Chapter 11

ECONOMY OF GEOTHERMAL ENERGY USE DEVELOPMENT

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Introduction

Main factor determining the decision of any investor for choice of concrete energy resource for covering concrete energy requirements is the resulting economy, i.e. final price of used energy unit over the defined exploitation time. However, present situation with energy production and supply make the process of taking decision in concrete political and economy environment quite complicate and requires evaluation of a long list of influencing factors. Furthermore, many of the influencing factors are changeable and it is not always possible to predict their changes over a defined period. Even for the already "proven" resources (fossil fuels and gas) predictions became insecure, being largely influenced by the changes of the world energy market. Generally, as more influencing factors should be taken into account as more insecure is the final result of the economy evaluation.

A list of methodologies for economy evaluation of different energy sources to be applied by different energy consumers exist. Common intention of all of them is to provide as more precise as possible orientation for the existence and influence of all the influencing factors, character of their possible changes over the evaluation period, security of energy production and supply and resulting price of <u>used</u> energy. As more is complicate the nature of energy source and technology for conversion the consisting in useful energy, as more complicate is the methodology for its economy evaluation.

When geothermal energy is in question, situation is particularly complicated. It covers a wide range of influencing factors, beginning with the important influence of regulatory aspects, long and expensive exploration and investigation for resource identification, completion and exploitation, alternative conversion technologies (including space heating, district heating, industrial process heating, etc. and a number of generating electricity options, from dry steam to binary and Kalina method). All listed makes the risk assessment quite complicated and un-understandible for investors. Plus, It's also not possible to avoid the social aspects, taking into account the costs to ensure local acceptance of the "strange" project, sometimes changing significantly the local traditional organization of life. Therefore, a simple general methodology for determination of economy of geothermal projects cannot be developed. In practice, economy of each project is different depending upon the characteristics of the resource, how that resource is used and characteristic combination of local influencing factors of different nature.

That is the reason that not composition of defined methodology of economy evaluation should be the target of an evaluator but providing a techno/economic evaluation frame, composed of various resource characteristics and concrete applied technologies which drive project economics and to incorporate it in the already accepted methodologies of important international finance institutions. In that way, a rather complete picture of influencing factors can be composed, enabling identification of "weak" and "strong" sides of concrete project technology composition and comparisons with other alternatives on disposal, understandable for possible investors and acceptable for possible creditors.

General composition of all evaluation models have very similar composition, including:

- Economic analysis of project viability – often from a national economic perspective
- Evaluation of technical alternatives
- Business planning
- Project financing for both equity and debt participants

Engineers and geoscientists are very familiar with creating some of these, but not with all, especially the last two.

Similarly, financiers and economists are familiar with the last, but not the first two.

As a consequence, the various models developed for a project will have different emphases and the developers will concentrate on different aspects of the model, to the detriment of others. Engineers will tend to concentrate on issues related to optimization of technical/technological composition or the operational performance of the plant. Financiers will tend to concentrate on aspects associated with debt drawdown, interest and repayment and will tend to give less focus to the accuracy of the engineering parameters.

The intention of this chapter is to help in identification all the influencing factors for development of a geothermal project, which can readily be modified by an experienced modeler with good spreadsheet skills for any of the widely accepted evaluation methodo-logies, like are the ones of the WB, EBRD, etc.

11.1. Composition of Influencing Factors

Final economy of a geothermal project depends mainly on the investment, O&M and development costs. They can be grouped in:

- Exploration costs;
- Drilling costs;
- Assessment and costs of covering the project risks;
- Investments in project design and supervision of its completion;
- Investments in geothermal source completion;
- Investments in heat transportation and distribution system;
- Investments in heat supply and monitoring system;
- Investments in heat user's facility(ies) construction;
- Investments in environmental protection;
- Annual heat loading coefficient;
- Operating and maintenance costs;
- Concession costs;
- Investments in further project development;
- Available finance conditions for covering the finance construction for project completion; and
- Generating profit.

Most of listed elements are not changeable with time, however some of them can be hardly precisely predicted (exploration costs, environmental protection measures, etc.). Furthermore, it's obvious that risks assessment can be very important factor of the evaluation as also the influence of local regulatory legislation.

Complicate character of any economic evaluation is immediately evident, particularly when taking into account that some of the influencing factors are under partial or complete control of the project designer but many of them are out of it. Plus, if comparisons with other energy sources are necessary (and it is, in order to make e relevant decision), changeable character of their prices, under the influence of changes of at the international energy market, should be estimated for the period of evaluation, and taken into account.

11.2. Identification and Evaluation of Influencing Factors

11.2.1. Obtaining access and regulatory approval

In order to obtain rights for exploration and, later on, for development of geothermal resources, access must be obtained through lease or concession from the surface and subsurface owners and state. In many countries, the state claims rights to all land and to all mineral and water resources. In other countries, land and sub-surface rights can be held in private ownership.

Unless the geothermal developer has clear title to both surface and subsurface estates, an agreement for access will have to be entered into with the titleholder of these estates. Such access will normally require a yearly lease fee and eventually royalties upon production. In areas where there is significant competitive interest, competitive bidding may be used to select the developer. In some countries, bidding is obligatory before getting concession either for exploratory works or exploitation. Royalties can be assessed on energy extracted, electrical or thermal energy sales, or just payment of tax to the state. Whatever the system is valid, it will have an impact upon project economics and should be carefully considered in terms of overall economic impact. In particular, developers of direct use projects, due to the limited rewards that can be expected, must carefully evaluate how royalties will be calculated.

The second of this type of factors that will have an impact on overall project economics is obtaining all regulatory approvals, including the completion of all environmental assessments and the securing of all required permits and licenses, including, if necessary, a water right. Increasing concern for the environment in nearly all countries of the world has resulted in sharply increased cost for preparation of the necessary environmental documents. Because so many elements of environmental protection are now contested, a contingency to cover the legal costs related to appeals must be included in any economic analysis.

Most direct-use projects are more limited in scale and, therefore, also their environmental impact should be smaller. In any case, these costs are only a small fraction of the cost incurred by the proposal for a major power generation project. However, even such a reduced cost can be significant in relationship to the scale of the project, and their economic impact should not be underestimated.

Unfortunately for the project developer, most of the cost related to obtaining access, environmental and regulatory approval must be incurred early in the project, even before detailed exploration or drilling can begin. That means taking risk before having any clear indication that any of these costs will or can be recovered.

11.2.2. Exploration

Once access has been secured and all necessary regulatory approvals have been obtained, the developer may initiate a detailed exploration program, employing sophisticated techniques that will lead to drilling of one or more exploration wells. He is expecting that, hopefully, these wells will be capable of sustaining a reservoir testing program, and possibly also serving as preliminary discovery and development wells. Reconnaissance is including such activities as a literature search, temperature gradient measurements in any of the existing springs or wells, soil sampling and geochemical analysis, geologic reconnaissance mapping, air-photo interpretation, and regional geophysical studies.

When the area of principal interest has been determined, the exploration program can be more intensely focused to the primary objective of sitting deeper exploration wells. Techniques likely to be employed include detailed geologic mapping, lineament analysis, detailed geochemical analysis, including soil surveys and geochemical analysis of all springs and wells, temperature gradient and/or core drilling, and geophysical surveys, including resistivity, magnetotellurics, gravity, and seismic.

Final phase in any geothermal exploration program involves the sitting, drilling, and testing of deep exploratory wells, and, subsequently, production and re-injection wells.

Not to forget, also these costs must be incurred early in the project, before having full orientation if it shall be possible to recover them by concrete use of resulting energy supply, i.e. they are increasing the total risk of the developer engagement.

11.2.3. Well Drilling

After completion of exploratory works or, better said, as their finalization phase, comes drilling of certain number of exploration and, later on, one or more exploitation and re-injection wells.

Well cost can vary from a low of a tens of thousands of euros for small direct-use projects to several million euros per well for wells required to access high-temperature resources for electricity generation. Success ratios for exploration wells may be as low as 20% and can not be expected to exceed 60% (Bloomquist, 2002); however, the risk of dry holes in the exploration phase remains high and can have a significant economic impact. Drilling cost is typically 30-50% of the total development cost for an electrical generation project and variations in well yield can influence total development cost by some 25% (Bloomquist, 2002).

If drilling is successful, the reservoir must then be tested in order to determine its magnitude, productivity, and expected longevity. Only after such testing a determination can be made for the eventual size and design of the generating facility or direct-use application.

Again, investment in this phase of development still has no full security that shall be returned by the later use of the energy resource. Furthermore, listed initial three phases are time consuming and can last several years.

11.2.4. Well field development

After completion of exploitation and re-injection wells, investor can have clearer orientation about capacity of the field to be used for particular energy production but it is still far from a secure one, allowing to take final decision(s) for its exploitation. To get this, geothermal field development should be completed.

Well field development for an electricity generation project can last from a few months to several years, depending upon the size and complexity of the project, the speed at which procurement contracts can be let (Koenig, 1995), and the availability of drill rigs. At this stage it also becomes important to collect detailed data and to evaluate the information available on the reservoir. For most projects this will include both production and re-injection wells.

Over half of the total production cost over the lifetime of the project will in fact be expenses associated with the well field engineering (Bloomquist, 2002). Because of this, it is imperative that wells must be properly completed, maintained and operated to ensure production longevity. But even with proper O&M, many wells will have to be periodically worked over and, for most power generation projects, 50% or more of the wells will likely have to be re-placed over the course of the project (Bloomquist, 2002), adding considerably to the initial well field cost and, of course, to the cost of generating power.

For small to medium-sized direct-use projects requiring only one or two production and re-injection wells, costs will generally be much lower because the water chemistry of most geothermal resources that are developed for direct-use applications is of generally higher quality than that available for power production. Well life can be expected to be much longer and few, if any, wells will have to be worked over or re-drilled during the economic life of the project.

It's necessary to underline that even so much influencing the economy of the project, this investment is still "in advance", i.e. much before having the possibility to return it through the sale of energy (heat) to the final user.

11.2.5. Provision of energy (heat)

Next step of a geothermal project development is completion of the energy source. Here, it should be taken into account that there is a main difference between completion of a fossil fuel(s) ran boilerhouse and completion of a geothermal energy source. When fossil fuels are in question, production and supply of the energent is not part of the project in development, i.e. no investments are necessary for itd organization it (except the storing and supply complete). It is responsibility of somebody else and, normally, it is a part of already developed supply system. In opposite, for a geothermal project, rather large investments are necessary. Even more, these investments are the most risky of the all the investments for the project completion. In addition, a number of extremely important legal, institutional, regulatory, and environmental factors must be fully evaluated and their economic impacts considered.

Part of this phase is design and completion of the necessary distribution network, including pump stations (when necessary), distribution pipelines, collectors, etc. Taking into account that this phase goes in parallel with completion of the energy consuming unit(s), that is the first phase for whose return of necessary investments can be evaluated after its completion.

11.2.6. Project design and facility construction

Finally, after having full information about the capacity of geothermal field and characteristics of the fluid, it is possible to go to the design and completion of heat user(s).

Two main groups can be identified, dictating particular approach to the problem and composition of the facilities. i.e. electricity production and direct uses.

- Electricity production

a) Power plant

Power plant design depends on specific requirements of a concrete geothermal reservoir dictating the electricity production technology to be applied. These include direct steam, flashed steam, double flashed steam, binary and Kalina cycle. Selection of the most economically viable power conversion technology can only be accomplished through a thorough evaluation of the differing strengths and weaknesses of various technologies relative to the characteristics of the resource and local circumstances, including environmental and regulatory requirements.

Pre-condition to enter into this phase of development means that detailed technical and economy evaluations are made for the nature and possibilities of the energy resource, i.e. already a conclusion that its capacity and characteristics justify exploitation for concrete use is made.

This part of the evaluation is mostly of technical/technological nature, i.e. depending on the nature of energy resource. Task is to determine optimal technology to be applied, in order to get the best efficiency of energy conversion under the possible economy conditions.

Completion of this phase enables to perform economic evaluation of all the previous investments and possibilities for their return in concrete time terms and under known finance conditions.

b) Equipment Selection

Selection of the equipment for power plant completion is a complex and high professsional problematics, directly connected to the chosen production technology. It includes the choice of the type of turbine to be used, condensers, cooling towers or air cooled condensers, systems of pumps and fluid distribution completes, etc. This part of the evaluation frame consist of techno/economical analysis enabling choice of optimal technical/technological solutions.

In addition to temperature, fluid chemistry is extremely important in cycle selection and power plant design. Many high-temperature resources are highly aggressive brines, with high contents of total dissolved solids (TDS), and bring a host of other problems that affect both design and economics.

At this stage of technologies development, it is not the task of project developer to prepare the complete design of power plant. He is making the choice of offered ready completes of specialized producers, accommodated to the local conditions. However, that doesn't mean that his task is easy and simple. High level of multidisciplinary knowledge is necessary to come to the right decision and right completion of the plant.

c) Power plant construction

A number of factors related to power plant construction can have a significant influence on project economics, including geologic conditions, terrain, accessibility, labor force, economies of scale, and site or plant assembly of major components.

Geologic conditions and terrain can be

expected to participate the cost of construction by 2 - 5% (Bloomquist, 2002).

Completion of the infrastructure of the plant site takes quite a good amount of the investment costs, too. Service building, offices, connection roads, water and electricity supply, canalization, arrangement of the courtyard, etc., etc. are a normal part of the investment in a power production plant construction.

When the labor force is in question, it is necessary to evaluate in advance its availability for construction works and for the plant exploitation. If the site is located in a rural area with little or no skilled construction labor force, most personnel will have to be brought to the site and, in fact, depending upon the commuting distance, a construction camp may have to be established to provide living quarters and meals for the workers or to built one of the planned buildings and temporarily to use it for such purpose. In any case, such situation can significantly increase the investment costs in comparison with the situation when skilled workers are locally on disposal.

At last but not list, costs of the technical staff completion and specialization should be taken into account. Specific "know-how" for plant exploitation is necessary and it is not on disposal, except probably in a very limited number of countries.

- Direct use projects

Project design and facility construction relative to direct-use projects should be much simpler than the one for electricity production, when taking into account that much lower temperatures and less dangerous thermal water chemical compositions are in question. However, it's not the case. It is much more complicate due to the fact that related to different type of heat consumers. A direct use project may be supplying the needs of a house or building with dwellings, greenhouse or aquaculture complex, a dehydration plant, an industrial facility, a district heating system supplying multiple commercial, industrial, and even residential customers. The problem is that all the listed uses share a number of design considerations having a bearing on the economics of the project. All are highly dependent upon resource characteristics, including temperature and flow, hydrostatic head, draw-down, and fluid chemistry. The characteristics of the resource will dictate not only the type of project that can be developed, but also the scale of the project, it's composition and the metallurgy of the components selected.

Another major design consideration is whether or not the heating system should be based on meeting the peak heat demand entirely with geothermal energy by using heat accumulators or the system should rely on a fossil fuel boiler for peaking and/or backup. In most cases, if geothermal system is designed for covering only the base heat loads, full economy of the system can be the best. For instance, for greenhouse applications and geothermal district heating systems, designing the geothermal system to meet 50 - 60% of the peak heating load will still allow the geothermal system to meet 90 - 95% or more of the annual heating requirement in most European climatic zones. Another strong argument for meeting peak demand with a non-geothermal system is the need for back up for both greenhouse applications and for district energy systems. Although the back up can be provided by use of standby wells and back-up generators to run pumps, a fossil fuel system may be the most secure alternative and also the most cost effective.

One very important fact should be taken into account in the listed analysis. Discussion for the justification to cover or not the peak loadings of the final user of geothermal energy is caused by the fact that the annual heat loading factor of the energy source is the crucial one, when final economy of geothermal energy use for concrete project is in question. Very high specific investment costs per installed energy (heat) unit cannot be returned by short engagement of the installed plant power over the year. As longer is the engagement, as smaller is the influence of the investment to the <u>used</u> unit of energy (heat). Therefore, project itself should be composed in that way to enable more or less continual use of the installed geothermal energy (heat) power (covering the base heat load!), or the system of user should be composed of different final users, each one with different daily and annual heat use characteristics, in order to enable more or less continual and equalized use of the installed geothermal energy (heat) power. That is the background of increased interest for composition of geothermal district heating systems. However, such an approach results with changeable economy of the system exploitation, where the initial one is the lowest and later ones with increased performances. That means that not one but a serie of economic analysis should be made, depending on the expected characteristics of the geothermal district heating system development.

Even not applicable for large projects using "indirect" connection to the well, still possibility to use directly the geothermal water in heating systems of the users should be evaluated, particularly for very small projects and thermal waters with very low mineralization. Difference in investment costs is significant and later complications in exploitation can be removed when project becomes larger by connection of new consumers and indirect use introduced.

Selection of the piping material is especially important in applications that consist direct use of thermal water. For such a case, pre-insulated pipes may not be appropriate. However, when the heat is transferred to a secondary fluid that is circulated in a closed loop, and where addition of corrosion inhibitors is practical, that should be a logical choice. Other points to consider include the choice between metallic and non-metallic pipes. If nonmetallic piping is selected, care must be taken to ensure that it has an oxygen barrier or that areas served with non-metallic pipes are separated by a heat exchanger from areas served with metallic pipes. If this is not done, severe corrosion problems may occur in the metallic pipe portions of the system due to oxygen infiltration.

Like for power generation, this part consists of techno/economic analysis enabling the choice of appropriate optimal technical/technological solutions for the concrete project completion and development.

When construction works are in question, it is again a significant part of the entire project investment. It consists primarily of wells, pumps, heat exchangers, peaking and/or backup equipment, piping, controls and regulation of supply. For instance, for district heating systems, the thermal energy transmission and distribution piping system will comprise 60% or more of the total construction budget. Situation is not much different for small projects, if properly completed. A major problem for most developers of bigger district heating systems is that the transmission piping must be sized to meet the needs of the system at full build-out although revenue will increase only slowly as the system expands and as the customer base increases. This dilemma is by far the most important economic consideration in determining the feasibility of introducing geothermal district energy service into an existing community. In a new community or a new area of a community, much of the cost of constructing the distribution system can be shared with the developers of other utility services, including sewer, water, and electricity.

This part of the analysis takes into account the influence of possible technical and not technical local factors to the final economic viability of constructing a geothermal direct use project. As bigger and more complicate it is, as larger number of influencing factors of different nature can be identified and taken into account.

11.2.7. Operation and maintenance

O&M costs are an important part of the energy production costs of a geothermal project. Due to the different composition of project elements, they are different than the ones related to energy production units, using fossil fuels. O&M costs of a geothermal projects are normally higher and should be carefully identified in order to get a clear picture when coming to the final evaluation of the economy of whole project over defined time period.

- Operation costs are mainly connected to the electricity consumption of different pumps. Particular attention should be paid to the optimization of pumps running costs in direct use projects, where they rarely have continual use with full power.
- Maintenance costs are related to all the equipment and materials used in the project. Taking into account the problems with scaling, corrosion, distribution pipes and arma-

ture, they are normally higher than in the systems using fossil fuels. In order to be precise in the economic evaluations, they should be carefully identified in advance, based on the previous experience of similar running projects.

- Good prediction of personnel costs is also a very important question, relating both the quality of project exploitation and it's economy. As already mentioned, part of these costs is related to the investment (necessary specializations). In any case, not very numerous personnel is necessary but some of them should be high specialized in order to be able to cover multidisiplinary "know-how" needs for proper plant operation. Also, costs of continual improving the knowledge should be calculated.

Main problem with personnel appear in small independent direct use projects, where is very difficult to cover the costs of specialized personnel. In such a case, the owner or at least one specialized worker should b a skilled worker and use of outside services for maintenance works applied.

11.3. Planning Revenues

Good planning of revenues is the last and most important phase, enabling final evaluation of the project economy. After having a clear picture for necessary investments, production and maintenance costs, costs of concession, taxes, etc., it is necessary to identify the market to accept the planned production, to define the price of the product which should be both competitive to the prices of the other producers and generate enough high profit to cover the payback of invested funds in an acceptable period, to enable further development of the plant and to realize a final positive difference over a defined time period, interesting for the planned investors.

11.3.1 Electricity generation

Economic viability of a particular geothermal power generation project will depend upon its ability to generate revenue, and revenue can only be generated from power sales. The output from the plant, and hence the source of revenue generated, will be highly dependent upon how well the plant is maintained, how it is operated, and the ability to take maximum advantage of incentives to produce at certain times or under certain conditions. Taking into account that geothermal energy source enables continual supply, independently of the weather season, it enables contracting the part of supply under the best possible conditions, i.e. during the summer and winter peak power demands. For example, a plant selling into a summer peaking service area must be able to provide maximum possible output when a premium is being paid for output. In any case, taking into account that the price of energy depends mainly the annual loading factor, as longer is the plant in use over the year as lower shall be the production costs per produced unit of energy.

Power market has its specifics in different countries and, in many cases, may be under the influence of non-economic factors. Therefore, particular analysis of the concrete market should be made, identification of influencing factors to the selling price of electricity, possibilities for incentives and other specific support, etc., in order to avoid possible wrong final decisions. In countries, where state has direct influence to determination of selling price of electricity, some legal background is necessary to be on disposal, as a guarantee for continual conditions for work over the planned period of evaluation.

11.3.2. Direct Use

When direct use projects are in question, two types of revenue generation can be identified, i.e."

- By selling produced heat to customers; and
- By using the produced heat as a part of some production technology process, or for using it in own offices or residence.

Difference is principal, i.e. in the first case heat is produced for selling it to some market, and in the second case for the own needs. Market analysis has strong influence to the planned economy of the project in the first one, and heat is used by already determined market in the second case.

When larger district heating schemes are in question, some advantages and some disadvantages relating to the final economy should be underlined:

- A large district heatingscheme can be composed of different users, such as are residential heating, industrial processes, including dehydration; agriculture, including greenhouses and aquaculture, and balneology. That enable combinations of users with different seasonal and annual heat loading curves plus application of cascade use of available temperature difference, i.e. high annual heat loading factor resulting with lower price of produced energy.
- Depending on the concentration of heat users and their distance from the energy source, heat distribution and supply scheme can become very expensive, i.e. can significantly increase the initial investment costs, which are anyhow high.
- Initial time for developing the full district heating scheme is normally very long. That is prolonging the payback time and, sometimes, destroying the possibilities to organize a feasible financing scheme for the project development. On the other hand, that is underlining good possibilities for optimizing already developed district heating schemes by introduction of base heating supplied with geothermal energy.

An additional problem should be also underlined when district heating schemes are in question. That is the problem of defining price system supporting introduction of higher energy efficiency of the heat use. Normally, pricing for heat supply in district heating systems goes by definition of so called fixed and variable portions of it. The capacity or fixed portion of the payment is based upon the capital invested, including wells, heat exchangers, thermal storage units, back up or peaking boilers, and the transmission and distribution network. The variable portion of the amount charged relates to O&M, including personal cost, cost for fossil fuels used in the back up and/or peaking boilers, and re-drilling of wells. Problem is that, when geothermal energy is in question, fixed costs go up to 80-85% of the total costs, which makes any saving by reduced use of heat without sense. On the other hand, investment in heat insulation is stimulated because being returned back very quickly.

Other practical problem of pricing is if it is based on the geothermal water flow or thermal consumption. In the later case, heat consumers shall always intent to use only the upper part of the temperature difference on disposal and, in that way, shall negatively influence the final economy of the system.

When smaller individual projects are in question, possible revenues should be analyzed more as a part of the costs of production process where the energy is used than as an independent problem. These costs should be competitive when compared to other possible energy sources. Same is the situation with the residential heating.

At last but not least, using the waste heat from a geothermal power plant for district heating purposes is an excellent possibility for additional revenues for the power production plant (lower price of electricity!) and for decreasing necessary investment costs for developing the energy source for district heating scheme (lower price of supplied heat!). In such a case, a common economy analysis should be made for both projects.

11.3.3. Combinations with fossil fuels and other renewable energies

Taking into account different supporting measures for RES development in many countries and proven advantages and disadvantages of some other RES (particularly the dependence of the season or day time), geothermal energy can be a very convenient and economically feasible answer for covering the base heat demand of many users. However, analysis of economy of whole project and the revenues becomes quite complicated in such cases because also the other energy source should be analyzed in details and an optimal combination determined.

11.3.4. Co-Production

Finally, when revenues are in question, also introduction of so called co-production can be applied, such as production of silica, CO_2 and other marketable products from geothermal brines. Silica production is rapidly becoming not only a very viable source of additional revenue for power plant owners, but also a key technique for improving power plant economics by reducing operation and maintenance costs. The removal of silica may allow additional geothermal energy extraction in bottoming cycles or additional uses of low-grade heat that are presently prohibited due to problems associated with scaling.

11.4. Decision Taking

Identification of influencing factors, their evaluation and definition of optimal technical, economic and other solutions doesn't mean that the project development proposal is giving enough information to take the final decision. Finally, an overall economic evaluation should be made by investigation possible changes of influencing factors. It's already said that some of them are changeable and cannot be precisely predicted. On the other hand, many of the influencing factors are with mutual inter-influence and that complicates variants evaluation due to the fact that very long list is in question. It's understandable that such evaluations are work and time consuming and can cost tens or even hundreds thousands euro. However, long-term geothermal projects are worthy of special attention because they require quite large investments, and because the cash outlay to start such projects often precedes the receipt of profits by a significant period of time. Main problem of evaluate long-term projects is practically determining whether the expected return from the project is great enough to justify taking the risks that are inherent in long-term investment.

These are a list of methodologies with different approaches for evaluation, however mostly accepted by the bigger financial institutions are the pay back method, the net present value (NPV) method, and the internal rate of return (IRR) method.

For any investor, the return-on-investment (ROI) is the only aspect of significance. This position has to be incorporated in the early phases of project realization and has to be considered in all decisions. Exactly in these decisions, however, engineers and geologists, due to their different approach to project management, do not have the ability to estimate all economic consequences of a decision. The strict economic approach achieved and will achieve, that investors can estimate the risk of their investment realistic and consequently will invest their capital risk-consciously in geothermal projects.

On side of the investors, for example, the World Bank supports this approach and demands it for any geothermal project. From the experience from project evaluations for the World Bank, engineers can evaluate in an excellent way the technical risks and geologists, as a matter of course, provide the base for the project realization. However, the investor is not interested in technical solutions or geological data, but only in the question with what certainty and how much ROI his investment will generate.

The World Bank is also confronted in developing countries with the problem that the existing structures of the administrative, legal and political conditions already make a project realization difficult. In the case of a purely technical or geological approach many things are kept out of focus, which leads a geothermal project to success or failure. In order to minimize the risk of investment from the angle of international financing institutes, like the World Bank or EBRD, a risk analysis in these countries is absolutely irreplaceable.

Always all possible risks have to be integrated in the analysis, as shown in the following diagram:

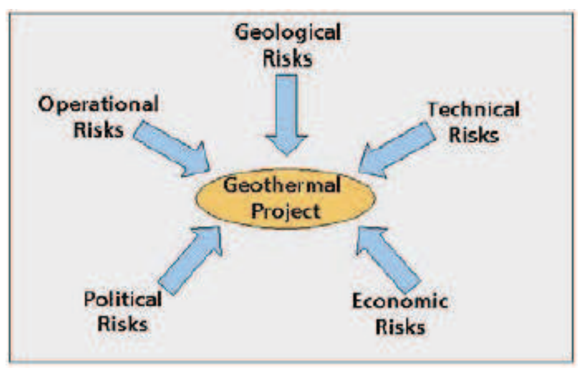

Fig.11.4.1.: Different kinds of risks in geothermal project development (Randle, J.B., 2005)

After this analysis a budget reserve has to be planned, which can be taken if a risk occurs (shown as an example in Figure 3).

It's necessary to underline that risks covering can influence very much the final result of the project proposal finance structure.

Fig.11.4.2. Reserve of budget for covering the risks (Randle, J.B., 2005)

11.4.1. Example

Obviously, tools are necessary to handle all the listed requirements of the economic evaluation analyses and to decrease their costs. That's the reason that a list of handy software can be found in the market. They have different approach to the problem, resulting with different applicability for particular project development, i.e. before accepting to use some of the offered software on disposal, it's necessary to look carefully what exactly it is offering, the reference list of previous applications and the level of reached success. They are lowering the costs of evaluation and accelerating it but still they are expensive because needing professional support, enough information and data in order to be useful.

As an example for such a software, the ENEX mathematical model, as presented by L. Eliasson and P. Valdimarson at the World Geothermal Congress 2005 can be used. It is related to the economic evaluation of power production from a geothermal reservoir in Iceland.

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, possibilities and justifiableness to finance its development.

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.

First fact to be taken into account is that 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 11.4.3. As can be seen, 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.

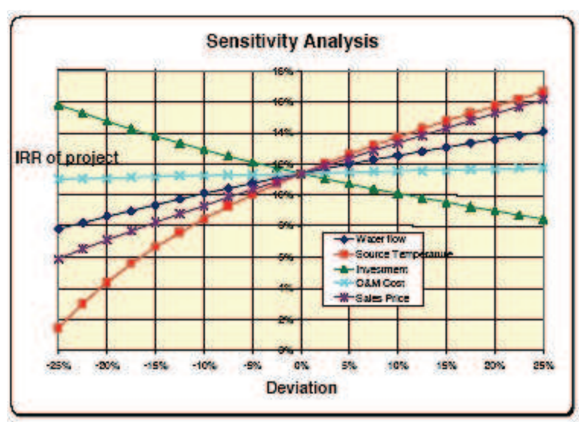

Figure 11.4.3.: The sensitivity of NPV of a project to changes in: temperature, yield, investment, sales price of electricity, and operation and maintenance. Source: Enex mathematical model.

Theoretically there are geothermal sources of different quality all around the world due to the fact that the core of the earth is magma. However, the quality is different because the world is not homogeneous but composed of different 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 by undertaking a pre-design and preparing a pre-feasibility study.

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

Basic initial equation for model development is:

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

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:

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

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 has been 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.

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 (Fig.11.3.4) for cogeneration where the fluid is used first for electrical generation and later form direct use.

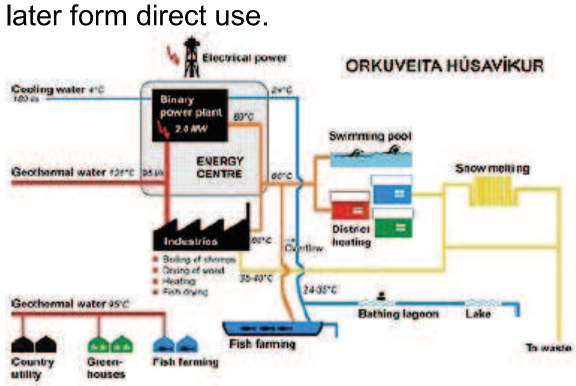

Fig.11.4.4. Scheme of the composition of production and consumption of energy of power plants in Svartsengi, Nesjavellir and Husavik

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 (for the conditions in Iceland). 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.

In that way, the NPV study has 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 *pel* is the sales price of electricity from the plant.

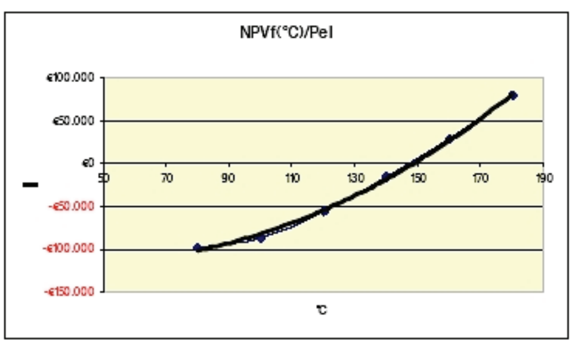

Fig.11.4.5.: The relationship between NPV of electrical generation to changes in: reservoir temperature. (Source: Enex mathematical model)

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.

If dependence of heat of the source is in question, 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 and showing good relationship even though small deviation can be seen between the regression line and the calculated values of the model.

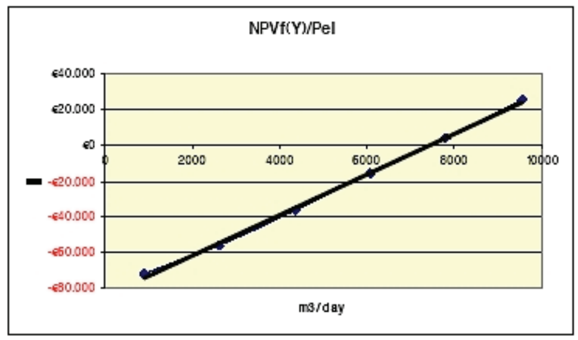

Fig.11.4.6.: The relationship between *NPV* of electrical generation to changes in: yield. Source: Enex mathematical model.

The relationship of dependence of mass flow from the source (Fig.11.3.6) is linear of first degree, the R^2 value is again quite high, or 0,9986, and 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.

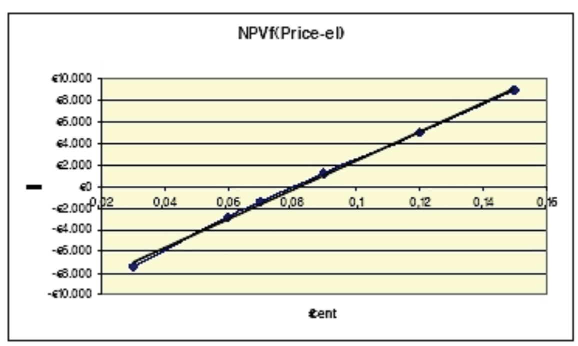

Fig.11.4.7.: The relationship between *NPV* of electrical generation to changes in: sales price of electricity. (Source Enex mathematical model)

Dependence on sales price of electricity (Fig.11.4.7) 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} 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 m^3/h

The model used is the following:

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

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.

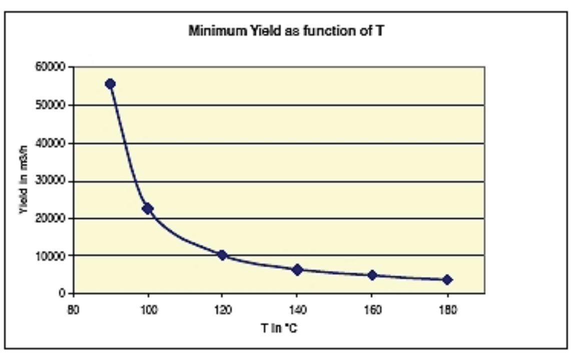

Fig.11.3.8.: The minimum yield needed to reach positive *NPV* for a given temperature of a reservoir.(Source: Enex mathematical model)

For the direct use, *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.

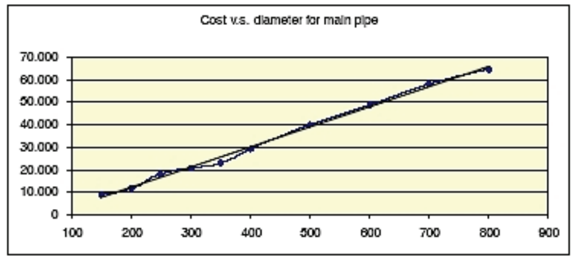

Fig.11.3.9.: The cost of laying down a main pipe for the transport of warm water as a function of its diameter. (Source: Enex/Fjarhitun Iceland)

The regression constant R^2 is quite high or 0,9957 and there is some nonlinearrity in the smaller diameters. This does not lessen the accuracy since the optimization of the exact diameter chosen is based on cost of the 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.

When characteristics of the market are in question, 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.

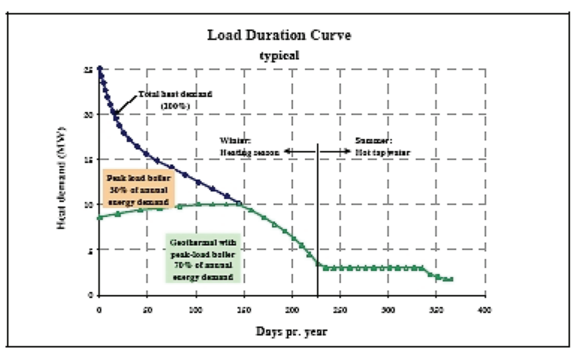

Fig.11.3.10: Typical heat curve for a central European city. (Source: Enex/Fjarhitun Iceland)

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.

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

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

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 (Bronicki, 2004).

As it can be followed, 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 to use it 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; and finally
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 to give an indication whether to proceed with the proposed project further or reject it.

Two facts should be underlined:

- Model enables unlimited variations of income parameters and is quite easy for handling; but
- It can be run only by the expert who really understand the system in question and has a multidisciplinal knowledge about all its aspects and influencing factors.

At last but not least, it's necessary not to forget that given example relate only to a part of the whole problematic of detailed evaluation economical justifiableness to realize a project proposal (Fig.11.4.11).

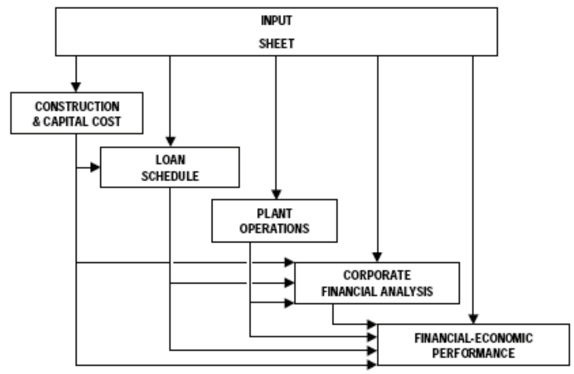

Fig.11.4.11.: Structure of a Financial Model (Randle, J.B., 2005)

11.5. Conclusions

A trial to present the frame for economic evaluation of geothermal projects, enabling design of concrete project through the process of techno/economic evaluation of each step of project development, from the resource reconnaissance phase to the final project completion and exploitation was made. It can be noticed that it is an active process of optimization, consisting evaluation and estimation of different possible technical/technological solutions, influence of different local and other influencing factors and different possibilities for exploitation of the resource in question with concrete type(s) of user(s).

Also, it was illustrated why such complicate approach is necessary, i.e.:

1. The nature of geothermal energy is rather complicate and risks of failing with the investments depend mainly on the capability of the team which is designing and exploiting the project. As more detailed and more professional analyses are made, as lower are the risks to design and complete an unprofitable project.
2. There are not two same geothermal projects in the world, i.e. composition of in-

fluencing natural, technical, technological, social, economic and other factors differs from case to case and doesn't allow composition of simplified common methodologies based on proven successful solutions. Each consisting part of the concrete technical/ techno-logical solution for concrete energy source should be carefully investigated and optimized in order to enable composition of a successful complete, economically liable in concrete surrounding.

The above said is also the reason why a straight answer to the question if geothermal energy is economically liable and competitive to fossil fuels and other RES cannot be given. Based on the collected experience, however, it's possible to state that:

- Electricity generation from geothermal energy can be economically liable and competitive in many regions and economy surroundings in the world. If still somewhere the produced kWh is more expensive than the one of fossil fuels origin, the difference is with intention to be smaller or even to be changed to positive ones under the present conditions of the fossil fuels market changes in the world. Just to mention, one of positive sides of geothermal energy application for generating electricity is that continual supply and price can be guaranteed over longer periods and independence of the fluctuations of the world energy market.
- Direct application projects are even more case sensitive than the electricity generation. Final economic liability of concrete project depends on a long list of different influencing factors, of whose not all request can be satisfied with the limited possibilities for covering the costs of development exploitation of smaller and even medium size projects. Many of them even do not justify funding of making necessary technical/technological and economy analysis for determination of proper technical solutions and exploitation of the heat source on disposal. However, collected experience confirms that when projects are carefully designed and particularly when rather high annual heat loading factor is reached, geothermal energy can be the most economical solution in concrete economical surroundings.

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