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Economic Evaluation of Power Production from a Geothermal Reservoir

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ABSTRACT

The economic value of any subterranean geothermal reservoir is not only a function of its quality (heat, quantity and dept) but also a function of the local surface ambiance.

Factors like the temperature of the environment and its fluctuation; the population in the area and its density have direct effects on the reservoir's value. Additional benefits such as tourism, potential industrial uses and balneology can also play a significant role.

Prices of electrical energy and heat are also included in the evaluation and the possibility to produce one with the other.

With sustainable usage of the reservoir as a principal condition, evaluation from environmental, social and economical viewpoint is considered.

The end result is a monetary evaluation of the reservoir in light of the surface parameters in addition to heat, dept to reservoir and likely yield for each well.

1. INTRODUCTION

Geothermal projects are of high investment nature and thereby high financial cost but relatively low operational cost. A typical sensitivity graph for such project is shown in Figure 1.

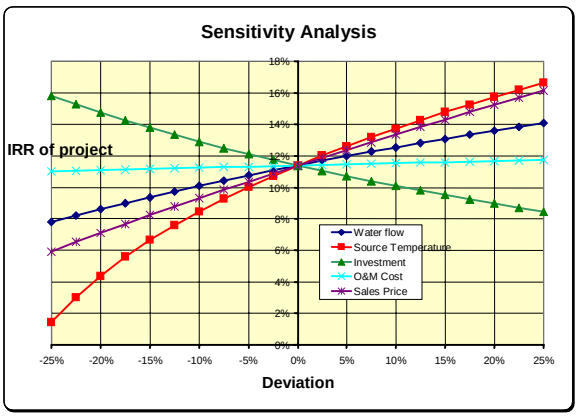


Figure 1: The sensitivity of NPV of a project to changes in: temperature, yield, investment, sales price of electricity, and operation and maintenance. Source: Enex mathematical model.

As can be seen in figure 1, the two important factors are the investment and the price of the product.

This has lead to the theory, that it is possible to create a relatively simple regression formula for the net present value (NPV) for a project given; the quality of the source i.e. yield and heat, the cost of getting to it i.e. drilling cost and on the value its products i.e. electricity and direct use.

A process model for the Kalina power cycle is used for estimation of the power plant economics. This model includes cost estimation, which is based on construction and operational experience from Enex, see (Valdimarsson, 2)

This paper describes this approach and the findings. Certain values are not revealed as they are part of Enex´s competitive advantage.

2. REASONING FOR USE

Theoretically there are geothermal sources of different quality all around the world due to the fact that the core of the earth is magma. The quality is different however because the world is not homogeneous but has fissures and cracks and mountains and walleyes.

The value of the energy source is also dependent on the size and what the market is ready to pay in addition to the distance to it.

To access the feasibly of harnessing geothermal resource the practice has been to undertake a pre-design and make a pre-feasibility study, with high costs running on tens of thousands.

By creating a holistic model, with a combination of expert system with costs of different parts of a power plant project in addition to a cost and power regression model for finding generation from warm water, the initial screening of potential projects can be done much faster and at far less cost than before.

Such a tool is quite valuable for initial screening of possible geothermal projects.

3. BASIC EQUATION

$$NPV = NPV_{el} + NPV_{du} \qquad (1)$$

NPV is the net present value of the project and the subscript $_{el}$ indicates the electrical generation and the $_{du}$ the direct use. It is often difficult to allocate costs to direct use or electrical generation but that allocation does not effect the total NPV being the sum of the both.

The net present value is the sum of cash flow from a project devaluated to present time with the required rate if return for the investment in such a project.

$$NPV = \sum_{k=1}^{n} \frac{F_k}{(1+i)^k} - I \qquad (2)$$

(White, Agee and Case, 1), where F_k is the the future annual income during the year k, i is the required interest

rate and *n* is the number of periods (years). *I* is the project investment.

An equation can be created for the relationship between the NPV_{el} and the parameters of the reservoir i.e. heat and mass flow if the source properties at the power plant wall are known and electricity can be sold at the power plant wall as well additional investment (in order to get to the reservoir) can be subtracted form the NPV_{el} later.

$$NPV_{el} = NPV_{el,(\text{at power plant wall})} - I_{el,add} \qquad (3)$$

$I_{el,add}$ is the investment necessary to get the source to the plant wall (i.e. piping and wells) and the necessary investment in power lines in order to get the electricity to the buyer.

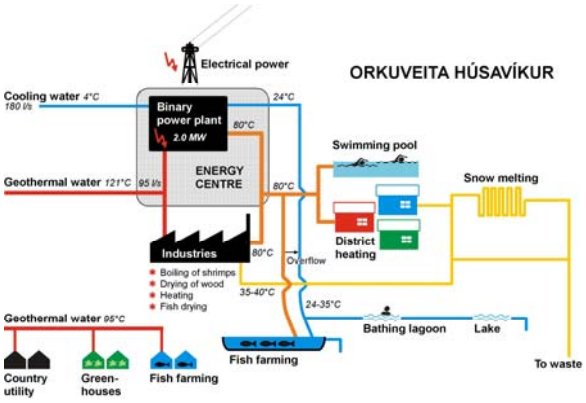
Similar things apply to direct use

$$NPV_{du} = NPV_{du,(\text{at power plant wall})} - I_{du,add} \qquad (4)$$

Inaccuracy in allocating additional investment to electricity or direct use does not affect the total *NPV* since.

$$I_{add} = I_{el,add} + I_{du,add} \qquad (5)$$

There are two ways to co-generate electricity and water for direct use. The generation can be in parallel or in series (or even mixture of both). It depends on the heat needed for direct use but it is usually more economical to use the heat first for electrical generation and then for direct use (As in the power plants in Svartsengi, Nesjavellir and Husavik as seen below).



It is still possible to separate the NPV_{el} from NPV_{du} by the separation of the mass flow if one is using the source directly for both and by the simplification made below for cogeneration where the fluid is used first for electrical generation and later form direct use.

4. SIMPLIFYING ASSUMPTION

There is not a major difference in the electrical output of a geothermal power plant weather it is multiuse or only generating electricity. There is even less difference in the efficiency of the power generation if one cools down the source to 80 or 70°C.

It is uneconomical to go further and use the energy below 70°C for electrical generation. If the heat is also used for heating then it is normally at around 80°C. The model takes this into account regarding how much energy one has but not regarding efficiency of the electrical generation.

This assumption is necessary to find the *NPV* for electrical generation and direct use separately.

The assumptions are based on the Kalina cycle for electrical power generation. Steam cycle is better for higher temperatures than 200°C and the ORC cycle is not far off and is better suited for condensing steam. It can be argued that the use of the Kalina cycle is logical as a bench mark for a heat source of finite specific heat capacity. (Valdimarsson, 2)

5. POWER GENERATION

The NPV study has now been narrowed down to a simple case similar to electrical generation from waste heat generation. The equation that is sought is:

$$NPV_{el,(\text{at power plant wall})} = function(T_{source}, Y, p_{el}) \qquad (6)$$

T_{source} is the heat of the source, *Y* is the mass flow into the plant and p_{el} is the sales price of electricity from the plant.

By analyzing the changes of *NPV* for these variables it is possible to come up with a regression model. It is conceivable that some of these relationships could be found analytically but no effort was made to establish such relationship.

Dependence on heat of source:

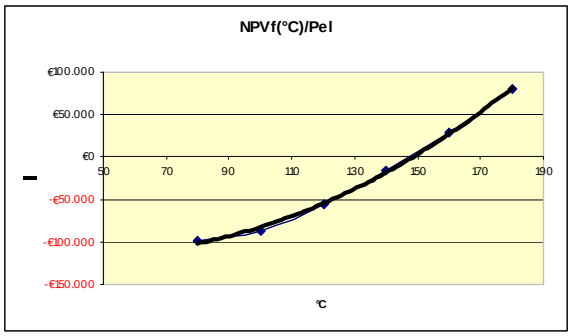


Figure 2: The relationship between NPV of electrical generation to changes in: reservoir temperature. Source: Enex mathematical model.

It is clear that the relationship between the heat of the source and the *NPV* is quadratic (or of higher order). It is to be expected as the efficiency of the thermodynamic cycle rises with higher temperature as does the energy quantity extracted from the fluid. The R^2 value is quite high, being 0,9984 showing good relationship even though small deviation can be seen between the regression line and the calculated values of the model.

Dependence on mass flow from the source:

This relationship (Figure 3) is linear of first degree, the R^2 value is quite high, or 0,9986, the small deviation is due to economics of scale. The regression model is though only considered for the use in the range of 1-20 MW where this effect is apparently not a major issue.

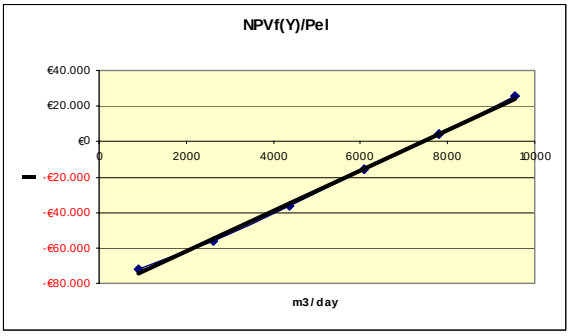


Figure 3: The relationship between *NPV* of electrical generation to changes in: yield. Source: Enex mathematical model.

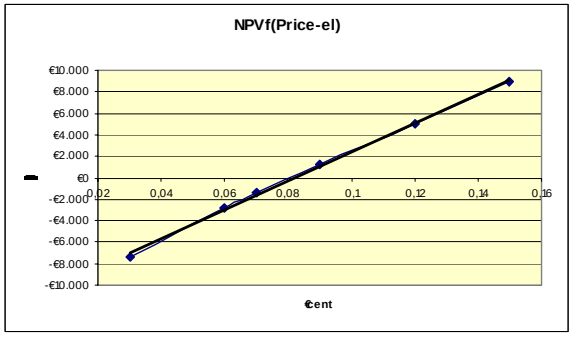


Figure 4: The relationship between *NPV* of electrical generation to changes in: sales price of electricity. Source Enex mathematical model.

Dependence on sales price of electricity:

This relationship (Figure 4) is linear of fist degree and the R^2 value is quite high or 0,9983.

These formulas taken together give us the following regression model:

$$\frac{NPV_{el,(\text{at power plant wall})}}{(p_{el} - c_{hand})} = function(T_2, Y) - I_{el,add} \qquad (7)$$

NPV is the net present value of the value from the power plant itself. $I_{el,add}$ is the additional investment needed to get the sufficient quantity of source fluid both pipelines and additional drilling. p_{el} is sales price of electricity pr kWh, and c_{hand} d is the additional cost of handling the fluid pr. kWh produced, e.g. for inhibitors, taxes, etc.. T_2 is the heat in centigrade and Y is the flow from the source in m3/h

The model used is the following:

$$NPV_{el} = f(T,Y) = (aY + b)T^2 + (hY + i)T + (rY + s) \quad (6)$$

Where *a*, *b*, *h*, *i*, *r* and *s* are regression parameters. The values of these parameters are given as far as they are significant as follows:

a	b	h	i	r	s
0,001xx	0,9xx	-0,03	-8xx,x	-9,xxx	-3xxxx

This equation enables us to graph the relationship between minimum yield and the heat of the source.

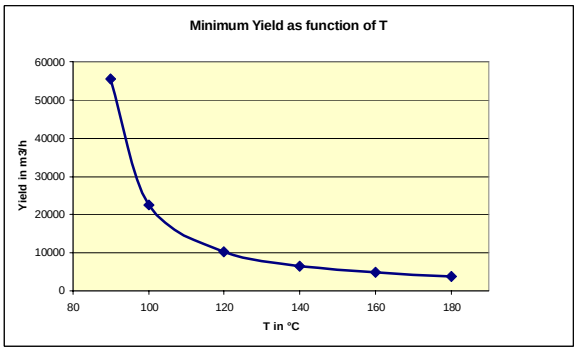


Figure 5: The minimum yield needed to reach positive *NPV* for a given temperature of a reservoir. Source: Enex mathematical model.

6. DIRECT USE

Getting the energy to the market:

The *NPV* of sales of water can be calculated directly, making regression models not necessary, with the exception of the relationship between the diameter of warm water line and cost of laying out such line.

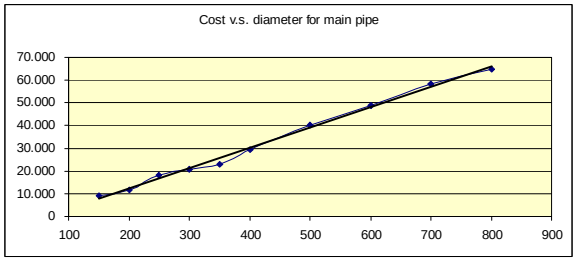


Figure 6: The cost of laying down a main pipe for the transport of warm water as a function of its diameter. Source: Enex/Fjarhitun Iceland.

The regression constant R^2 is quite high or 0,9957. There is some nonlinearity in the smaller diameters. This does not lessen the accuracy since the optimization of the exact diameter chosen is based on cost optimization on the design stage. Linear assumption is actually better until exact design parameters are known.

There are different cost factors for different areas. Laying down pipes in the city is more expensive than through farmland or other open landscape.

Defining the market:

Fluctuation in direct use is often high. A commonly used simplification is to sum up the annual use annual heating degrees for district heating for instance

Other uses like drying of crop or wood drying can have even more fluctuation.

Water parks or other Balneology suits this resource quite well.

It is justifiable for the first estimate to summarize the annual income from direct use and discard the effect on the efficiency of power generation.

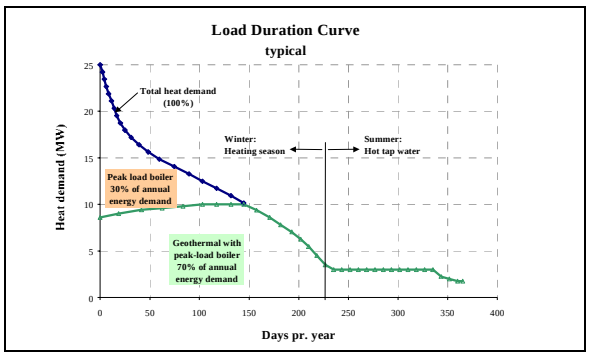


Figure 7: Typical heat curve for a central European city. Source: Enex/Fjarhitun Iceland.

Using a fixed annual income from direct use then it is possible to calculate the NPV_{du} exactly in the same way as in Equation (2):

$$NPV_{du} = \sum_{k=1}^{n} \frac{F_k}{(1+i)^k} - I \qquad (8)$$

Required rate of return:

The interest rate that is required from an investment of this type, often referred to as *MARR*, or minimum annual rate of return, is defined by the company in order to undertake a project. It is similar to *WACC*, weighted average cost of capital for the company; if the project bears in itself the same or similar risk as the average risk from the normal operation of the company.

The *MARR* can be in the range of 5-25% depending on the risk of the project. Ormat, a leading player in the geothermal market uses 12-18% as their target for a feasible project in the 3rd world. (Broniki, 3)

7. CONCLUSION

The creation of relatively simple model to evaluate a reservoir from its expected down-hole properties and surface valuation of the market has been discussed. The procedure is as follows:

a. First step is to estimate the likely heat and yield from given reservoir.

b. Estimate the drilling cost and the cost of the fluid gathering system.

c. Evaluate the buyer both for electricity and direct use and estimate the cost of getting our products to the customer.

d. Use the regression model to evaluate the NPV_{el} of electrical generation and additionally calculate the NPV_{du} from direct use.

The above evolutions are done in the preparatory expert system around the regression model resulting in a quick *NPV* estimate for a given reservoir in order give an indication whether to proceed with the proposed project further or reject it.

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