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TECHNICAL AND ECONOMICAL EVALUATION OF USING LOW-ENTHALPY GEOTHERMAL ENERGY IN RADOMSKO, POLAND

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ABSTRACT

Technical and basic economical analysis for different ways of exploitation of geothermal energy in Radomsko, Poland are presented in this paper. The analysis includes calculation for two-wells and one-well systems of exploitation as well as for a borehole heat exchanger. Moreover the possibility of using an existing well for exploitation is examined in this paper. The calculations are based on geological, hydro-geological and economical data from the Radomsko district – localized at the Polish Lowland. The economy of each of the alternative exploitation schemes has been analysed on an annual basis over the lifetime of the project. Finally, the location of the first geothermal plant and planning of geothermal wells in Radomsko are proposed.

1. INTRODUCTION

The Radomsko town is situated at the river Radomka in the central part of Poland, in the Lodz Region. Radomsko is a city with a population of 52,000. A railway line between Katowice and Warsaw and a highway, which will soon become a part of the motorway Cieszyn - Lodz - Gdansk, go through the town. The highway is crossed with the other "A" road, Wroclaw - Kielce. Radomsko is just 190 km away from Warsaw (capital of Poland), only 105 km from Katowice, 90 km from Lodz and 38 km from Czestochowa. The location of the Radomsko district and town is shown in Figure 1. Radomsko is a developed city with a modern technical infrastructure and advantageous location. Big attention is paid to protection of the environment. In December 1998 the building of a sewage purification plant was finished. Biological and mechanical sewage purification have been projected to neutralize liquid sewage in an average 24 hour flow, estimated at about 28,000 m^3. It means that it is possible to take sewage from 57 thousand citizens. There are many parks in the city - places where children can play and places where everyone can go for a walk and take some rest. The tophography of this region is not diversified; the height above sea level is between 220 and 275 m.

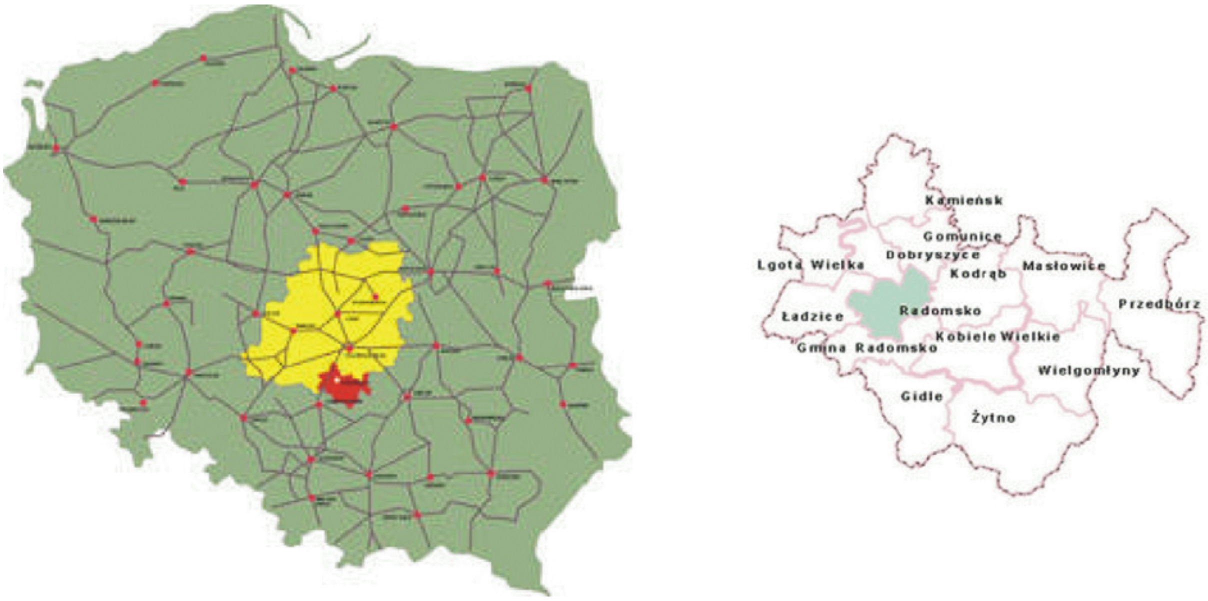

FIGURE 1: Location of Radomsko district and town

2. GEOLOGICAL CONDITIONS

2.1 Geological stratigraphy

Radomsko district is located on the axis part of Miechow Basin adjacent to the Lodz Basin. This NW-SE basin is about 50 km wide and is filled with sediments, the oldest dating from the Devon time, described here below based on information from existing exploration wells:

a. At the top are sediments of *Upper Cretaceous* age covered by *Tertiary* and *Quaternary* surfaces. The thickness of the Upper Cretaceous sediments is nearly 270 m. Main rocks of the Upper Cretaceous age are light grey marls and white-grey limestones. The porosity of these sediments reaches about 22% in well Gidle-1.
b. *The Lower Cretaceous* sediments are made of green-grey siltstones with glauconite. The thickness is from a few tens to a few hundred metres, porosity reaches about 35%, and permeability reaches 3250 mD, but is on average 1430 mD.
c. *Upper Jurassic – Malm* consists of dolomites, cavity limestones with silicates, ooliten limestones, and dark grey marls (Gignoux, 1951). Reservoir properties of this container are improved, because the roof of Malm is eroded. The thickness of these sediments is from 250 to 700 m, porosity is 4-17%.
d. Below Malm there are *Middle Jurassic sediments – Dogger* a good layer for a water reservoir. This layer is built of Bajos sandstones, porosity is above 16%.
e. *Lower Jurassic – Lias* consists here of mudstones and siltstones with grey and green clays. Lias is a very good containers layer, it is a common source of geothermal water in the Polish Lowland. The thickness of these sediments is from 100 to 300 m. Porosity reaches about 20%.
f. *Upper Triassic – Rhaetic* sediments consist of brown red mud-sandstones. The thickness of these sediments is from a few tens to a few hundred metres and the porosity is about 9%.
g. *Upper Triassic – Keuper* sediments are made of three layers - gypsum, sandstone and anhydrite-dolomite. The best reservoir properties exist in the sandstone - reed sandstone. The thickness of all these sediments is from 200 to 500 m and the porosity is 11-16%.
h. *Middle Triasic – Muschelkalk* consists of dark grey or pink limestones and brown-grey dolomites. The porosity of these rocks is near 15%.
i. *Lower Triassic – Upper Bunter* sandstone consists of pink siltstones. The porosity of these sediments is in the range 4-20%.

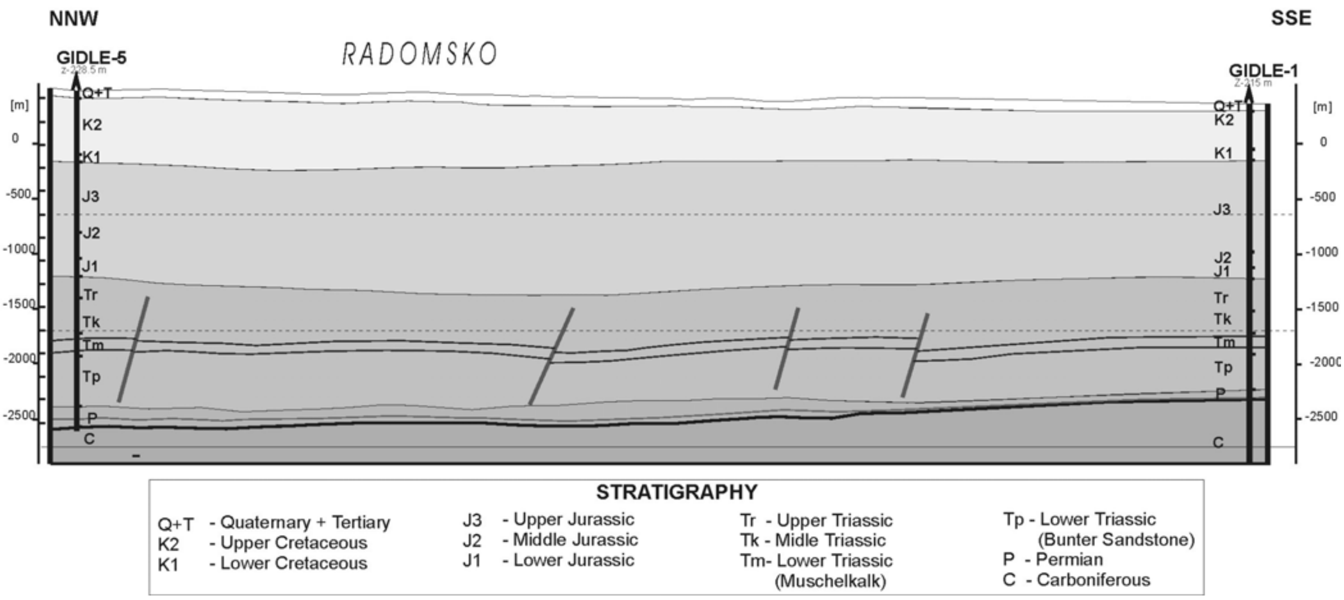

FIGURE 2: Geological cross-section across the Radomsko district

j. Below the Triassic sediments there are *Permian sediments*. These are represented by anhydrite and dolomite, with good reservoir properties - 14% porosity and 17 mD permeability.
k. Below Permian there are *Lower Carboni-ferous* sediments made of greywacke sandstones, clay and mudstones.
l. The oldest sediments penetrated by existing wells in this region are *Devonian sediments* (depth 3000-3200 m). They are represented by mudstone - marles and organogenic limestones.

Figure 2 shows a geological cross-section through the area (Sokolowski, 1992).

2.2 Exploration well data and geophysical research

There exist 13 old exploration wells in this region. From them a lot of information has been gained about the geology and the aquifers. About 30 seismic profiles have also been made here. The geological cross-section in Figure 2 was made on the basis of information from the wells Gidle-1 and Gidle-5 (GEONAFTA, 1969a and b) and from the seismic profile 17-VII-81. The Gidle-5 well is located in the Stobiecko Uniejskie in the west part of Radomsko town. The well was drilled in 1969 to a depth of 2765 m. It can probably be re-used as a geothermal well. More information about it is given in Figure 3, which shows the geological profile of the well. The location of Gidle-5 and other wells is shown in Figure 4. The figure also shows the temperature distribution in the area.

2.3 Reservoir properties of aquiferous layers and potential resources of geothermal energy

The main geographic, geological and reservoir parameters are presented in Tables 1 and 2 (Plewa, 1994).

TABLE 1: Geographic description of Radomsko region

	Area (km^2)	**Population (no.)**	**Population density (inhab/km^2)**
Lodz province	18,219	2,673,000	147
Radomsko district	1,443	125,000	87
Radomsko town	51	51,069	1,001

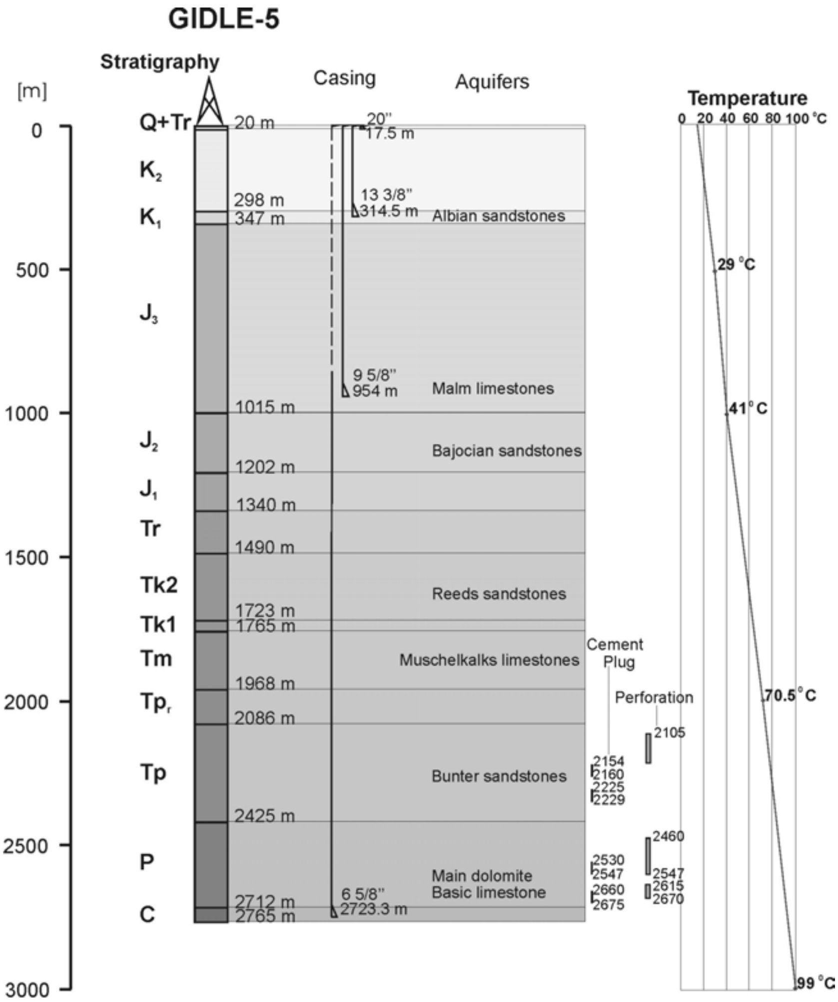

FIGURE 3: Geological and technical profile of Gidle-5 well

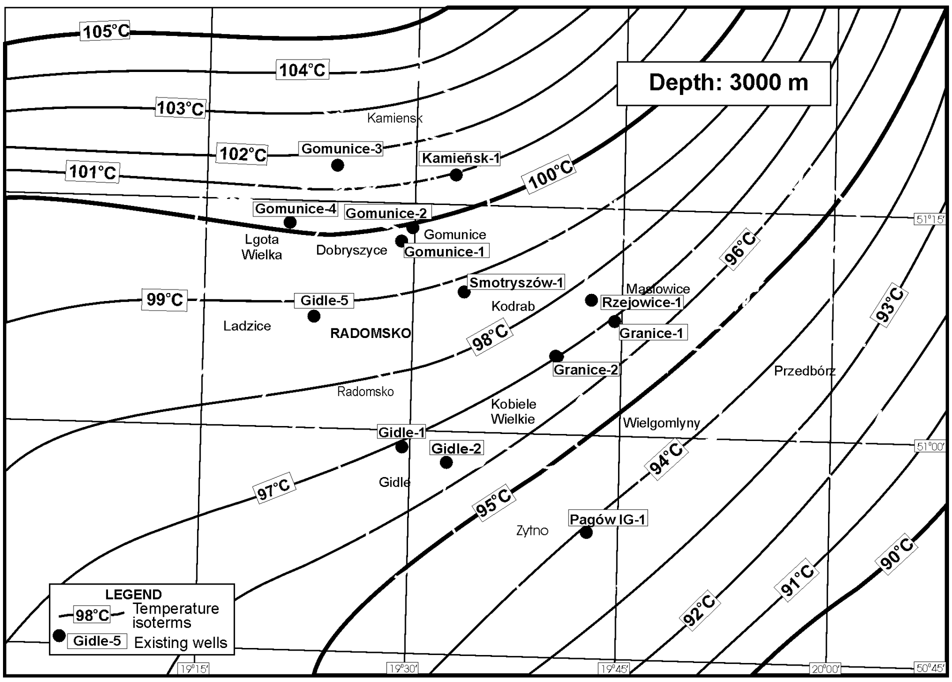

FIGURE 4: Temperature distribution at 3000 m depth and location of wells

TABLE 2: Geothermal description of Radomsko region (Sokolowski et al., 1999)

Name of aquifer	H (m)	h_1 (m)	h_2 (m)	ϕ (%)	T_r (°C)	E (10^9GJ)
Upper Cretaceous	200	270	50	15	15	-
Lower Cretaceous	-70	50	30	22	20	-
Upper Jurassic	-120	680	65	12	31	17
Middle Jurassic	-800	200	40	15	44	27
Lower Jurassic	-1000	150	60	15	49	48
Upper Triassic	-1150	350	50	14	57	50
Middle Triasic	-1500	350	90	15	67	125
Lower Triassic	-1850	350	50	10	78	57
Zechstein	-2200	300	70	12	88	105
Permian	-2500	250	70	14	96	66

H - Depth of formation top; h_1 - Average thickness of the sediment unit;
h_2 - Average thickness of aquifers; ϕ - Porosity;
T_r - Temperature of reservoir water; E - Heat energy;

3. DESCRIPTION OF DIFFERENT EXPLOITATION SYSTEMS

Geothermal energy development in the world has traditionally been related with natural heat anomalies available at the surface or at shallow depths in particular regions. France has opened the way to a new prospect for geothermal energy development, the use on a large industrial scale of geothermal energy in normal gradient areas (BRGM, 1981). Not only was it shown that geothermal energy resources exist in such areas, but also that it was technically possible and economically feasible to develop projects in such conditions. In many resource maps and technical papers, zones suitable for geothermal development have long corresponded with active plate boundaries. However, the geothermal resources are much more widely distributed. In normal gradient regions, the heat flow is on average 60 kW/km^2, and generally varies from 40 to 100 kW/km^2. Taking into account the thermal conductivity of rocks, this corresponds to a gradient of 2-5˚C per 100 m. Radomsko, like most Polish regions is similar to the Paris Basin. We can use the French experience in Polish projects, and in Radomsko.

Three parameters play a distinct role in determining the amount of water which can be extracted from a geothermal well of given characteristics:

- Fluid pressure in the reservoir, which determines whether the well is artesian, and the depth down to which the water level is drawn during pumping;
- Permeability of the reservoir rock;
- Thickness of the reservoir.

The product of thickness and permeability is transmissivity. Transmissivity is the most important parameter of geothermal reservoirs. Of course, water salinity, temperature and viscosity also play a role in the production characteristics of the geothermal well. Permeabilities above 5 Darcy are considered sufficient for geothermal production, but values of 20-50 Darcy are more suitable for average operations. Values as high as 100 Darcy may be observed in very good geothermal reservoirs. This allows flow-rates of 50-250 m^3/h for wells of standard diameters.

The installed power of a geothermal system is expressed by the product of the flowrate and of the temperature difference before and after using the water:

$$P \;=\; Q\rho c_p\,(T_p - T_i)\,/\,3600 \qquad (1)$$

where P = Thermal power of the geothermal system [kW_t];
Q = Flow-rate of the production well [m^3/h];
ρ = Density of water [kg/m^3];
c_p = Heat capacity of water [kJ/kg K];
T_p = Temperature at the production well-head [°C];
T_i = Temperature of injection (after extraction of energy) [°C];
1/3600 = Conversion rate [h/s].

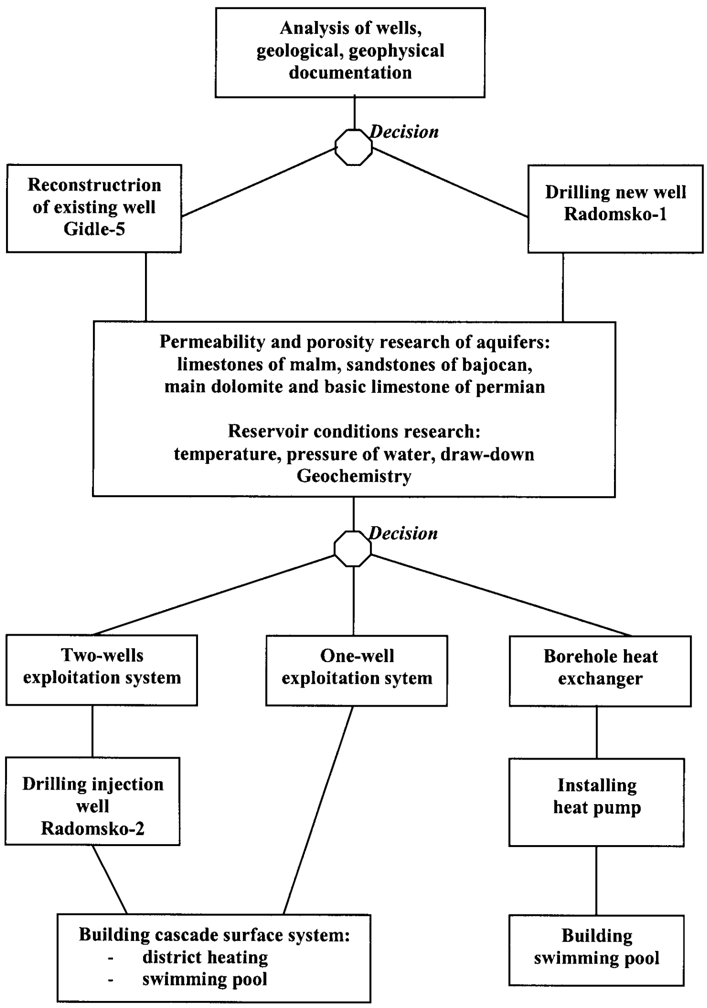

FIGURE 5: Proposal of exploration and work for geothermal development in Radomsko town

For a typical low-enthalpy field in Poland with temperature differences in the order of 30-50°C, the installed power of a single geothermal system varies from 1.20-10.75 MW. Recognition of these parameters, pressure and permeability is not sufficient for Radomsko town, so we can't decide about exploitation system without additional information. A detailed analysis of existing documentations from wells and geophysical research is the first step. After that we can make a decision about the next step. There are two ways, reconstruction of an existing well, Gidle-5, or drilling a new exploration well. Information based on this will enable a decision on the exploitation system. If research gives good results about aquifers, we can plan a one-well or two-well exploitation system. If the results are not positive we can use the exploration well as a borehole heat exchanger.

The location of this exploration well is connected with potential customers of geothermal energy. The scheme in Figure 5 explains step by step the three alternative proposals for Radomsko.

3.1 Use of existing oil and gas exploration well Gidle-5

Well Gidle-5, is located in the west part of Radomsko town. This well was drilled to search for gas and oil and is 2765 m deep. The Gidle-5 well has the following casings:

20"	0-17.5 m, cemented to top;
13 ⅜"	0-314.5 m, cemented to top;
9 ⅝"	0-954.0 m, cemented to 530 m;
6 ⅝"	0-2723.3 m, cemented to 2125 m.

After tests, cement plugs were made in the well at the depths 2670-2615 m, 2547-2460 m, 2105 m, 1150 m and 20-0 m (surface cement plug). Re-using this well requires the following work:

a. Reconstruction of Gidle-5 as a production and reinjection well.
   Drilling out cement plugs;
   Reinjection aquifer is limestones of Malm and/or sandstones of Bajocan, hence it is necessary to perforate the well at the reinjection interval 950-1100 m;
   Production aquifer is main dolomite and basic limestone of Permian, hence it is necessary to perforate the well at the production interval 2500-2700 m.
b. Research of temperature mineralization and pressure of water, test of flowrate;
c. Running-in submersible pump to the well;
d. Running-in packer to the well between pipes 9⅝" and 4½";
e. Installing heat exchanger, pipelines and other surface equipment.

For this system, we can predict the following water parameters:

Temperature at the production wellhead:	80˚C;
Temperature of injection:	20˚C;
Flowrate:	60 m^3/h.

The cost of drilling operations in Gidle-5 and related operations can be estimated as follows (in USD):

Well Gidle-5			
Casing and packer	100,000	Wellhead	45,000
Preparatory job, rigging-up	130,000	Drilling out cement plugs	50,000
Testing	450,000	Rigging-down, reclamation	100,000
		Total	875,000
Other operations			
Submersible pump	30,000	Surface equipment	50,000
		Total	80,000
		Grand total	**955,000 USD**

3.2 Two-well exploitation system (doublet)

The scheme for a two-well exploitation system is shown in Figure 6. Realization of this system requires the following jobs (Sokolowski, et al.,1999):

a. Drilling Radomsko-1, exploitation and injection well, with the following design:
   Depth 2750 m;
   Casing 20" 0-40 m;
   13 ⅜" 0-900 m;
   9 ⅝" 0-2300 m;
   7" 2250-2750 m;
   Reinjection aquifer is limestones of Malm and/or sandstones of Bajocan, hence perforating reinjection interval is 950-1100 m;
   Production aquife is Main dolomite and basic limestone of Permian, hence perforating production interval is 2500-2700 m.
b. Research of temperature mineralization and pressure of water, test of flow-rate;
c. Drilling Radomsko-2 injection well
   Depth 1350 m;
   Casing 20" 0-40 m;
   13 ⅜" 0-600 m;
   9 ⅝" 0-1350 m;
d. Running submersible pump into the production well;
e. Installing heat exchanger, pipelines and other surface equipment.

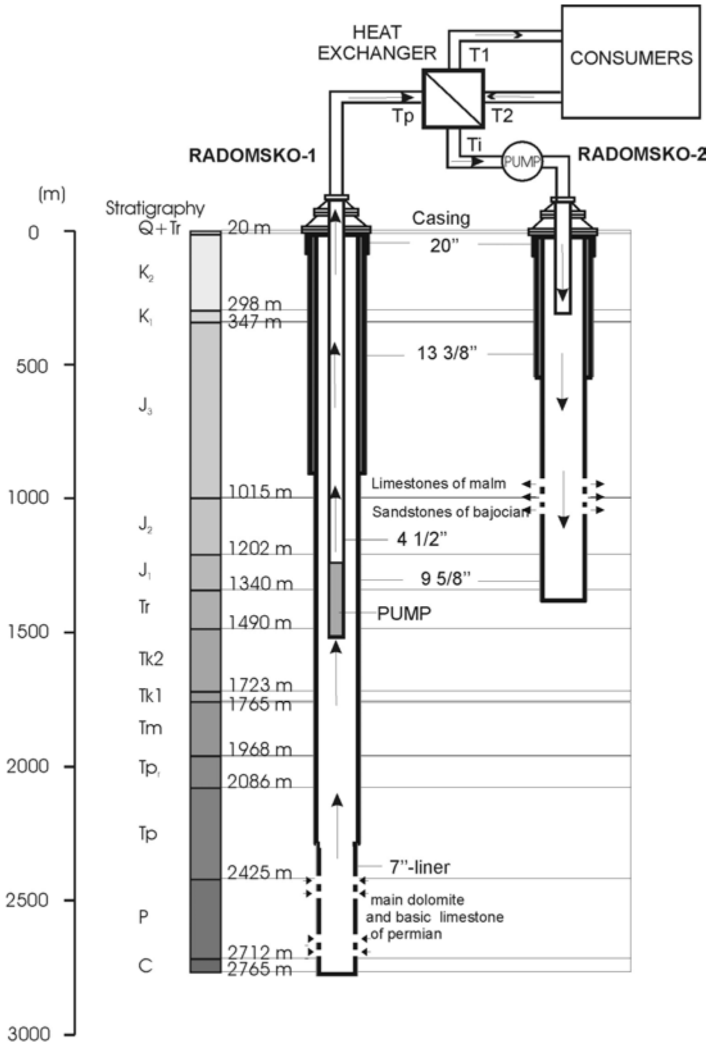

FIGURE 6: Scheme of two-well exploitation system

In this system we can predict the following water parameters:

Temperature at the production wellhead	90˚C;
Temperature of injection	20˚C;
Flowrate	100 m^3/h.

The cost of drilling and related operations can be estimated as follows (USD):

Well Radomsko-1			
Casing	260,000	Wellhead	45,000
Preparatory job, rigging-up	130,000	Drilling and cementing	900,000
Testing	365,000	Rigging-down, reclamation	100,000
		Total	1,800,000
Well Radomsko-2			
Casing	130,000	Wellhead	45,000
Preparatory job, rigging-up	60,000	Drilling and cementing	500,000
Testing	282,000	Rigging-down, reclamation	75,000
		Total	1,092,000
Other operations			
Submersible pump	30,000	Surface equipment	70,000
		Total	100,000
		Grand total	**2,992,000 USD**

3.3 One-well exploitation system

A scheme of a one-well exploitation system is shown in Figure 7. Realization of this system requires the following jobs:

a. Drilling Radomsko-1, production and reinjection well with the following design:

Depth		2750 m;.
Casing	20"	0-40 m;
	13 ⅜"	0-900 m;
	9 ⅝"	0-2300 m;
	7"	2250-2750 m;

Reinjection aquifer is limestones of Malm and/or sandstones of Bajocan, hence perforating reinjection interval is 950-1100 m; Production aquifer is Main dolomite and basic limestone of Permian, hence perforating production interval is 2500-2700 m;

b. Exploration of temperature mineralization and pressure of water, test of flowrate;

c. Running-in submersible pump to the well;

d. Running-in packer to the well between pipes 9 ⅝" and 4 ½";

e. Installing heat exchanger, pipelines and other surface equipment.

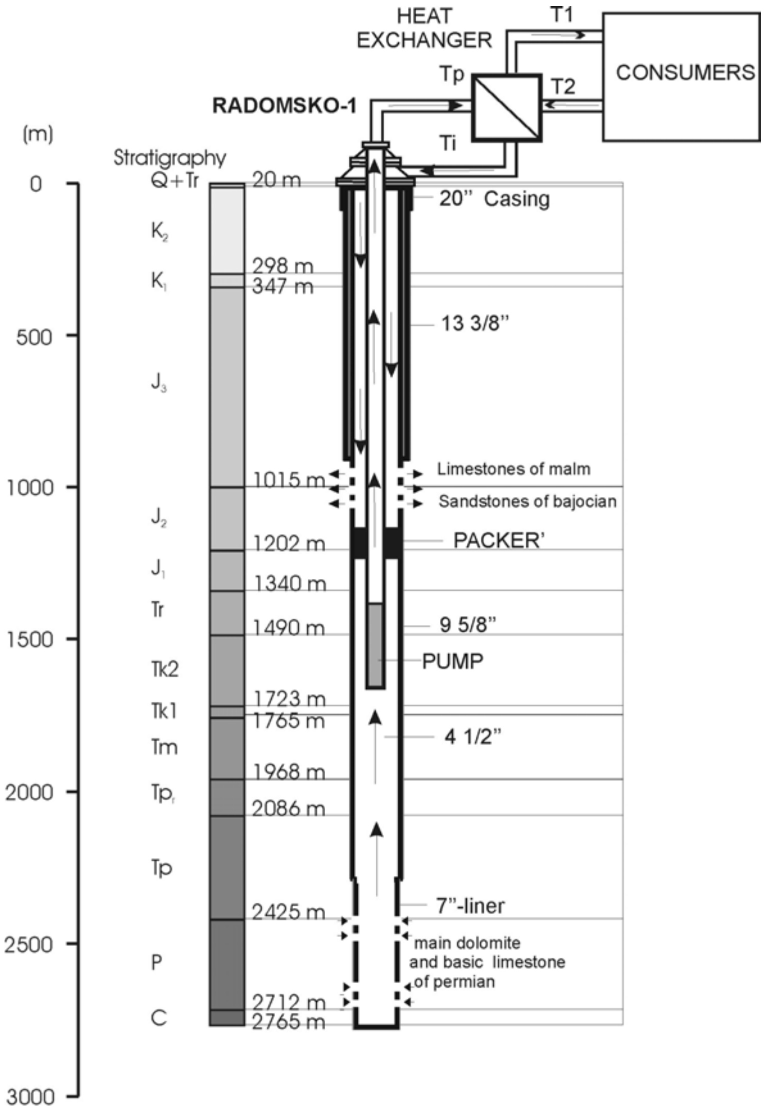

FIGURE 7: A scheme for a one-well exploitation system

In this system we can predict the following water parameters:

Temperature at the production wellhead	80˚C;
Temperature of injection	20˚C;
Flowrate	60 m^3/h.

The cost of drilling and related operations can be estimated as follows (USD):

Well Radomsko-1			
Casing and packer	290,000	Wellhead	45,000
Preparatory job, rigging-up	130,000	Drilling and cementing	900,000
Testing	450,000	Rigging-down, reclamation	100,000
		Total	1,915,000
Other operations			
Submersible pump	30,000	Surface equipment	50,000
		Total	80,000
		Grand total	**1,995,000 USD**

3.4 Borehole heat exchanger

A scheme for a borehole heat exchanger is shown in Figure 8. Realization of this system requires the following jobs:

a. Drilling Radomsko-1 for a borehole heat exchanger with the following design:

Depth		2750 m;
Casing	20"	0-40 m;
	13 ⅜"	0-900 m;
	9 ⅝"	0-2300 m;
	7"	2250-2750 m.

2. Running production pipes 2 ⅜" into the well;
3. Running insulation pipes 4 ½" into the well;
4. Running packer into the well between the pipes of 4 ½" and 2 ⅜";
5. Removing water from annular space between the pipes 4 ½" and 2 ⅜";
6. Installing heat pump, heat exchanger, pipelines and other surface equipment.

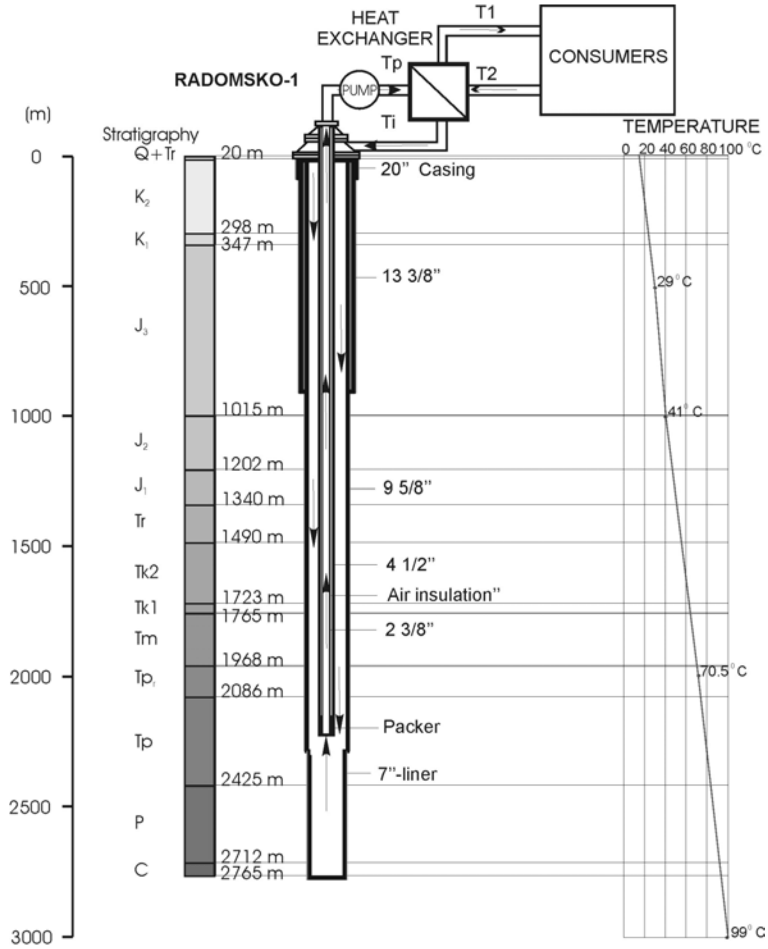

FIGURE 8: A scheme of a borehole heat exchanger

In this system we can predict the following water parameters:

Temperature at the production wellhead	50˚C;
Temperature of injection	5˚C;
Flowrate	15 m^3/h.

The cost of drilling and related operations can be estimated as follows (USD):

Well Radomsko-1			
Casing	260,000	Production pipes	100,000
Preparatory job, rigging-up	130,000	Drilling and cementing	900,000
Testing	50,000	Rigging-down, reclamation	100,000
		Total	1,540,000
Other operations			
Heat pump	100,000	Surface equipment	70,000
		Total	170,000
		Grand total	**1,710,000 USD**

3.5 Comparison and selection of the best solution

On the basis of Equation 1, we can calculate the thermal power for individual solutions, as follows:

Two-well exploitation system (doublet):

$$P \ = \ 100\ \frac{m^3}{h} \cdot \frac{1}{3600}\ \frac{h}{s} \cdot 997\ \frac{kg}{m^3} \cdot 4.2\ \frac{kJ}{kg°C} \cdot \left(90\ °C - 20\ °C\right) \ \approx \ 8{,}145\ kW_t$$

One-well exploitation sytem:

$$P \ = \ 60\ \frac{m^3}{h} \cdot \frac{1}{3600}\ \frac{h}{s} \cdot 997\ \frac{kg}{m^3} \cdot 4.2\ \frac{kJ}{kg°C} \cdot \left(80\ °C - 20\ °C\right) \ \approx \ 4{,}184\ kW_t$$

Borehole heat exchanger:

$$P \ = \ 15\ \frac{m^3}{h} \cdot \frac{1}{3600}\ \frac{h}{s} \cdot 997\ \frac{kg}{m^3} \cdot 4.2\ \frac{kJ}{kg\,°C} \cdot \left(50\ °C - 5\ °C\right) \ \approx \ 773\ kW_t$$

Borehole heat exchanger with heat pump:

$$P \ = \ 773\ kW \cdot 1.33 \ \approx \ 1{,}028\ kW_t$$

Comparison of investment costs and thermal power for individual solutions is shown in Table 3. There, six different cases are considered. Three of them are based on new wells only, while the other three are based on the utilisation of the existing Gidle-5 well.

TABLE 3: Comparison of investment costs and thermal power for individual solutions

Exploitation system	**System with new wells**			**System with existing Gidle-5 well**		
	Cost (USD)	**Power (kW_t)**	**Cost of 1 kW_t (USD/kW_t)**	**Cost (USD)**	**Power (kW_t)**	**Cost of 1 kW_t (USD/kW_t)**
Two-wells	2,992,000	8,145	367	1,962,000	8,145	241
One-well	1,995,000	4,184	476	955,000	4,184	228
Borehole heat exchanger	1,710,000	773	2,212	600,000	773	776

This comparison shows us that for a system with new wells, the two-well exploitation system is the best solution, thermal power is highest and the cost of 1 kW_t is the smallest. For a system including the existing Gidle-5 well, the total cost is reduced by about 1 million USD in every solution, and the cost of 1 kW_t is similar for two-well and one-well systems.

3.6 Proposal for location of a geothermal plant

The geothermal plant should be situated in the west part of the city near the Gidle-5 well. Local authorities are planning development of recreation and sport activities in this part of the city. Heat energy from the geothermal plant can be used in a cascade system for house heating of this part of the town and for heating a swimming pool situated in a planned recreational terrain. The location of the existing and new wells, as well as the area for recreation and sport activities is shown in Figure 9.

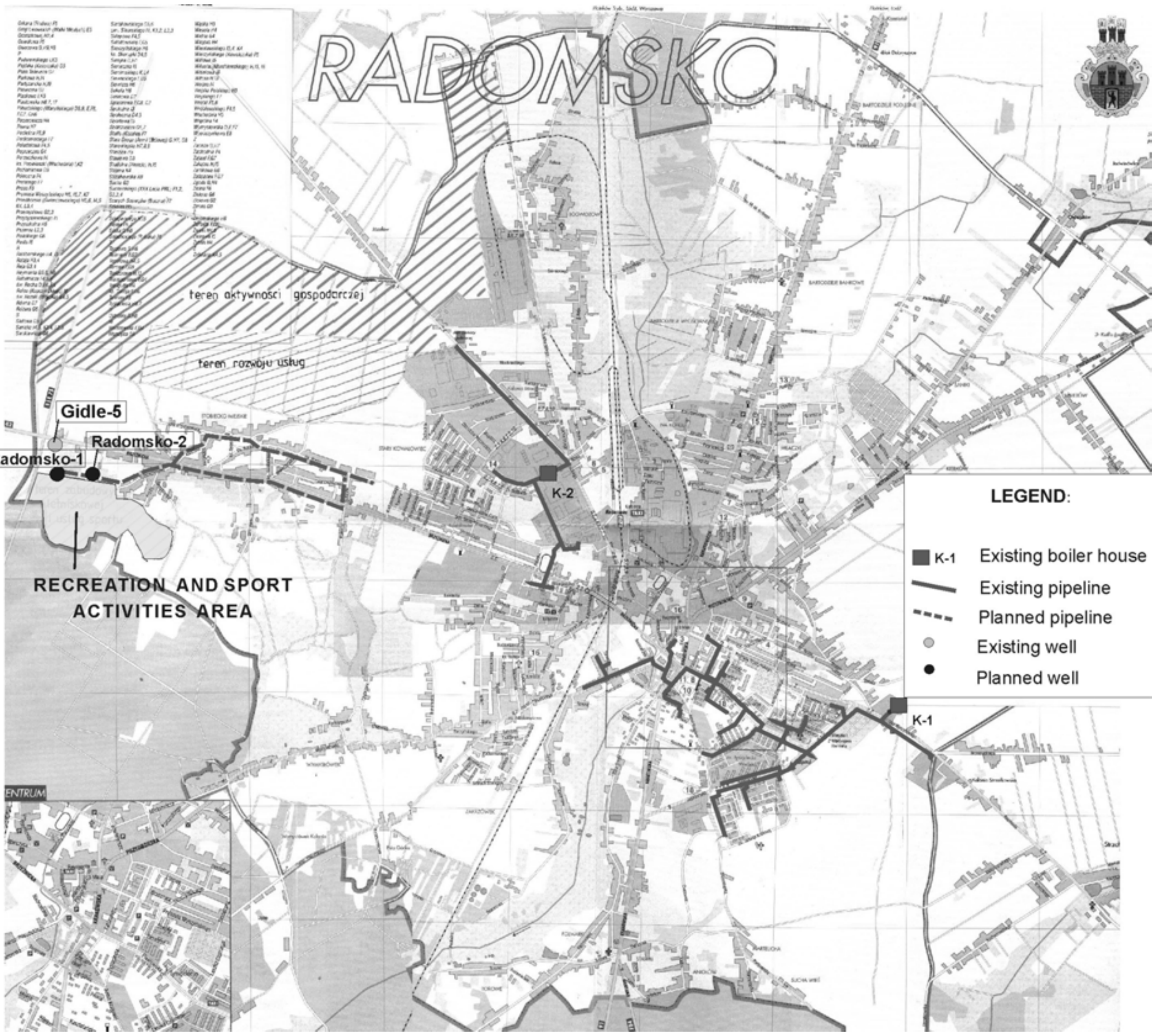

FIGURE 9: Street map of Radomsko with existing district heating and planned geothermal system

4. ECONOMIC ANALYSIS OF A GEOTHERMAL PLANT

The basic methods of analysis, which rely upon the discounting of payments to adjust for differences in timing are very simple. However, there are many different organizational contexts within which appraisals are carried out and these affect the way in which cost and earning streams are determined and, hence, their magnitudes.

4.1 Economical parameters

Cash flow (CF). The financial profile of any project consists of a series of positive and negative payments over time. The basic problem of financial/economic appraisal is to adjust the cash flow to an equivalent basis in time so that they can be compared with each other or with those of other projects. There are a number of ways in which this is done and a variety of indices can be formulated which measure aspects of the economic/financial value of a project.

Discount rate. The value of money does not depend only on its actual amount but also on the time at which the money is spent. The profits result from the ownership of the money in any form. Present value PV of the amount FV (future value) got after years j equals

$$PV_j = \frac{FV_j}{(1+r)^j} \tag{2}$$

where r = Discount rate;
j = Number of years.

Discounting of cash flows is of great importance for economical evaluation of an investment. Investment costs and future profits are disclosed in different steps of execution of a venture. That is why discounting of the value over a specific time (year) is a necessity. It makes possible the comparison of values of spent/earned money in different years.

Discount rates can be specified in different ways. Equation 3 gives good estimates of real discount rates.

$$r_a = \frac{r_c - i}{1+i} \tag{3}$$

where r_a = Real discount rate;
r_c = Interest rate of bank credits.

A more careful approach is the following equation:

$$r_a = \frac{r_k - r_d}{1+i} \tag{4}$$

where r_d = Interest rate of bank deposits;
i = Real inflation rate.

For estimating long-term investment ventures, which are important for a community, or for profits not shown directly, calculations of a social discount rate are often applied (2-4%).

Net present value (NPV) calculation is the dynamic method which takes into consideration the change of the money's value over time. The basis for calculation of net present value is the discounted values of annual cash flows. The calculation of net present value is performed in three stages. The individual payments are discounted by the appropriate amounts to determine their present values. The present value of earnings E, in year j, *PVE*, is calculated by Equation 5, and the present value of costs K_j in year j, PVK_j by Equation 6. This reduces all costs and earnings to an equivalent basis in time.

$$PVE_j = \frac{E_j}{(1+r)^j} \tag{5}$$

where E_j = Earnings in year j;

and

$$PVK_j = \frac{K_j}{(1+r)^j} \tag{6}$$

where K_j = Costs in year j.

The total present values of earnings *PVE*, and of costs, *PVK*, are obtained by summation in the following equations:

$$PVE = \sum_{j=1}^{j=n} \frac{E_j}{(1+r)^j} \tag{7}$$

and

$$PVK = \sum_{j=1}^{j=n} \frac{K_j}{(1+r)^j} \tag{8}$$

where n = Time [years].

The net present value, *NPV*, of the whole project is calculated by taking the difference between earnings and costs and subtracting any initial investment *I*, as shown in Equation 9:

$$NPV = PVE - PVK - I = \sum_{j=1}^{j=n} \frac{E_j - K_j}{(1+r)^j} - I \tag{9}$$

If the net present value is positive at this discount rate, the project is viable. If it is negative then the project is non-viable. When comparing the net present value of two projects, it is rational to choose the higher (Harrison et al., 1990).

Internal rate of return (IRR). This parameter shows the interest rate earned by investing in a particular venture and receiving cash flows as a result of that investment without regard to any other investments (Lund et al., 1998).

4.2 Investment costs of building a direct use geothermal plant and expected profit

The economic calculations shown below are made by the present value method, where all costs and revenues are discounted back to the present value to arrive at a net present value for the project (Lund et al., 1998). Table 3 includes the main economical information for the individual variants of exploitation. Six different alternatives have been considered:

- **Alternative I**: Two-well system of exploitation with existing Gidle-5 well. This means that the existing Gidle-5 well will be used for reinjection, and a new Radomsko-1 well used as a production well.

- **Alternative II**: Two-well system of exploitation with a new Radomsko-1 well. This case needs two new wells, the production well Radomsko-1 and reinjection well Radomsko-2.

- **Alternative III**: One-well system of production with the existing Gidle-5 well. This means that the existing Gidle-5 well will be used for production and for reinjection at the same time.

- **Alternative IV**: One-well system of production with a new Radomsko-1 well. This means that a new Radomsko-1 well will be used for production and for reinjection at the same time.

- **Alternative V**: Borehole heat exchanger in the existing Gidle-5 well. This means that a borehole heat exchanger will be installed in the existing Gidle-5 well.

- **Alternative VI**: Borehole heat exchanger in a new Radomsko-1 well. This means that a borehole heat exchanger will be installed in a new Radomsko-1 well.

Foregoing information enables calculation of some economical parameters such as cash flow (CF), net present value (NPV) and internal rate of return (IRR). Results of these calculations for each individual variant are shown in the charts in Figures 10-15.

Comparison of different variants enabled a choice of the best solution for Radomsko which is alternative I. This variant has the best economical and technical properties. This case can give the technical and economical parameters shown in Table 5.

TABLE 4: Economical analysis for individual systems of exploitation

		Two-well system		One-well system		Boreh. heat exch.	
		Ex. well	**New well**	**Ex. well**	**New well**	**Ex. well**	**New well**
Alternative		**I**	**II**	**III**	**IV**	**V**	**VI**
Investment cost							
Drilling and related operations	[USD]	1,962,000	2,992,000	955,000	1,995,000	600,000	1,710,000
District heating	[USD]	2,880,000	2,880,000	1,800,000	1,800,000	360,000	360,000
price of 1 m pipeline	[USD]	300	300	300	300	300	300
length of pipeline	[m]	9,600	9,600	6,000	6,000	1,200	1,200
Thermal station building	[USD]	100,000	100,000	100,000	100,000	100,000	100,000
Price of 1 m^2 surface 2,000	[USD]	50	50	50	50	50	50
Design and management*	[USD]	247,100	298,600	142,750	194,750	53,000	108,500
Total investment cost	**[USD]**	**5,189,100**	**6,270,600**	**2,997,750**	**4,089,750**	**1,113,000**	**2,278,500**
Investment cost in individual years							
2002 30%	[USD]	1,556,730	1,881,180	899,325	1,226,925	333,900	683,550
2001 40%	[USD]	2,075,640	2,508,240	1,199,100	1,635,900	445,200	911,400
2003 20%	[USD]	1,037,820	1,254,120	599,550	817,950	222,600	455,700
2004 10%	[USD]	518,910	627,060	299,775	408,975	111,300	227,850
Annual operating cost**	**[USD]**	**77,837**	**94,059**	**44,966**	**61,346**	**16,695**	**34,178**
Own financial means	**[USD]**	**2,335,095**	**2,821,770**	**1,348,988**	**1,840,388**	**500,850**	**1,025,325**
CREDIT***							
Pay back	12 years						
Scale	55% of investment						
Beginning of repayment	2 years						
Interest rate	8%						
Value	**[USD]**	**2,854,005**	**3,448,830**	**1,648,763**	**2,249,363**	**612,150**	**1,253,175**
YIELD							
Operating time in year	300 days						
Price of 1 GJ energy	[USD]	8	8	8	9	10	20
Available thermal power	[kW]	8,145	8,145	4,184	4,184	1,028	1,028
Heat consumption in year	[GJ]	211,118	211,118	108,449	108,449	26,646	26,646
Annual yield	**[USD]**	**1,688,947**	**1,688,947**	**867,594**	**976,044**	**26,458**	**532,915**
Year of investment beginning	2002						
Exploitation time	5 years						
Discount rate	10%						
Income tax	22%						

* Design and management costs are 5% of the total investment cost;
** Annual operating cost is 1.5% of the total investment cost;
*** Credit from bank was considered as a special type of credit connected with low interest rates because of the pro-ecological character of the solution.

TABLE 5: Main technical and economical parameters for the best alternative, no. 1

Technical		**Economical**	
Temperature of exploited water	90˚C	Total investment cost	5,189,100 USD
Temperature of reinjected water	20˚C	Annual operating cost	77,837 USD
Flowrate	100 m^3/h	Accumulated cash flow	22,556,582 USD
Available thermal power	8,145 kW	Net present value	3,065,797 USD
		Internal rate of return	17%

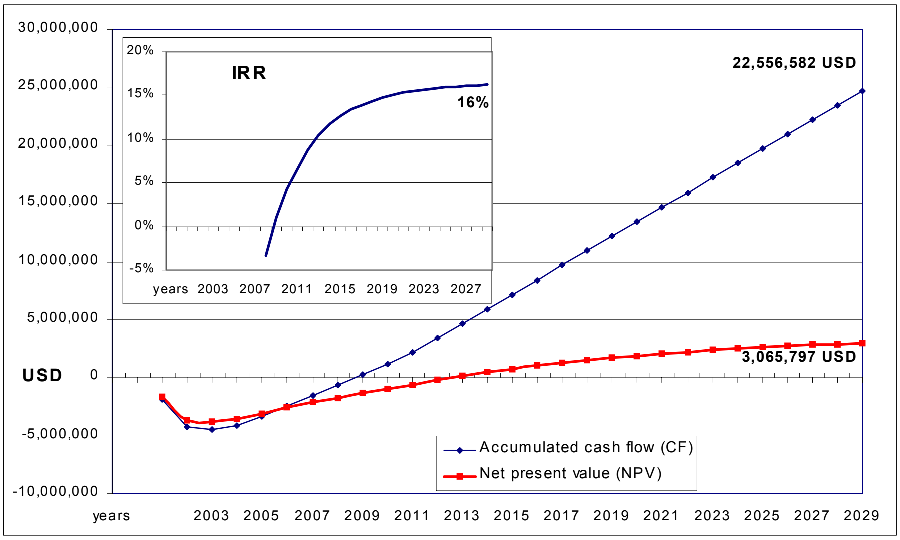

FIGURE 10: Economic analysis of a two-well system of exploitation with the existing Gidle-5 well (Alternative I)

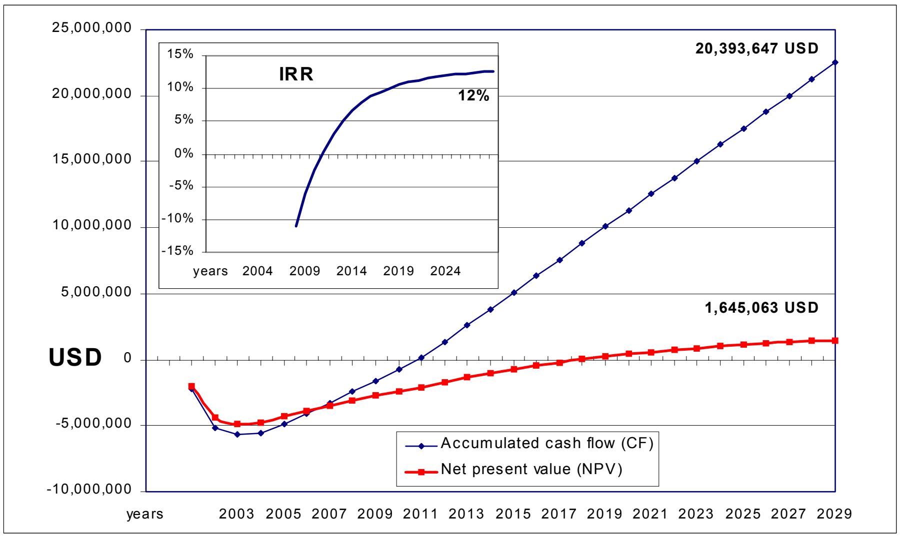

FIGURE 11: Economic analysis of a two-well system of exploitation with a new Radomsko-1 well (Alternative II)

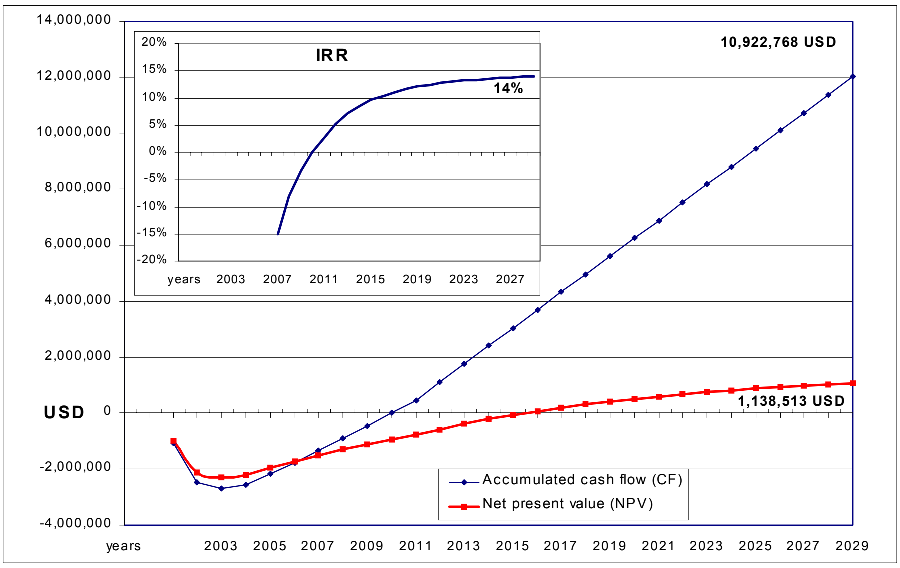

FIGURE 12: Economic analysis of a one-well system of exploitation in the existing Gidle-5 well (Alternative III)

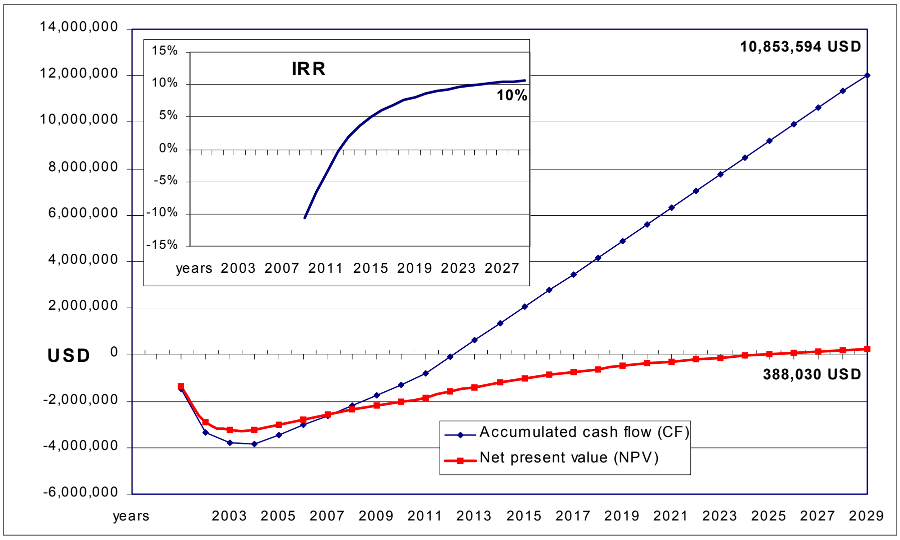

FIGURE 13: Economic analysis of a one-well system of exploitation with a new Radomsko-1 well (Alternative IV)

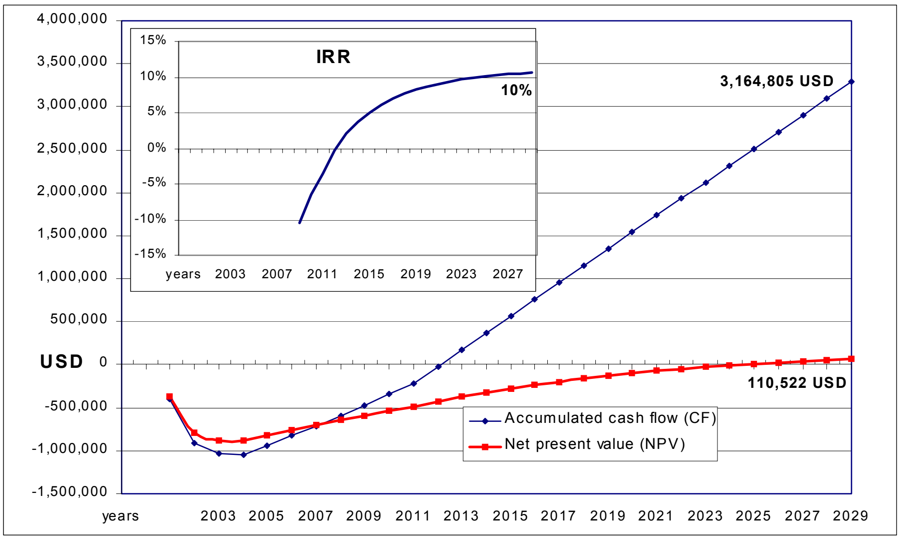

FIGURE 14: Economic analysis of a borehole heat exchanger in the existing Gidle-5 well (Alternative V)

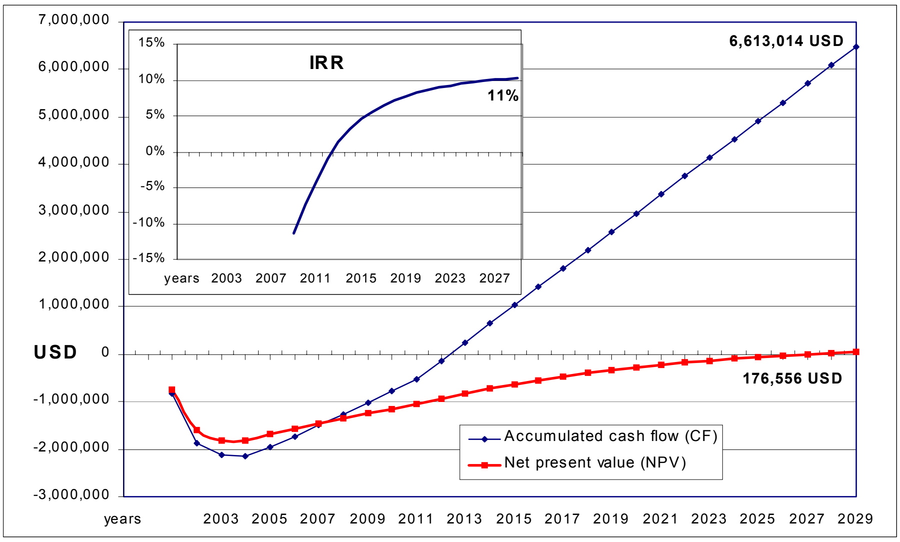

FIGURE 15: Economic analysis of a borehole heat exchanger in a new Radomsko-1 well (Alternative VI)

4.3 Financing of geothermal projects

There are basic types of international financing available to the energy sector (Elíasson, 2001) which are

Grants;
Special purpose funds;
Loans.

It is possible to obtain partial financing of definitive, well-defined and feasible geothermal development projects in the form of a grant from EU funds provided such a project unequivocally falls under an appropriate key-action specification set by the European Commission. These partial (<40%) funds are available from the Vth Framework Programme (5FP) and other independent EU programmes such as the ALTENER, SAVE, CRAFT which are run by the EC's DG TREN and the INCO-Copernicus which is run by DG TREN. The 5FP programmes applicable in the case of geothermal energy are the SYNERGY (international projects) and ENERGY (Thermie) programmes.

There are a number of possibilities of obtaining partial financing of geothermal energy projects from special purpose financing sources such as the Nordic Environment Finance Corporation (NEFCO), the United Nations Development Programme's Global Environmental Fund (UNDP-GEF) and the various Nordic Development Co-operation Funds (here called Nordic aid), e.g. Sida, Danida, Icida etc.

- *NEFCO.* Participates as a risk capital financier in environmental investment projects, particularly in Central and East European countries with positive effects also for the Nordic region. Projects should be both ecologically and economically sound, i.e. viable investment projects with a positive environmental effect (equity investments 25-35% of total - minimum 125,000 Euro and maximum 3,000,000 Euro per project).

- *UNDP-GEF.* With the WB the UNDP-GEF helps countries to translate global concerns into national action in fighting ozone depletion, global warming, and loss of biodiversity, and pollution of international waters. It provides grants (Small Grants Programme - max. grants up to USD 50,000) and a concessional loan fund of agreed incremental costs associated with above 4 focal points.

Polish institutions can finance geothermal projects in Poland such as this project for Radomsko. There are following institutions:

- *EcoFund*. The EcoFund is a foundation established in 1992 by the Minister of Finance for the purposes of effective management of funds obtained through the conversion of a part of Polish foreign debt with the aim of supporting environmental protection-related endeavours (so-called debt-for-environment swaps). To date, Polish debt-for-environment swap decisions have been taken by the United States, France, Switzerland, Italy, Norway and Sweden; hence the EcoFund is managing funds provided by all the aforementioned countries (a total of USD 571 million to be spent in the years 1992-2010).

- *The National fund for environmental protection and water management.* Its objectives and scope of activities are defined by the following acts:

  Protection and shaping of the environment act
  Water act
  Geological and mining act

  The main objective of the National fund is funding projects which serve the protection of the environment. These projects have been described in the "National environmental policy" adopted by the Polish Parliament in 1991 and specified in the "Implementation programme for the National environmental policy by the year 2000". Their implementation is supervised by the Minister of Environmental Protection, Natural Resources and Forestry.

- *KBN* - The State Committee for Scientific Research is a governmental body which was set up by the Polish Parliament on 12th January 1991. The act has established the committee as the supreme authority on state policy in the area of science and technology. According to the act, the committee is the major central governmental source of funds for research. The committee became active during the period of transition from a centrally-planned system to a market economy.

5. CONCLUSIONS

There are some aquifers in the Radomsko district, which can be used as a source of low-temperature geothermal water. The best conditions are in Zechstein and Permian sediments. The depth of these is from 2200 m to 2500 m and the reservoir temperature is between 88 and 96°C.

Water from aquifers can be exploited in three ways:

- Two-well exploitation system, with 8,145 kW_t available thermal power;
- One-well exploitation system, with 4,184 kW_t available thermal power;
- Borehole heat exchanger with 1,028 kW_t available thermal power.

Total drilling costs and related operations are

- 2,992,000 USD for a two-well system;
- 1,995,000 USD for a one-well system; and
- 1,710,000 USD for a borehole heat exchanger.

The well Gidle-5 exists already in the Radomsko town. This well might be used for exploitation of geothermal energy. If this is possible, the cost of the exploitation system can be reduced by 30%.

Technical and economical analysis show which exploitation system brings the best solution. It shows that the best way of exploiting geothermal energy in Radomsko is a two-well system with the existing Gidle-5 well. The total investment cost for this variant amounts about 5,189,100 USD, and the net present value is 3,065,797 USD. The internal rate of return is 17% for 25 years of exploitation.

Polish and international institutions can finance geothermal projects such as this. Such Polish institutions are: EcoFund, The National Fund for Environmental Protection and Water Management and KBN - The State Committee for Scientific Research. There are also some international grants available, such as ALTENER, SAVE, CRAFT and others from V^{th} Framework Programme (5FP) and other independent EU programmes.

Heat from the described system can be used in a cascaded system for house heating in the western part of the town and for heating a swimming pool situated in a recreation area scheduled in the western part of the town.

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REFERENCES

BRGM, 1981: *Low enthalpy geothermal energy technical and economic feasibility, development in France.* Bureau de Recherches Geologiques et Minieres, Geothermal Department, Orleans Cedex, 9 pp.

Elíasson, E.T., 2001: *Feasibility analyses and financing of geothermal projects.* UNU G.T.P., Iceland, unpublished lectures.

GEONAFTA, 1969a: *Geological documentation of Gidle-1 well.* Geological Bureau GEONAFTA, Krakow, unpublished data report.

GEONAFTA, 1969b: *Geological documentation of Gidle-5 well.* Geological Bureau GEONAFTA, Krakow, unpublished data report.

Gignoux M., 1951: *Stratigraphic geology.* W.H. Freeman and Co, San Francisco and London, 682 pp.

Harrison, R., Mortimer, N.D., and Smárason, Ó.B., 1990: *Geothermal heating: A handbook of engineering economics.* Pergamon Press, Oxford, 558 pp.

Lund, J.W., Lienau, P.J., and Lunis, B.C., 1998: *Geothermal direct- use engineering and design guidebook.* Geo-Heat Center, Oregon Institute of Technology, Or, USA, 454 pp.

Plewa S., 1994: *Distribution of geothermal parameters on the territory of Poland* (in Polish). Wydawnictwo CPPGSMiE PAN, Krakow, 138 pp.

Sokolowski J., 1992: *Geosynoptical atlas of Poland.* Wydawnictwo CPPGSMiE PAN, Kraków, 52 maps.

Sokolowski, J., Kotyza, J., Florek, R., Ludwikowski, B., 1999: *Estimate resources of geothermal energy for Radomsko.* POLGEOTERMIA Sp. z o.o., Krakow, unpublished project.