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Feasibility Studies for Geothermal Projects

Bjarni Pálsson

Landsvirkjun, Háaleitisbraut 68, 103 Reykjavík, Iceland

Bjarni.Palsson@Landsvirkjun.is

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ABSTRACT

Geothermal projects are complex and require high upfront investments before a decision can be made if to execute the project or not. It is important to carefully plan and organize the project preparation to ensure that the right information is available at the right time and presented in correct manner to help making the right decisions. The economy of geothermal projects is sensitive and errors in resource assessment and project design can be very costly. And the history of geothermal projects shows that such errors have been made in the past.

This paper presents a stage gate process to help organizing the project preparation with the aim of optimising the financial success at the same time as minimising risk. The key document for the decision making process is the feasibility study. The paper discusses the essential content and advice on how to prepare that document in a way that it benefits both management team for investment decisions, financial institutions for funding decision and even governmental institutions to decide if a permit should be provided.

1. INTRODUCTION

Geothermal projects are both capital intensive and highly complex due to the nature of underground exploration, complex permitting and the multidisciplinary expertise required. Therefore, to optimise the possibility of financial success, it is of great importance to take the right decisions at the right time in the process. To allow for that, the exploration program and all the other project preparation must be focused on gathering all the right information and have available when needed to take a decision if to continue or not.

The set of information that executives require to take a decision on a project is often presented in the form of a business case. Financial institutions typically request slightly different presentation of the available information, often referred to as bankable documents. In both cases, the central document is the feasibility study, outlining the project, its justification, technical solution, execution strategy, budget, timeline, financing plan, financial assumptions and financial modelling. Various other supporting document include, but are not limited to the power purchase agreement (if available), government guarantees (if applicable), procurement strategy, environmental and social impact assessment, permits, rights and licences etc.

In the relatively short history of geothermal projects, not all projects have been successful. The most common error has been not having sufficient steam available to fuel the geothermal plant. This may be due to wells not being sufficiently productive, fluid properties, such as scaling or corrosion, or production decline being faster than anticipated. Environmental factors may also restrain production. This could be caused by limitations in reinjection capacity, or factors that have negative impact on society, such as air quality issues, seismic activity, land elevation changes, noise etc. In all cases, it may be claimed that an investment decision had been made without all necessary information.

Geothermal projects are often driven on a very tight economical model so a slight reduction in income can have a significant impact on the feasibility of the project. It is sometimes claimed that geothermal projects are high risk – low reward projects. Therefore, it is a major challenge of the project team to minimise the risk at the same time as optimising the reward. The author of this paper has lead geothermal project preparation at Landsvirkjun, the national power company of Iceland, for a decade or so. The information provided in the paper is based on the experience and opinion of the author but not of Landsvirkjun.

2. PHASE DEVELOPMENT

Geothermal projects often require high upfront investment (Monroy, 2016). Significant cost may have to be invested in infrastructure prior to exploration, such as making an access road, setting up camp for workers with access to water, electricity, telecommunication etc. Sometimes, the right to use a geothermal resource, land, water, gravel etc. must be bought prior to drilling. The exploration drilling itself may cost up to 20-30% of the overall project cost (Gehringer and Loksah, 2012). Therefore, when defining the geothermal project strategy, it is tempting to optimise the investment to design and build as large installation as possible to minimise the cost per MW and get as high revenue as possible from start of production.

In addition, significant part of the operational cost is independent of plant size. For example, all power plants require a plant manager, operators, maintenance crew, day and night shifts, a control room, workshop, spare parts storage, canteen, accommodation for staff etc. The additional manpower cost required if the plant is later expanded is minimal, compared to the initial phase.

However, it is important to notice that as projects are bigger, the risk also becomes greater. Experience from geothermal projects all over the world has shown that various issues can affect the success of large geothermal projects. No matter how comprehensive exploration activity has been conducted, there will always be uncertainty about the response of the resource, environment and society and even how wells will perform.

The results of an early stage geothermal resource assessment, typically based on a volumetric model, is often presented in the form of a probability curve for the estimated resource capacity or as a P10, P50 and P90. Figure 1 shows for example the probability distribution for the Theistareykir field from 2009 (Gudmundsson et al., 2008). For each geothermal project, a decision must be made if the first phase should be sized cautiously (left side of the probability distribution) or if an aggressive approach is chosen (right side of the probability distribution).

Development of a geothermal power project in a single phase to the maximum size that the geothermal field is believed to be able to support, e.g. with installed power > P50 is called a single-phase development. Installing a geothermal power plant in several relatively small phases, where the resource risk is minimised by sizing the first phase significantly below P50, and the experience from the first phase is considered before taking a decision on the next phase, is often referred to as phase development.

Landsvirkjun has the policy that prior to a decision to build a geothermal power plant or extend an existing plant with a new phase, at least 50-70% of the steam should be available and the wells should have been flow tested for several months. At the time of the resource assessment, presented in Figure 1, Theistareykir Ltd. (now 100% owned by Landsvirkjun) decided to perform Environmental Impact Assessment for a 180 MW power plant, to be built in 4 x 45 phases. Theistareykir had been estimated to be in total 40-50 km2, from geological mapping and TEM resistivity measurements. However, exploration drilling had indicated that at least part of the field had cooled down or was simply an outflow zone with reversed temperature profile. In 2014, when the equivalent of around 58 MW of steam had been gathered from 9 deep exploration wells that all had been flow tested extensively, Landsvirkjun took the decision to build 2 phases, in total a 90 MW power plant. Phase one was commissioned in November 2017 and phase 2 will be commissioned in April 2018. Drilling of 8 production wells in 2016-2017 showed that a greater part of the field seemed to have cooled down due to cold water inflow and another part of the reservoir had very low permeability. Landsvirkjun plans to operate the power plant for at least 3 years before taking a decision on further development.

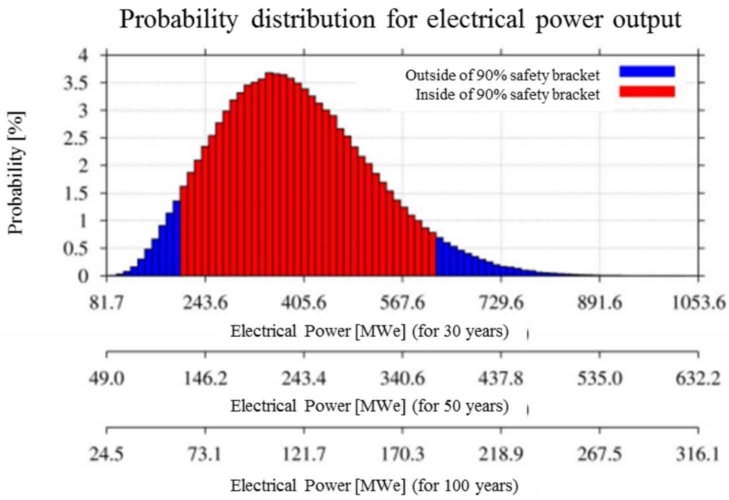

Figure 1: Probability distribution for the Theistareykir geothermal field, Iceland from 2008, based on a volumetric model (Gudmundsson et al., 2008).

The cons and pros of phase development and single phase development are presented in Table 2.

Benefits of phase development	**Benefits of single-phase development**
Quicker to build each phase: - Fewer wells; - Shorter steam lines; - Smaller power house, more simple turbine installation. Quicker to get full power of each turbine online. Results from previous phase used to decide on size, technology, well location etc. Less risk of a major failure.	Lower Capital Expenditure (CAPEX) per MW: - Cost of drilling each well; - Cost of equipment, turbines, generators etc.; - Cost of initial common infrastructure, e.g. roads, camp, control centre. Lower operational cost (OPEX) per MW: - Fewer employees per MW.

Table 1: Comparison between the cons and pros of single phase development and phase development.

Out of the items listed in Table 1, risk of failure may be the most important one. Many, even most geothermal projects, have suffered from unforeseen events that have had a major impact on the project economy. The most common error has been not having sufficient steam available to fuel the geothermal plant. The following sub-chapters describe a few cases that are essential for all geothermal developers to know and learn from.

2.1 Experience from the Geyser geothermal field in California, USA

The Geyser field is one of world's largest and best known geothermal fields, around 78 km2, located in the Mayacamas Mountains, north of San Francisco and Napa Valley in Northern California. The reservoir is superheated, with relatively low pressure, based in a sandstone formation with the heat source believed to be from a large magma chamber and intrusions from that.

Exploration drilling started in 1921 by John Grant to power a short lived 35 kW power generation, commissioned in 1923 (Hodgson, 2014). The first modern wells were drilled in 1955 followed by the 12 MW Unit 1 online in 1960, operated by PE&G. Over the next three decades, in total 23 power plants were built, most by PE&G and later NPCA, and several operators were drilling for steam in different leases, such as Magma Power Co, Thermal Power Ltd., Union Oil, GRI, Occidental Oil and Shell Oil. The installed power peaked in 1989 when reaching 2043 MW (Salmon et al., 2011). At that time, reservoir pressure had started to decline significantly and at least two power plants never got sufficient steam to start production. The Geysers Technical Advisory Committee (TAC) was founded to seek solutions. Their key finding was that the reservoir pressure decline was caused by limited natural inflow and that major re-injection into the reservoir was required. To meet the demand for re-injection water, a major scheme was initiated, piping over 800 l/sec. of treated effluent water from the Lake County (45 km) and city of Santa Rosa (65 km). At the same time, Unocal and later Calpine started buying both steam field rights and power plants to simplify the operation. The production declined to around 800 MW before stabilising. Currently, active installed power is 1517 MW and capacity factor has been around 60%, equivalent to just over 900 MW power production (Calpine website).

In the 1980s and the 1990s, significant additions were made to the environmental law and regulation framework that impacted geothermal utilisation, such as on ground water, air quality and seismicity. All power plants currently have installed various types of H2S abatement systems with up to 20% additional operational cost. Although successful in stabilising production levels, the injection scheme caused significant increase in seismic events as can be seen in Figure 2, seriously affecting the relationship with the local community.

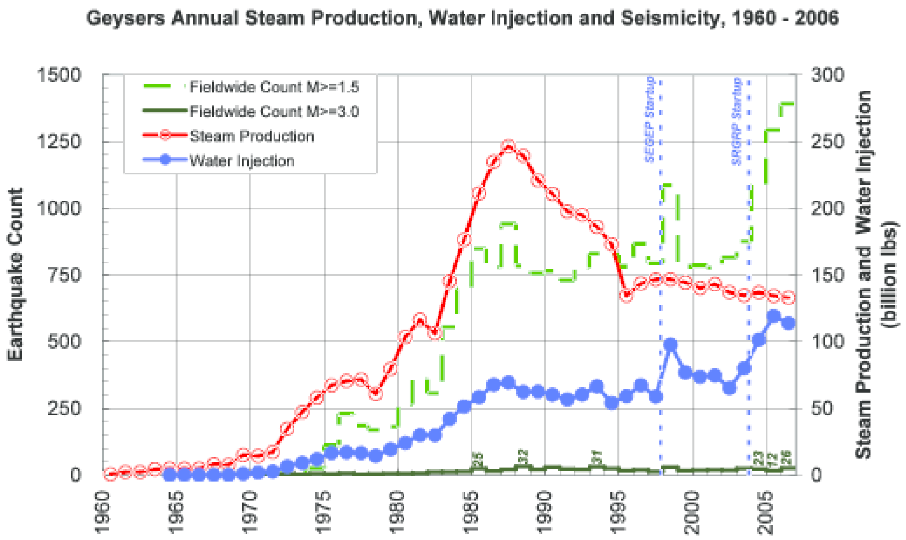

Figure 2: Steam production and water history of Geyser geothermal field, 1960-2006 and its impact on earthquakes (Cladouhos et al., 2010).

Looking back, the overestimate of the reservoir potential at the Geysers, resulted in over-investment equivalent to some 1000 MW. If it is assumed that the investment in today terms is around $3 million per MW, this over-investment is equivalent to $3 billion.

2.2 Experience from Iceland

Although geothermal utilisation in Iceland has a long history, the first projects were associated with direct use for heating, bathing and industrial applications. First power generation was from the 3 MW Bjarnarflag Power Project in 1969 but since then over 700 MW have been installed, counting for around 25% of installed power in Iceland. Overall, the history is considered a success but this development has not been without failures and mistakes that can be learned from.

The greatest learning can be made from the development of the Krafla Geothermal Power Plant. In the early 1970's, the government of Iceland sought an opportunity to generate at least 20 MW to meet an urgent demand for power in Northeast Iceland. Following surface exploration and drilling of two shallow exploration wells in the Krafla Geothermal Field, a decision was made in early 1975 to install two 30 MW Mitsubishi turbines, dual flow double pressure. However, a volcanic eruption started in December 1975 followed by eight different eruptions until 1984. The volcanic activity is believed to have had negative impact on steam quality and drilling for steam proved very problematic (Gudmundsson, 2001). In early 1977, installation of the second turbine was cancelled and when turbine one was started in late 1977, only 7 MW of power was available from 12 wells. Initially, each well was equipped with a separator and in the first year, two turbine rotors were severely damaged by impurities in the steam from superheated wells. Steam quality became sufficient when a central separation station had been built where particles from the superheated steam were washed out with the separation water from the lower enthalpy wells. Turbine one reached full 30 MW power in 1984, after drilling of 23 wells. Turbine 2 was eventually commissioned in 1997 when the gas concentration had decreased somewhat following the end of the eruption period. By then, in total 34 wells had been drilled in the area. Out of them 24 were usable, ranging in power output from practically 0-20 MW with the average just over 3 MW.

As the average fluid enthalpy was significantly higher than the turbine design criteria, some of the wells were specifically drilled to reach low enthalpy fluid to balance the turbine correctly.

Some of the wells in Krafla had started very well, with superheated fluid and power exceeding 10-20 MW but declined within days, weeks or months to just several MW. In 2008 and 2009, wells K-39 and IDDP-1 encountered rhyolite magma at 2500 m and 2100 m depth respectively, illustrating the shallow depth of the heat source. The fluid from the near magma formation has proven to be both highly corrosive as well as prone to silica scaling and therefore very difficult to handle. It is believed that up to 10 wells have suffered from this "black depth" syndrome (Einarsson et al., 2010).

The lessons learned from Krafla are many but most importantly that the information available at the time of decision were far from sufficient. Although the resource was clearly sufficiently large, it is highly complex and the fluid properties were significantly different from what was anticipated. As a business decision, it was financially catastrophic at that time, although the operation has been more successful since 1984.

The next two geothermal power projects in Iceland, the 78 MW Svartsengi in 1978-2008 and 120 MW Nesjavellir power project, commissioned in the years 1990-2005 (Table 2), both combined heat and power, were built cautiously in many phases over a long period. Both are relatively successful, still running close to full power from relatively few wells. It could be claimed that the brine disposal from Svartsengi power plant had not been successful as it formed a large blue pond in the lava, which now is the basis of a highly successful business on its own, the Blue Lagoon Geothermal Spa.

Year	Heat	Electricity
1990	100 MWth	
1994	+50 MWth	
1998	+50 MWth	
1998		60 MWe
2001		+30 MWe
2005		+30 MWe
Total:	**200 MWth**	**120 MWe**

Table 2: Phase development of the combined heat and power Nesjavellir Geothermal Power Plant.

Following the success of Svartsengi and Nesjavellir, the next two geothermal power projects in Iceland were built with confidence, the 100 MW Reykjanes Power Plant 2007 and the 303 MW combined heat and power plant at Hellisheidi. However, both have suffered by lack of steam, Reykjanes due to reservoir pressure decline and Hellisheidi due to pressure decline in the main production zone and lack of permeability outside of that. Hellisheidi also has suffered from various environmental impacts. The re-injection of up to 850 kg/s has caused seismic events up to 4 on Richter scale that can be found quite clearly in the capital of Reykjavík and high concentration of H_2S, damage to moss has also been an issue.

2.3 Experience from El Salvador

The first geothermal plant in El Salvador is Ahuachapán. Following an exploration drilling program, three condensing units were installed, in total 95 MW. First a 30 MW unit in 1975, followed by another 30 MW unit in 1978 and finally a 35 MW unit in 1981. However, "reservoir pressure dropped significantly during the first years of operation. Therefore, just 2 units were operating and the 3rd used as a back-up" (Herrera et al., 2010). From 1975 to 1999, brine was transported through a 71 km long concrete canal to sea. However, re-injection into wells in the nearby Chipilapa field, which provided pressure support, and further drilling have improved the capacity factor from around 60% up to around 85%.

The operator of Ahuachapán, LaGeo learned from the failures there when they started developing the next geothermal field, Berlin in the 1990's. First, they installed two 5 MW low cost back pressure units in 1992. After good experience, these were replaced by two 28 MW condensing units in 1999 and after successful implementation of deep injection, the third condensing unit, 44 MW, was installed in 2007. Finally, the field was optimised by installing a 9 MW bottoming cycle in 2010.

2.4 Current trends

Several papers have been written throughout the years on development strategies and some are aimed at illustrating the potential of getting power earlier online with phase development (Figure 3).

Although development strategies around the world vary, the author feels that cautious approach is gaining support. In Africa, installation of wellhead plants, generating only 5-10 MW each appears to be considered in many cases as a first step to start generating power and at the same time testing both resource and environment while further drilling, engineering, permitting and financing of a full-size plant. More than 15 such plants have been installed in Kenya over the last 5 years and such projects are being considered in other regions, such as Asia and Latin America as well. Such approach would also help convince financiers about the resource, technical and environmental risk.

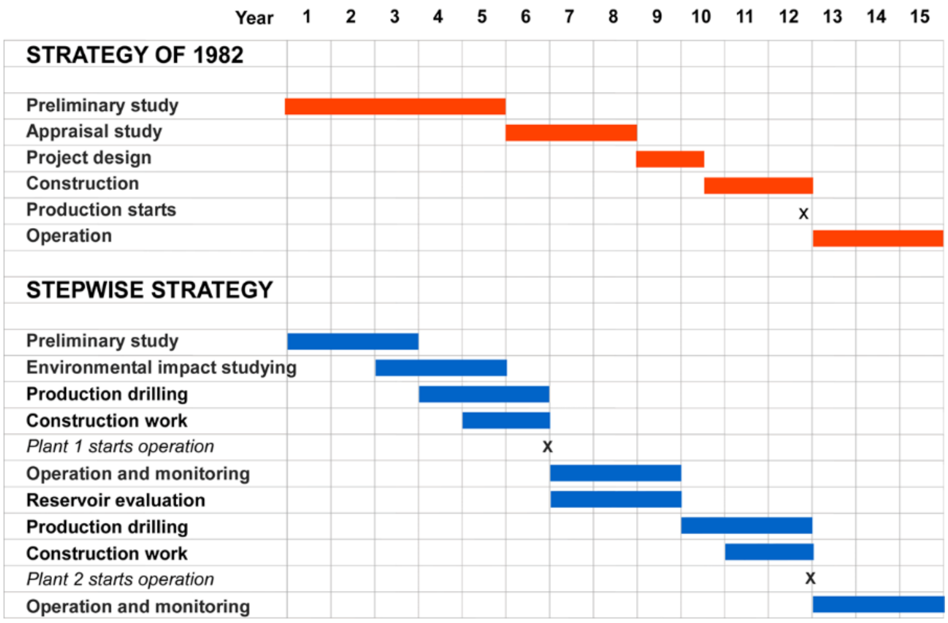

Figure 3: Comparison of development strategies (Ármannsson et al., 2015).

3. STAGE GATE PROCESS FOR GEOTHERMAL PROJECTS

Preparation of a geothermal power project is a long and complex process and it may cost up to 20-30% of the total project cost to reach to the level of being able to take a decision on if to develop the field or not. Therefore, it is of great importance to perform the project preparation in a systematic and disciplined way to maximise the chance of taking the right decision for the minimum cost. Landsvirkjun has adapted a formal stage gate process to ensure a systematic way of developing geothermal projects in an efficient manner, described in Figure 4.

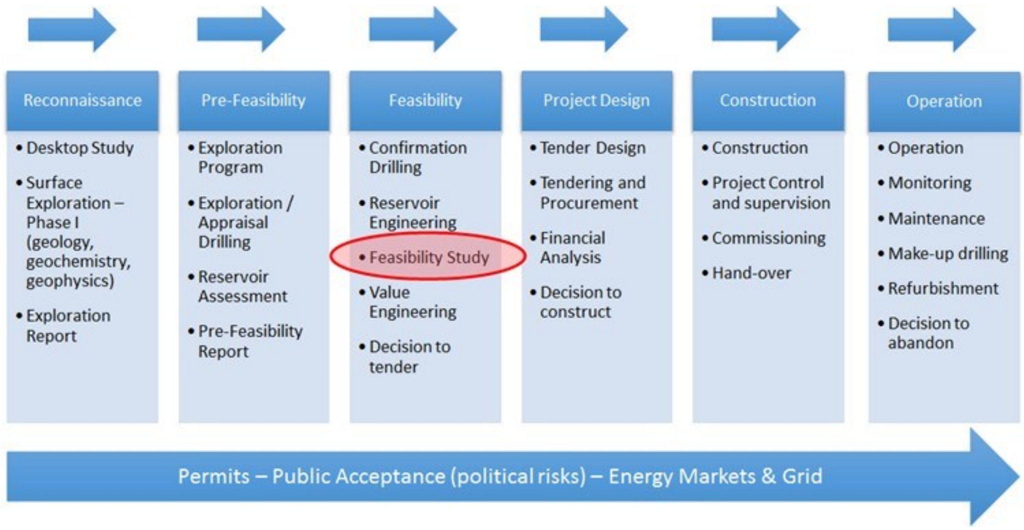

Figure 4: Stage gate process for geothermal projects at Landsvirkjun. At the centre of the process is the feasibility stage at which the feasibility study is the core.

The initial stage (*Reconnaissance*) is the inexpensive desktop study, reviewing all available information and generating a surface exploration plan to fill the gap in the information. Typical cost is in the range of hundred thousand USD and this may take from several months to one or more years, depending on factors such as permitting barriers, financing etc. (Harvey et al., 2016).

The next stage (*Pre-feasibility*) normally starts by completing surface exploration and making the first resource assessment, typically at cost significantly below $1 million. It is possible that the first exploration drilling is made towards the end of this stage, typically a relatively inexpensive well, simply to prove that this is a geothermal field. At the end of the pre-feasibility stage, a pre-feasibility report is prepared and reviewed to justify the costly feasibility stage.

During the *feasibility* stage, the developer must invest in 3-6 exploration wells where each well may cost $5-7 million. In addition, he must conduct Environmental Impact Assessment (EIA), do further reservoir engineering assessment, feasibility design and various other tasks, that will eventually form a feasibility study. Typical cost of a feasibility stage is around $20-$30 million for a 50 MW power project.

At the *project design* stage, the detailed design is made, tender documents prepared and the remaining rights and permits are applied for. If not already finalised, power purchase agreements and transmission agreements are also secured. If needed, the developer may need to drill appraisal wells to further reduce resource risk. At this point the project is considered bankable and the developer may seek funding from financial institutions. Then, he must present bankable documents about the project, where the feasibility study is the central document.

With a detailed project cost estimate, transmission cost, financial cost and power price in hand, financial analysis can be made to be used for final decision if to execute the project and construct the power plant (Gehringer and Loksah, 2012). Typical cost for this part is around \$20-\$30 million, mainly fees for engineering and legal advice and therefore, the total outlaid cost prior to taking a decision is around \$50 million or around 25%, as seen in Figure 5.

The cost of the *construction* stage is still significant, around 75% of the overall cost, but it comes at a time of the project when it has been defined in detail, the risk has been significantly lowered and therefore it carries significantly lower yield than the cost of the project preparation. The project preparation cost is typically financed with grants or equity which carries significantly higher return on equity (ROE).

The reasons why such an emphasis is made of project failures in this paper is to underline the importance of feasibility studies, not only to list the outcome of exploration studies, engineering design and project cost, but also to address risks and present scenarios and development strategy that both optimises project profitability at same time as minimising project risk.

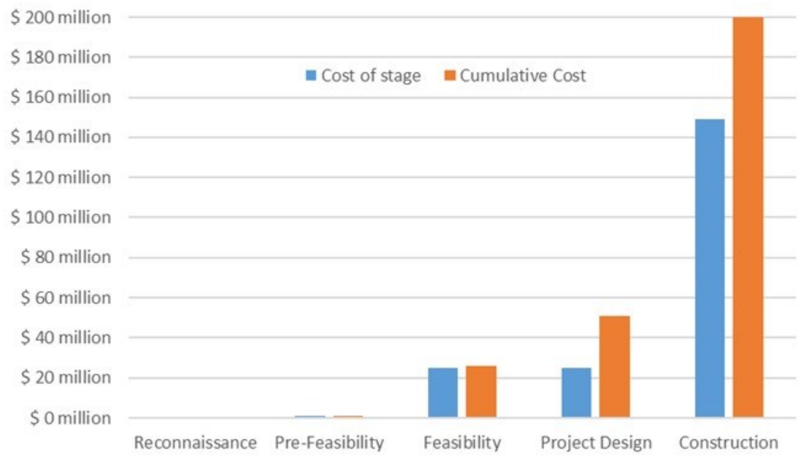

Figure 5: Typical cost distribution for a 50 MW geothermal project with total cost of \$200 million.

4. THE GEOTHERMAL BUSINESS CASE

A business case is a document that captures the reasoning for initiating a project or task. It is often presented in a well-structured written document but may also sometimes come in the form of a short verbal argument or presentation. The logic of the business case is that, whenever resources such as money or effort are spent, they should be in support of a specific business need. Information included in a formal business case could be:

- The background of the project;

- The expected business benefits;

- The options considered (with reasons for rejecting or carrying forward each option);

- The expected costs of the project; and

- A gap analysis and the expected risks.

Consideration should also be given to the option of doing nothing including the costs and risks of inactivity. From this information, the justification for the project is derived. The business case sums up the outcome of the feasibility study with a special focus on the business opportunity. A good business case compares more than one business option and focuses not only on project profitability but also on weighting together risk and return on investment where the scope of the risk assessment is wide, including but not limited to resource risk, technical risk, legal risk and financial risk.

As mentioned before, a business case can be focused for different readers for different purposes. The main three groups are:

1. Executive managers and Board of Directors of the geothermal company

This is the conventional terminology for a business case, where it is used for internal decision making on if to continue with a project or prioritizing power projects (portfolio management). In this case, a special focus is on ensuring that all critical aspects of a project preparation have been fully covered.

2. Financiers

In this case, the set of information is often referred to as „bankable documents“. The purpose of this is to convince the readers that money put into the power project is likely to be paid back.

3. Permit providers (e.g. government, national energy authority)

In this case, the main purpose is to convince the readers that the power will be online on time and in the right quantity and that the resource will be used in a responsible manner.

In a geothermal business case, the main purpose is to illustrate that the following aspects have been addressed and that they have given positive outcome:

- Resource assessment;
- Drilling program and drilling procurement plan;
- Fluid handling (flow testing);
- Design and cost estimate;
- Operational plan;
- Permits, rights and ESIA to use the resource and build and operate the power plant;
- Transmission agreement;
- Power purchase agreement and securities;
- Project risk assessment and risk management plan; and
- Financing scheme, grants, insurance schemes etc.

And eventually illustrate that the geothermal business case is financially viable, presenting financial analysis, including various parameters and sensitivity.

There are typically main approaches towards presenting a business case:

1. One comprehensive document, covering all aspects of the business case, typically 100+ pages.
2. Short summary report with references to various supporting documents (Figure 6).

There is not a single formula for what the summary document is called or how it is structured. It is typically referred to as a “concept note” or a “prospectus” and it may vary from 6 to 20 pages in length. The support documents can also vary but are typically expert reports on various topics, reviewed by external experts, or a collection of essential documents available such as permits, contracts etc.

Figure 6: An overview of a business case or set of bankable documents, where at the centre is the feasibility study.

5. FEASIBILITY STUDY FOR GEOTHERMAL PROJECTS

As stated above, the feasibility study is the key technical document for the process to take a decision on a geothermal project. It is authoritative when it has been prepared by a third party reputable and experienced firm (Ngugi, 2014) and will in most cases be reviewed in detail by financiers themselves or experts on their behalf.

In general, a feasibility study is an analysis of how successfully a project can be completed, accounting for factors that affect it, such as economic, technological, legal and scheduling factors. Project managers use feasibility studies to determine potential positive and negative outcomes of a project before taking a decision on investing a considerable amount of time and money into it.

The center of the feasibility study is the project feasibility design. The feasibility design summarises the outcome of the geothermal exploration, provides a conceptual design for the project, from well design, steam lines, steam separators, power plant including turbine-generator and cold end equipment, re-injection scheme, control and electrical systems and connection to transmission system, buildings, roads and other civil works etc. The feasibility design document also provides a cost estimate, ideally to Class 3 or 4 (AACE, 2016), based on bill of quantities and unit price estimate and project planning or schedule of activities. From this information, the payment scheme can be determined as well as man power requirement, used for determining size of workers' camps and other infrastructure related to the construction. A typical content of a feasibility design report is presented in Table 3.

1. Geothermal exploration and resource assessment
   - Results from exploration
   - Conceptual model and reservoir model
   - Drilling program
2. Process flow diagram
3. Steam supply system design
   - Two phase steam gathering system
   - Separation station
   - Steam lines to turbines
   - Re-injection lines
4. Water lines
   - Utility water for power plant
   - Sewage system
5. Turbine design
   - Choice of technology: flash or binary? Single, double or triple flash? Single or double flow?
6. Cold end design
   - Condenser, cooling tower and additional water requirements
7. Auxiliary systems
8. Connection to transmission
9. Low voltage system for internal use
   - Connection from generator for own use, transformers, medium voltage, low voltage and diesel generator (spare)
10. Control systems
11. Buildings
    - Building sites
    - Powerhouse, service building and transformer shelters
    - Separation station and valve houses
    - Workshop and terminal building
    - Camps and employees buildings
12. Roads
13. Architectural design
14. Project planning
    - Scheduling, manpower requirements, costing and payment schemes
15. Drawings

Table 3: Typical content of a feasibility design document.

In addition to the information from the feasibility design, a feasibility study report will include a few other sections, typically the following:

- Owners statement, presenting the experience and financial, managerial and organisational capacity of the development company to execute the construction and operation.

- A brief project description.

- Project justification, such as market reasons.

- Project execution strategy, i.e. for procurement, funding, management etc.

- Time line through project preparation to commissioning.

- Budget, i.e. funding required to run the project and financial plan on how to pay for all costs.

- Financial model and assumptions.

Typically, the project is compared to other projects to justify this is the correct project to invest in, both for the development company, as well as for the financial institution considering financing.

6. CONCLUSIONS

Geothermal projects are complex and require large amount of money to be invested before a decision can be made if to execute the project or not. Complicated and time consuming permitting process is not to make things easier. The complex nature of the geothermal exploration requires experts from various disciplines and an experienced project management team to collect all expert reports together in one coherent project plan.

The history of geothermal development shows that geothermal projects can easily go wrong if not all aspects of the geothermal project are addressed adequately.

Therefore, a great deal of discipline and organization is needed in the preparation and decision making of successful geothermal projects.

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