the thawing of the polar ice-fields and therefore the rise of the sea level.

The U.N. also took note of these phenomena. First time, in 1972 a conference was called together to discuss these questions. Following this up to now there have been more world-conferences arranged, where the World's member-countries declared: the future of the humanity is the stake, and the reduction of the yearly utilization of fossil energies to a definite extent was ordered. (Geneva 1979: Declaration of the United Nations Conference on the Human Environment; Rio de Janeiro 1992: The United Nations Conference on Environment and Development; Kyoto 1997: United Nations Framework Convention on Climate Change)

Consequently from the preliminaries the energy policy of the EU is based on the maintainable development and the rules concerning it. The main point is an aspiration for implementation of the safe, non-expensive energy supply suitable for environmental respects [1]. So, among the fundamental principles of the energy policy of the EU, the enlargement of the utilization of the renewable energy carriers is of excellent importance. In order to simulate and support their spreading in 2008, in Strasbourg the EU-rules against climate change were accepted. The essence of these rules is: to reduce the emission of the air-contaminant materials by 20% until 2020, to raise the rate of the renewable energy sources to 20% and to improve the energy efficiency by 20%. (In Hungary the renewable energy covers only an insignificant percentage of the total energy demand. In order to raise this value near the value expected by the EU, the New Hungarian Developing Plan sets an aim, the rate would raise to 14 % in 2020)

The 2001/77/EC directive gives the definition of the „renewable energy": „The renewable energy sources: non-fossil renewable energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases)" [2]. As evident, the geothermal energy is also considered as renewable energy, although it would be considered only partially renewable energy source.

2 The geothermal energy

The geothermal energy means the thermal energy originated from the inside of the Earth and mainly derives from decomposition of radioactive elements with long half-life period but it is considered as important that the heat caused by friction between the stone slabs. The geothermal energy accumulates either in areas of volcanic activities or in sedimentary, water-permeable, porous rock reservoirs. This is true only for the so-called wet, geothermal systems lasting until 10 km of depth, not for the HDR (Hot Dry Rock). The parts of the geothermal system are: thermal spring, water reservoirs and a geothermal fluidum of high temperature (likely water, vapour or their mixture; the last two may be artificial). The characteristic index numbers of the geothermal energy are: the geothermal gradient: – characteristic value of the change in temperature in the earth's crust: the amount of temperature-increase falling on a unit of depth-increase – terrestrial thermal flow density: – „flowing quantity of heat through a unit area in unit time". These values are – considering the earthly average – in case of thermal flow density (because its dispersion on the surface of the Earth is uneven, so is the result of the different values) on the continents 65 mW/m^2 and in the oceans 101 mW/m^2; in case of geothermal gradient 25-30 ^{o}C/km. Against this in Hungary the thermal flow density is 90-100 mW/m^{2}and the geothermal gradient in some places transcends 50 ^{o}C/km. The reason is that Hungary is to be found in the Pannon-basin which has essentially slighter lithosphere than the neighbouring regions. So, the hot material of the earth's crust is nearer to the surface. The other reason is that the basin is filled with good heat insulating sediments (clay, sand) [3, 4].

One of the most important potential renewable reserves in Hungary is the geothermal energy. Considering the utilization we can distinguish the water economics, the water supply (e.g. balneology) and the energetic utilization, within the scope are the direct heat utilization, producing electric energy and the combinated energy production and the heat utilization [3].

The utilization of the geothermal energy is profitable in more respects [3]:

- Shifting fossil energy sources + our country's import-dependency can be reduced
- The air-pollution can be reduced
- It is continually disposable
- It is independent of the weather-conditions
- It is in service of protection of local drinking water
- It means the use of local energy carrier with suitable renewable technology, using it in a preserving way.

But there may be disadvantages of the utilization i.e. if it is not utilised in a preserving. This occurs, when the protection of the hydrodinamically uniform reservoirs, closed water-basins are not guaranteed, i.e. there is no recharge. So, the quantity and the temperature of the exploited thermal water can diminish, what can affect the drinking-water bases and an environmental damage can possibly happen [3, 4]. The high salt-content, the derivates of the carbon hydrates (e.g. phenol, benzene), high COD, ammonium endanger the quality of the soil, the quality of surficial and undersurficial waters, the ecosystem and can reduce our water-reserve under surface. The waters of high CO_2-content and or/and high CH_4-content can also make difficulties because these getting into the atmosphere can increase the green house effect.

That is a problem in Hungary, as well that the utilization of the thermal heat is legally unregulated. The problem of the recharge into the sandstone exists everywhere in the country in several places (in spite of the fact that in Hódmezővásárhely and elsewhere the heat-utilized thermal water has been successfully recharged into the sandstone for years).

The utilization of the geothermal energy in Hungary today – compared with the possibilities – is low. Considering the mainly balneological and energetic purposes, the direct heat utilization is typical. Tables 1,2,3 include the data:

Tab. 1. Electricity/Heat in Hungary in 2006 (IEA) [5]

	Electricity Unit: GWh	%	Heat Unit:TJ	%
Production from				
- coal	7 092	19,78	90 807	15,96
- oil	521	1,45	890	1,45
- gas	13 160	36,4	48 476	78,91
- biomass	1 171	3,26	479	0,78
- waste	226	0,63	1 018	1,66
- nuclear	13 461	37,54	594	0,97
- hydro	186	0,52		
- geothermal	0		168	0,27
- solar PV	0			
- solar thermal	0		1	0,0016
- wind	43	0,12	0	
- tide	0		0	
- other sources	0		0	
Total production	35 859	100	61 433	100

3 Life cycle assessments

The method applicable for analysing the environmental effects of the direct utilization of the thermal heat: this is the Lyfe Cycle Assessment – LCA. Both life cycle and life cycle

Tab. 2. The situation of the utilization of the geothermal energy in Hungary in 2004 (IGA) [6]

Electricity generation	There is no installed geothermal generating capacity as for December 2004
Direct uses	
Total thermal installed capacity in MWt	694,2
Direct use in TJ/year	7,939.8
Direct use in GWh/year	2,205.7

Tab. 3. The utilization of the thermal waters – According to the situation in 2004 more than 900 thermal-water wells were working – KvVM [7]

Using	%
Drinking water supply	26
Agricultural water supply	21
Balneology, therapeutics, therapy tourism	31
Other (multifunctional, communal, industry)	22

assessment are conceptually defined in MSZ ISO 14040. The life cycle means: „consecutive sections of the efficacy system of the product, from the obtaining or from the origin of the natural source of energy until the reusing or rendering in a harmless way". The life cycle assessment means: „collecting and evaluation of the input / output belonging to the efficacy system of the product and the potential environmental effects during its whole life cycle" [8]. The aim of the LCA is to help with choosing among the products, processes or services of the same function but different environmental effects. The method can be applied for product development, for preparation for decisions, for marketing purposes etc. In case of LCA it is important to mention, that the method analyses only the environmental effects of the investigable matters but the aim isn't to make an economic analysis [9].

The life cycle assessment consists of 4 steps [9]:

1 Definition of purpose and sphere of efficacy i.e. making out the purpose of the investigation and the limits of the investigated system(s) (the extent of the assessment and which parts of the system are not respected), respectively the determination of the function-unit what the LCA employs as a comparative-unit. The individual LCA treatings can be compared (the function-unit is usually the equivalent of a product, process or service).

2 Inventory phase – collecting the in- and outputs of the material- and energy-flows of the investigated system, inclusive the transport.

3 Effect-estimation – estimating the effects, the influences of different material- and energy-flows on the environment, considering the extent and the importance of the exercised influences, the normalization (helping method for better understanding of the relative dimensions of the effects) and weighting factors. The methods of the effect-evaluation are today in development.

4 Evaluation – interpretation of the results of the inventory and the effect-estimation sections, comparating their statements, drawing the conclusions from these, formulating proposals.

One of the accepted methods during the producing the inventory and the effect-estimation is the CML-method (Centrum voor Milieuwetenschappen Leiden - the Institute of Environmental Sciences of the University of Leiden). That means a tendency towards efficacy, i.e. emissions connected with the matter of investigation and other environmental influences are ranged into effect-categories or environmental problems. Mostly used efficacy categories are the global climate change, the acidification, the eutrophication, the damage of the ozone-shield in the stratosphere, the formation of photo-oxidants, the human-toxicity and the eco-toxicity [10].

Another accepted method of the efficacy-evaluation is the „eco-indicator 99" method. Compared to the CML-method, the most important difference is that the eco-indicator is founded upon the approaching of damage-orientation. Three areas are investigated: damage of human health, deterioration of the quality of the ecosystem and the exhaustion of the resources. The damages effecting the human health for example are characterized by numbers of the non-healthy life-years (Disability Adjusted Life Years – DALY). The deterioration of the quality of the ecosystem is described by the rate of died out species on a concrete area in consequence of a special environmental load. The exhaustion of the resources is measured by the „surplus energy" falling on 1 kg exploited material. This originates from the fact, that the remaining resources can be exploited only by major energy-input in the future. The results are summarised according to three areas easily and user-friendly but scientifically supported eco-points [10].

The characterization and the evaluation can be performed by the co-ordination and classification of the obtained inventory-data to the efficacy category, with emphasizing the most dangerous data and with considering the normalization and the weighting factors. The environmental effects must be weighted. The environmental effect must be transformed into an environmental index. The normalization is a helping method to a better understanding of the relative size of the effects: all effects calculated for the life cycle are compared with knowledge in connection with the total effect in this class. The eco-indicator method takes the European average of the caused effects for basis at the normalization. The exercises of the normalization for analysing the life cycle are different, depending on the used methods [9].

The single environmental efficacy categories are as follows [11]:

- Depletion of fossil fuel
- Depletion of minerals
- Land use

- Acidification / Eutrophication
- Eco-toxicity
- Climate change
- Ozone layer depletion
- Carcinogenic substances
- Respiratory effect (organic)
- Respiratory effect (inorganic)
- Ionising radiation

During our work we used the eco-indicator 99 method, inside the SimaPro 7.1 life cycle assessment program.

4 Presentation of our work

In course of our work we chose the wide known long distance heating system in Kistelek, based upon the utilization of the geothermal energy; in case of the long distance heating and hot water supplying system based upon a non-renewable energy carrier we chose a district heating plant in Budapest (district heating plant Rózsakert). The data can be considered as data of general validity in case of such systems (utilizing only natural gas). Our aim was to reveal and evaluate the environmental effects of these systems using the SimaPro 7.1 life cycle assessment eco-indicator 99 method.

Taking into consideration that an old established method (using natural gas) was compared to an exploitation of a new alternative chance (geotermia), we analysed the environmental effects of the utilization of the renewable and non-renewable energies, comparing their values. The name of Y axes of the diagrams is Pt, it means eco-points.

Regarding the investigations we strove to collect the greatest number possible discoverable data within 1 calendar year but it is to be noted, that the precision of the received results depends on the reliability of the data obtained from the operators of the single systems to a great extent. The data-collection means partly questionnaire-surveys, partly personal meetings and area-survey.

The function of each single system is heat energy production and in compliance with it we chose a function-unit 1 MJ produced heat energy (appearing at consumers), generated from the data for 1 calendar year.

For system, based on non-renewable energy carrier (in this case: natural gas) we analysed the operation alone, considering as background (no parts of the analysis) the buildings and system-parts (heat exchangers, the pipe system and its building up) which can be considered as common in case of the systems based on the renewable and non-renewable energy source. There were no parts of the analysis the setting up and the demolishment, because at present case this is an already existing and developed system all over the country. On the other hand, there are no available data, so regarding the environmental efficay-categories, there was no land use analysis. Considering the geothermal systems there was also no analysis about the installation (e.g. establishing degasfying reservoir), except the long lived well-drilling as a process of the biggest importance with its environmental influence during the installation. Taking into account, that the average life duration of wells is 50 years, we interpolated the received data to the planned period of time [12, 13].

The analysis of the geothermal system in Kistelek takes time beginning from the well-drilling, during the heat extracting of the fluidum (inclusive the appropriate water-treating) until the water-recharging, considering the already mentioned system-parts as a background output.

In view of data can be said that these are originated from exact reliable measurements (protocol of investigations, measuring instruments). Only some data originate from the technical literature or from estimations (installation of wells – e.g. flowing away water in course of compressor-using; data in connection with the maintenance, e.g. in case of district heating plant Rózsakert: paint used in the maintenance). But declarable: the received data from the operators are the most correct data from their sphere of authority.

The district heating plant Rózsakert was not divided into modules: we administered it as one unit. During the evaluation the accuracy of the environmental effects of the district heating plant Rózsakert (based on natural gas) was slightly deformed. In the „data-library" of program life cycle assessment SimaPro 7.1 the input/output data of combustion of a given quantity natural gas can be found. Here the average CO and NOx emission data can be also found, but these do not significally deviate from the measured values [12].

We divided the energy utilization system in Kistelek into smaller parts, so called modules. So, we analysed the parts lying on one another but they are well separable. The single modules of the system in Kistelek can be summed in Fig. 1 (the system in Kistelek – Kistelek – geothermal). This system is a modern district heating plant, basing only on geothermal energy carrier to provide the heat-demand for the district establishments. The heat supply is realized in a closed system by double recharging wells to protect the water-producing and deep-sited water feeding deposits. This gives yearly 10 490 GJ thermal energy from 160 000 m^3exploited thermal water [13].

We took the available data in the SimaPro 7.1 life cycle assessment program and by its support we performed the assessment, on the basis of which the extent of the environmental effects appearing in course of producing 1 MJ heat energy can be shown in connection with the single modules. On the Fig. 2 these are shown.

It is discernible from the figure, that in course of the operation the modules using the electric energy contribute to the environmental effect in almost the same extent because these systems are built on one another, surely the thermal water passes

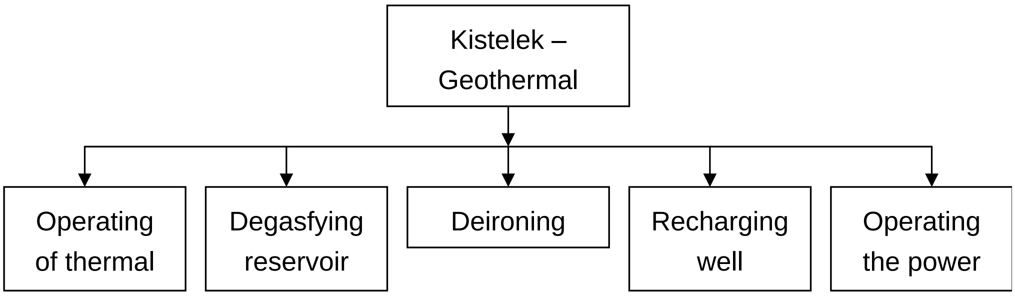

Fig. 1. The single modules of the system in Kistelek

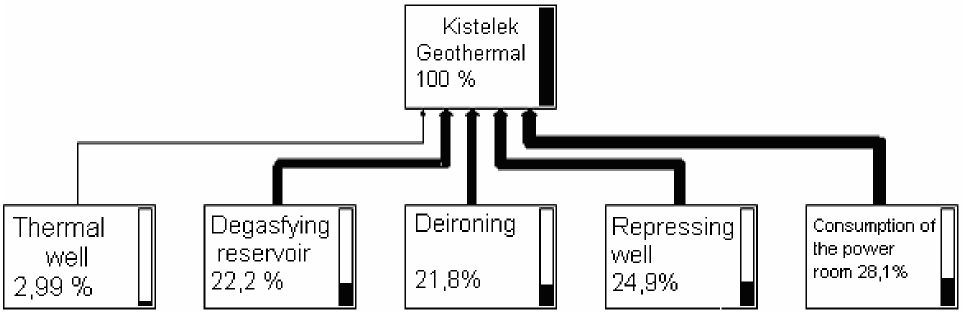

Fig. 2. The extent of the environmental effects regarding with the single elements of system in Kistelek

through these units successively to the recharging. The values of the „thermal well modulo" originate from the interpolation of the single settlements for 50 years. As it is visible that they can be compared with the yearly operating data in connection with the yearly environmental effects.

As regarding the gas fired district heating plant Rózsakert, it is easy to see, that the natural gas heating involves the environmental effect of most importance (95,8%) and it is followed by the electric energy using (4,1%).

But comparing the utilizing geothermal and natural gas systems (i.e. considering the efficacy in producing 1-1 MJ energy), then the district heating plant on natural gas basis contributes to of the environmental effects of the both systems in 85 %, and the geothermal system in Kistelek only in 15 %. So, it is unambiguous that system utilizing natural gas involves environmental effects to a 5-6 times higher extent. The proportions are shown on the Fig. 3 (district heating plant Rózsakert – Rózsakert Fossil).

On Fig. 4 the measure of the single environmental effects is shown. In case of fossil fuel the high value originates unanimously from the gas-consumption and in case of Kistelek from consumption of electric energy. For the sake of the better visibility of the other environmental effects, the fossil fuel is not shown on the logarithmic scale Fig. 5. Inside of Figs. 4 and 5 there are separatively shown the environmental effects of the district heating plant and the geothermal system in Kistelek. So, the measures of the environmental effects of the simple systems can be easily compared.

Analysing the single effects separately, can be seen, that the important effects are the respiratory inorganics, the climate change, the acidification/eutrophication, the carcinogens and the ecotoxicity.

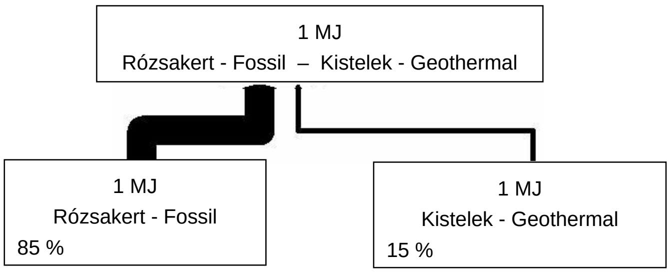

Fig. 3. The distribution of the united environmental effects of systems utilizing natural gas and geothermal energy between the both systems

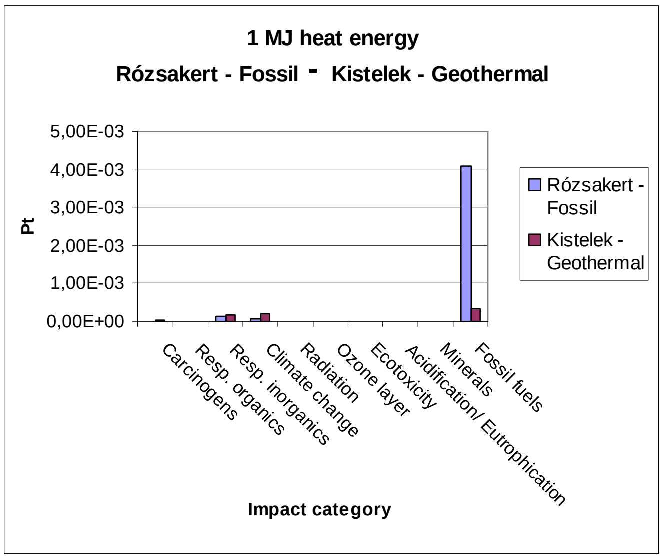

Fig. 4. Environmental effects of the gas fired district heating plant and the geothermal district heating system in Kistelek fuels

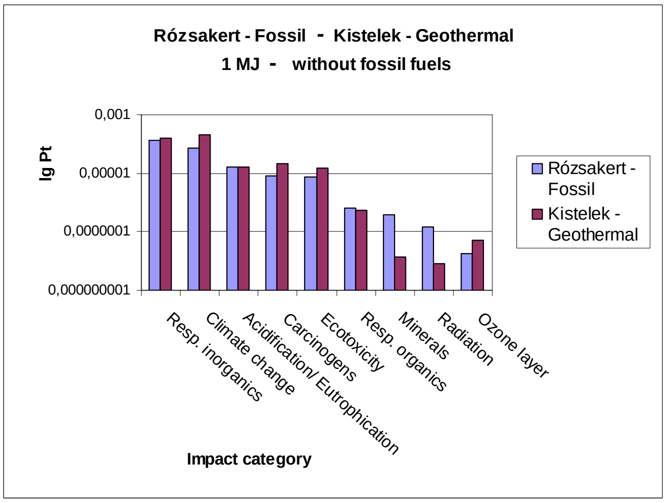

Fig. 5. Environmental effects of the gas fired district heating plant and the geothermal district heating system in Kistelek – without fossil fuels

In case of resp. inorganics at the district heating plant the natural gas heating gives 63,69%, the using of electric energy means 36,18% – by the system in Kistelek using the electric energy gives 93,8%, the Diesel-consumption 6,2%.

In case of climatic change the natural gas consumption in the district heating plant gives 66,27%, and consumption of the electric energy gives 33,59%. In the system in Kistelek the degasfying reservoir participates in the effect 59,76%, the electricity 38.72% and the single well-purifying procedures 0,67%.

At the acidification/eutrophication the natural gas consumption gives 69,68%, the electric consumption 30,18% – in Kistelek the electric energy using means 90,19%, the Diesel-energy 9,8%.

In case of carcinogens the exciting agent is the electrical consumption: in the district heating plant is 78,76% (20,71% gas consumption), in the geothermal system in Kistelek is 98,73%.

By the ecotoxicity the electric energy consumption (in the district heating plant 62,85%, in the geothermal system 97,04%), the natural gas consumption (in the district heating plant 36,30%) and the Diesel-usage (in the geothermal system 2,96%) are also the main causing agents.

These values which participate in the environmental effects are shown on the comprehensive Fig. 6 where the significance of the single processes in arousing the effects can be well seen.

It can be said about the system in Kistelek, that the electric energy consumption of the degasfying reservoir, the deironisation and the pumping up and recharging pumps are the most significant. However, the environmental effect of gases evacuating in course of degasfying and gases originating from the high gas-content of thermal water (with green-house effect) is of great significance. It is important to note, that the constructors of the system-operators in Kistelek draw up the energetic utilization of the gases of high methane-content. This would diminish the environmental effects of the electric energy supply and the degasfying reservoir. The environmental effect of the Diesel-fuel, used in course of purifying actions and well-drilling, is not negligible.

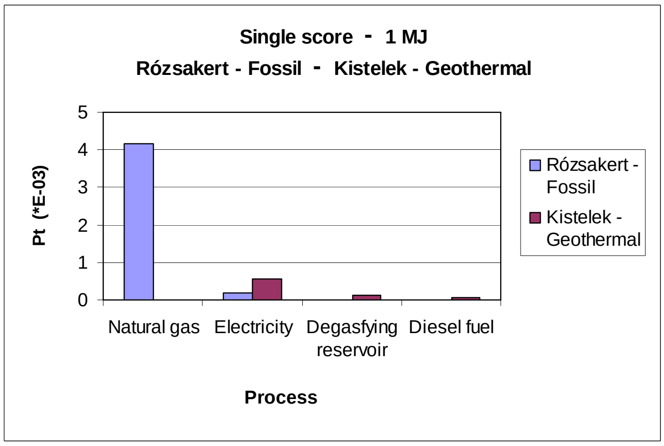

Fig. 6. Diagram 3 – Single core – District heating plant Rózsakert – Kistelek – geothermal

It is to be said, that the geothermal system compared with the district heating plant on natural gas basis produces as a consequence smaller environmental effects. They mainly consist of non-renewable energy carriers producing electric energy and of using Diesel-fuel. The measure of these effects shows the Fig. 7 where we compared the characteristics of the system in Kistelek with an ideal condition where there is no electric energy consumption to be perceptible the extent of the environmental effects of using electric energy, and to be able to read off the diagram, that this really causes the significant rate of environmental effects of the geothermal systems.

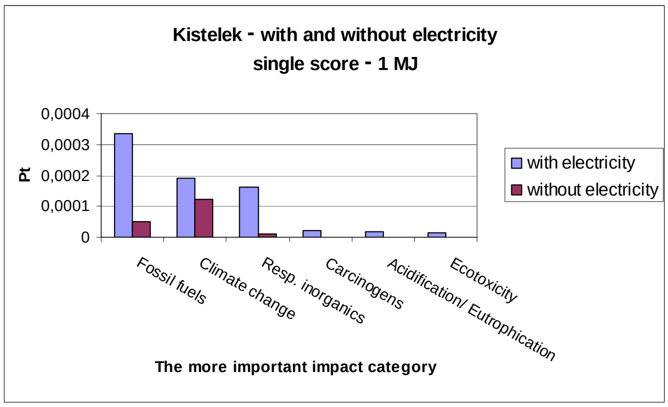

Fig. 7. Characteristics of system in Kistelek compared the situation with and without electricity

5 Conclusion

To sum it up, it can be declared, that considering the environmental effects of the utilization of the geothermal energy it is more advantageous than the natural gas utilization. It is necessary to take into consideration the composition of the gases dissolved in the water and that the composition of the thermal water shows differences in Hungary. As a result of this the emissions of the air polluter substance of the geothermal systems may be significant different. It is not negligible the result is not so good because of the present construction of the electric energy production than would have been expected.

Over and above in that case, when using the thermal heat of thermal water, would be operated by electric energy, produced from renewable energy sources, the extent of the environmental effects would diminish significantly. This would be more environmental-friendly, comparing with systems using natural gas.

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References

1 *Opinion of the European Economic and Social Committee on The use of geothermal energy (2005/C 221/05)*.

2 *COM 2001/77/EC: Directive on Electricity Production from Renewable Energy Sources*.

3 *A geotermikus energia hasznosításának lehetőségei Magyarországon*, available at http://www.zold-hid.hu/konferenciaanyaga.doc. Conference, 2002. Harkány, 23-24 January.

4 **Szőnyi Mádl J**, *A geotermikus energiahasznosítás nemzetközi és hazai helyzete, jövőbeni lehetőségei Magyarországon*, Budapest, 2008, 31. March, available at http://www.geotermika.hu/portal/files/mta-geotermika.pdf.

5 available at http://www.iea.org/Textbase/stats/electricitydata.asp?COUNTRY_CODE=HU.

6 available at http://www.geothermal-energy.org/geoworld/geoworld.php?sub=map{\&}region=europe{\&}country=hungary.

7 **Rakics R**, *Megújuló energia, geotermikus energia, termálvizek hőhasznosítása*, Környezetvédelmi és Vízügyi Minisztérium, Szentes, 26 August 2005, available at http://www.kvvm.hu/cimg/documents/RR_geotermia_08.24.2.ppt10.

8 *MSZ EN ISO 14040*.

9 **István Z, Molnár Sipos T, Szita Tóth K**, *Hazai on-line LCA adatrendszer – vállalkozások környezetbarát fejlesztésének támogatására*, available at www.lcacenter.hu.

10 **Tiderenczl G, Medgyasszay P, Szalay Z, Zorkóczy Z**, *Épületszerkezetek építésökológiai és -biológiai értékelő rendszerének összeállítása az építési anyagok hazai gyártási/előállítási adatai alapján*, available at http://real.mtak.hu/1364/1/46265_ZJ1.pdf. OTKA T/F 046265, 2004-2006.

11 *Introduction to LCA with SimaPro 7.1*, 2007 June. PRé Consultants – user manual.

12 *A Rózsakert hőkörzet ismertetése*. 2007. Budapest, December – private information.

13 *Kistelek Geotermális Közműrendszer*. 2007. Kistelek – private information.