ECONOMICS OF GEOTHERMAL ENERGY

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ARSTRACT

In order to be successful, geothermal energy must be cheaper than the competitors, i.e. the alternative forms of energy. Depending on the use of the geothermal energy, the competitors are: 1) electricity production: fuel oil, and 2) heat production: natural gas.

For the production of electricity, the geothermal energy is cheaper than the alternative fuel oil energy for a wide and actual range of fuel oil prices and well productivities, while for the production of heat the range is becoming narrow.

1. INTRODUCTION

The main concern of a likely investor when examining the feasibility of a geothermal development derives from two basic questions: 1) how great is the risk of having no technical success (no productive wells), is it possible to remove it and, if yes, with how much money? and 2) once obtained the technical success, how do the economics of the project face alternative solutions?

The risk of a geothermal development cannot be removed, so that there is no direct answer to the first question; however it is possible to figure out economic scenarios resulting from full to minimum rate of success.

The geothermal energy may be used either for conversion into electric energy or direct heat (dwellings or process) ,or, sometimes, for a combination of both. The factor determining which is the primary use of the geothermal energy is the temperature of its resource, which is reflected into a different degree of risk and into a different level of costs; two different scenarios are therefore envisaged: one for generation of electricity and one for generation of heat (only the use for district heating is considered).

2. METHODOLOGY

For each one of the two base scenarios (electricity or district heating) an effort has been made in order to individuate leading parameters in the economic comparison between the geothermal project and the alternative project.

To achieve this goal, a series of possible projects has been defined and, for each of them, the costs of the unit of energy (electric kWh or thermal GJ) have been calculated, according to the "present value" methodology, under several hypotheses of unit costs and project configurations. The costs of the units of energy are then compared with those obtainable with fossil fuel sources

In order to simplify such a voluminous task, some simplifications have been applied, amongst which the most important is that the plant cost per unit power (US$/kW) is considered as a constant (given a plant configuration), with the only exception of the transport pipe from the source to the user in the case of district heating. Such a simplification is not as coarse as it appears to be: it is a fact of the present technology the "modularity" of the plants. which are manufactured according to a "standard" six, so that often a plant consists of multiple identical units, with a reduced specific (per kW) saving, but with large benefits in assembling, erecting and delivery time.

The cost of the energy is calculated by the ratio: yearly expenditures over yearly production. The yearly expenditures consist of the capital recovery plus operation, maintenance, engineering and administration (all together simply called Operation and Maintenance).

The discount rates applied are 6,8,10% for the generation of heat and 8,10,12% for the generation of electricity, over a life time of 20 years. The different discounted values create "ranges" of figures, which may also be read as variations in the investments, discounted at a unique rate.

Specific economic parameters, such as inflation, exchange rate, financial conditions, interests during construction, are not taken into account.

The costs considered are those of an international open market, with no taxes applied. However, it must be noted that taxes for oil products are applied in many countries.

Comments on the implication of the simplifications adopted will be given when presenting the results.

3. GENERATION OF ELECTRICITY

3.1 Geothermal Project

The cost of the geothermal project is represented by all the works and plants needed in order to produce the goods (kW of electricity) which originate the income; such works and plants are listed in Table 1, together with an estimate of their costs. The costs are subject to variations due *to* market conditions and these would reflect in variations of the cost of energy.

TABLE 1 - INITIAL HYPOTHESES GENERATION OF ELECTRICITY GEOTHERMAL SOURCE

Investments		
Field:		
wells (1,500 m, 9"⅝)	US$	1.5 E6
surface equipment	US$	0.2 E6
steam **pipes**	US$	**0.3 E6**
water **pipes**	US$	0.1 E6
reinjection and failures **rates**	%	*70*
Power Plant:		
Equipment	US$/kW	1,000
Civil Works	US$/kW	100
Assembly and Erection	US$/kW	150
Operation and Maintenance		
Percentage of relevant capital investment		
Wells:		
working over **and redrilling**	%	30
Power **Plant:**	%	15

However: due to the **peculiar** structure **of** the costs of **wells (cost** per well nearly constant - Hiriart, 1994) and of the plant (cost **per** kW nearly constant), **the leading** factor **in** determining the cost of the energy produced is the productivity **of** the wells, (as presented by Girelli, 1989).

The quantification of these concepts is presented in **Fig. 1**, **where** the costs of the energy **produced** (US$/MWh) **are** plotted **versus** the productivity **of** the well (MW/well).

According to the hypotheses, the **cost** derived **from** the investment on **the** power plant is constant and the one derived from the wells follows a hyperbolic **trend;** at a productivity **of about** 3 MW/well, it can be seen that *the* equalization between the two costs (wells and power plant) is reached, supporting the rule **of** thumb **of** a 50-50 share.

In Fig.2 the total cost (sum **of** the two shares) is shown.

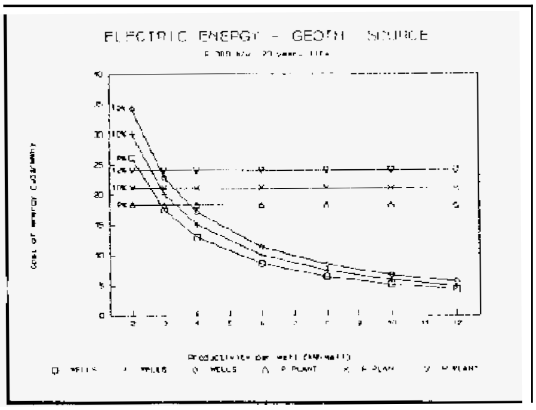

Figure 1 Cost of energy vs productivity of the wells (shares from the wells and from the power **plant)**

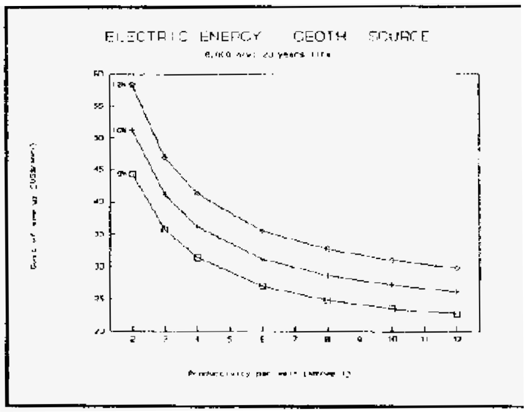

Figure 2 Cost of energy vs productivity of the wells

3.2 Alternative Project

The alternative **project** consists of a thermal power **plant,** burning **fuel** oil, **in the** range of **power** 80-100 MW, which **is common** for developing countries. In order **to** produce energy, it is needed to burn fuel, **that** becomes **a** part of the yearly expenditures. The cost of the power plant **and its** technical characteristics are indicated in Table 2

TABLE 2 - INITIAL HYPOTHESES GENERATION OF ELECTRICITY FOSSIL SOURCE

Investment for the Power Plant	US$/kW	800
Operation & Maintenance	US$/MWh	6
Technical Data		
heat rate	kJ/kWh	9,250
fuel heat content	kJ/kg	40,000
fuel specific. consump.	kg/MWh	230
yearly hours **of** full load	h/y	6,500

The relevant calculations are presented in Fig.3, where the cost of the energy produced (US$/MWh) are plotted versus the cost of the oil barrel (US$/barrel).

It can be noted that also in this graph there is an equalization point, at about 14 US$/barrel, where the cost deriving from the power plant is the same as the one deriving from the fuel.

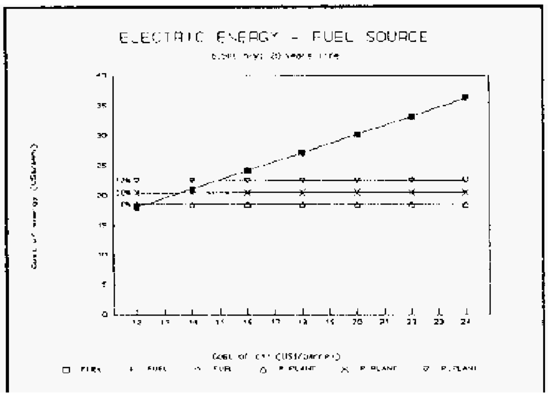

Figure 3 *Cost* of energy vs cost of oil barrel (shares from the puwer plant and from the fuel)

In Fig.4 the total cost (sum of the two shares) is indicated.

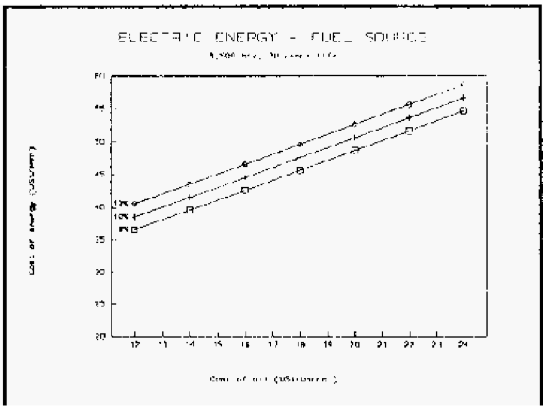

Figure 4 Cost of energy vs cost of oil barrel

3,3 Comments

The comparison between the costs of electric energy derived from geothermal arid fossil sources must start from the present cost of the barrel of oil and the likely, or statistical, productivity of the geothermal wells.

Comparing Fig.2 with Fig.4, it appears that, at the present cost of the barrel, of about 14–15 US$, any geothermal field with a productivity over *3* MW/well can produce electricity cheaper than a thermal power plant.

Since a reasonable average production of a geothermal well! even after its stabilization period and considering the long term longevity, is over *5* MW in most of the geothermal fields, it comes out that the use of geothermal energy tu produce electric energy in very attractive indeed.

Looking again at the two graphs, it can be easily seen that with a productivity of 5 MW per well, the geothermal source is competitive up to a cost of the barrel below *9* US$ (out of scale in the graph),

In order to better focus such favourable results, it is advisable to comment further on the initial hypotheses (Table 1).

These hypotheses include an extra cost of 70% of the cost of each well, allowing for reinjection and failures, meaning that in a field of 17 well, 10 are productive and 7 are not, because of failures (dry wells) or because devoted to reinjection.

A large deviation from this hypothesis would very likely imply that the field is weak (poor permeability and poor production); this fact would he evident since the first drilling?, leading tu a negative result of the feasibility study.

In conclusion, it is reasonable to state that a good geothermal field can produce electric energy at a cost lower than that achievable by conventional thermal puwer plants, provided the cost of the oil barrel is greater than 9 US$.

I. GENERATION OF HEAT

The alternative source is thought to be natural gas directly delivered to the user. The cost does include the transport network.

There should be also the *cost* of the home boiler but, thinking of heating apartments and also of large utilization periods per year (see the following results), the cost of the home boiler has been disregarded.

The initial hypotheses are reported in Table 3.

TABLE *3* – INITIAL HYPOTHESES GENERATION OF HEAT NATURAL GAS

Efficiency of the boiler		.85
Heat content of the natural gas	MJ/m^3_n	34.0
Natural gas specific consumption at the user	m^3/GJ	34.6

According to these hypotheses, the cust of the energy is simply given by the specific consumption ai the user (m^3_n/GJ) multiplied by the cost of the natural gas (US$/$m^3_n$). This is of course a linear relationship, plotted in Fig.5.

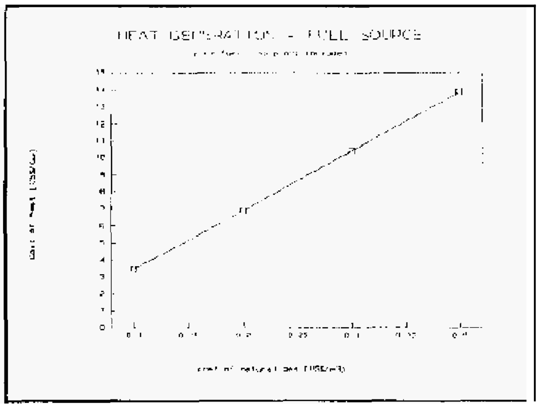

Figure 5 Cost of energy vs cost of natural gas

The present cost of natural gas is about 0.14 US$/$m^3_n$, giving a cost of energy of about 5 US$/GJ.

A geothermal project for the generation of heat needs a minimum of two wells, one for production and the other one for reinjection (a doublet). The production from the wells is induced by a pump and this creates a sort of "standard" for the flow rate of each well (but not for the energy needed to pump that flow rate, since the hydraulic head is peculiar of each well). The transport is in a closed twin circuit, with hot water going to the user and cold water coming back to the geothermal field.

The costs of the production plant and of the distribution network are considered to vary linearly with the flow rate, whereas the cost of the transport pipe is increasing less than linearly with it.

By these assumptions, the non-linear parameters with respect to the thermal power installed, are the distance from the source to the user and the size of the plant. The latter is less important, since it affects only the transport pipe.

These concepts and the costs related with the works and plants are summarized in Table 4.

The goods sold (GJ of heat) are linear with the hours per year of utilization of the geothermal heat source, so that the period of utilization becomes the leading factor in determining the cost of the energy sold.

The first calculation made is a "scanning" of the possibility of producing heat at a cost competitive with the natural gas. Therefore the case examined is the one of less cost, with no transport pipe included, that is with the user right at the geothermal field.

The obvious importance of this calculation consists in determining whether the condition can exist in which the geothermal heat is cheaper than the alternative one (natural gas).

TABLE 4 - INITIAL HYPOTHESES GENERATION OF HEAT GEOTHERMAL SOURCE

Investments		
wells (1,500 m; 9"5/8)	US$	1.5E6
minimum step:		
1 doublet	US$	3.0E6
corresponding to	US$	250/kW_t
production plant	US$	800/kW_t
distribution network	US$	60/kW_t
transport pipe (twin circuits) Po = 12 MWt	US$	$40x(P_o/P)^{0.4}$ /kW_txkm
Operation and Maintenance		
percentage of relevant capital investment		
wells	%	1
production and distribution network	%	8
transport pipe	%	1
Electric Energy (pumping)		
electric energy price	US$/MWh	60
electric energy consumption:		
wells	kW_e/MW_t	15
transport (twin circuits)	$kW_e/(MW_t$xkm)	0.4
Technical Data		
flow rate (pumped)	m^3/(hxwell)	2110
temp.drop geothermal	°C	60
temp.drop geothermal user	°C	52
heat generation	MW_t/doublet	12
pumping heat (prod+reinj.)	m	200
head losses in transport pipe (twin circuits)	m/km	6

The results are presented in Fig 6, where the costs of the energy produced (US$/GJ) are plotted versus the hours of utilization per year.

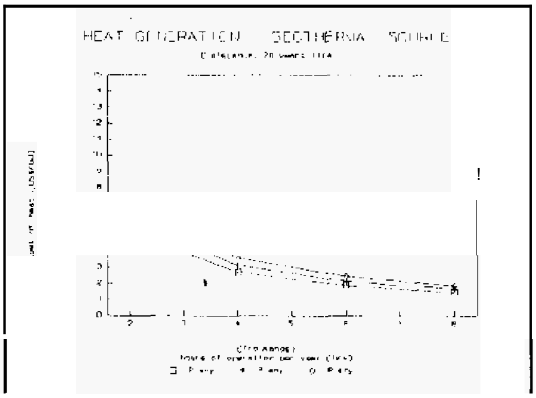

Figure 6 Cost of energy vs hours of utilization per year

A first important result is achieved, in order to be competitive (cheaper than 5 US$/GJ) the geothermal energy must: 1) have utilization times over 3,000 h/y or 2) be subsidized by very soft financial conditions (interest on capital lower than 6%).

This is the reason for the use of low discount rates (6, 8, 10%) for the calculations of the generation of heat.

Similar calculations have been carried out stepping up the thermal powers (12,24,36 MW,) and the distances (5,10,15 km) from the source to the user.

The situation is more and more critical and the most effective way of reducing the cost of energy is by increasing the hours of utilization.

As a resumé of these calculations, in Fig.7, for a selected discount rate (8%), the costs of energy are plotted versus the distance of transport for different hours of utilization and for different thermal powers.

It can be seen that with an utilization greater than 4,000 h/y, even distances of more than 10 km can be economically justified.

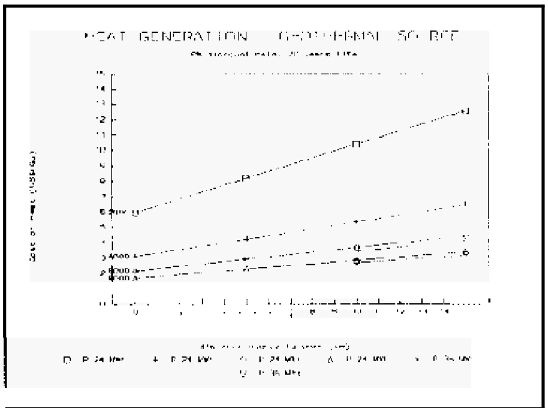

Figure 7 Cost of energy vs distance from source to user

This picture can be completely modified if the taxes are included in the cost of the natural gas. In fact: if the user is a community which has to buy the natural gas on the market, taxes would be part of the price.

Making reference to the situation in Italy (after all we are in Florence!), the price of natural gas for the user is around 0.60 US$/m$^3_n$, giving a cost of energy of about 20 US$/GJ. This reference cost of energy would make economical nearly any geothermal project.

5. DISCUSSIONS AND CONCLUSIONS

The simplifications introduced in the initial hypotheses permitted to reach a schematic picture about the economics of geothermal energy, when compared with conventional alternative sources.

The simplifications must be kept in mind when interpreting the results presented.

In particular it is clear that 1) for the generation of electricity, any geothermal field with a production of over 3 MW per well is very likely to be competitive with alternative source of energy, fully justifying the start of the works after the discovery of the field, whereas 2) for the generation of heat the picture is not so straight forward and very likely a thorough feasibility study is needed case by case.

A feasibility study includes drilling of wells in order to discover the field, characterize the fluid and assess its longevity; it is a necessary step before proceeding to start the project (and, often, to get the money needed for the implementation of the project).

The cost of drilling two wells, plus the related studies, can be (Table 1 and 4) in the order of 4–5 million US$; this figure applies both to generation of electricity or heat.

It is clear now that it is quite different to invest such amount of money for a project where (electric energy, 30 MW power plant) it is likely to get benefits in the order of 3 million US$/year, with a turnover of about 15 million US$/year, or for a project where (district heating) the economics depends on so many factors that the amounts of benefits or turnover are very difficult to predict. This explains why, in mild climatological conditions like in Italy, all the large scale district heating projects, relying on a deep well, had the well already drilled (for hydrocarbons) before even starting with the preliminary studies.

The picture for the district heating projects could change completely, if the economics is based on the "pockets" of the user, who is personally charged by taxes on natural gas. In this case the user could be happy of getting a discount on his heating bill, while the investor would see a wide range of opportunity for his benefits, but with the uncertainty of being one day charged with taxes.

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