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# Stages of a Integrated Geothermal Project

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## Abstract

A geothermal project constitutes two big stages: the exploration and the exploitation. Each one has a single task whose results allow defining the feasibility of a geothermal project, until achieving the construction and operation stage of the power generation plant. The first stage contains the area recognition, its limitation to the target, and elimination of external factors until defining a geothermal zone with characteristics to be commercially exploited. The main studies and analysis that can be applied during the exploration stage are listed, and the major indicator to continue with the project or suspend is the prefeasibility report. The major risks in the exploration stage are due to studies that are carried out on the surface; at this stage, the costs can be considered low. The main results of the exploration are the selection of sites to drill three or four initial wells. Each well provides a direct overview of the reservoir: depth, production thicknesses, thermodynamic parameters, and production characteristics. The drilling of three to four exploratory wells is recommended, as far as there is certainty of the feasibility of the project, and the development of the field begins with drilling of sufficient wells to feed the plant. In this stage, the cost increases, but the risks decrease.

**Keywords:** geothermal project stages, regional exploration, drilling exploratory, drilling well locations, costs during exploration, producer wells, geothermal direct uses

## 1. Introduction

The geothermal word is used to refer to the heat existing inside the earth. From a practical viewpoint, geothermal is the study and the use of the heat energy that by conduction through the rock or transported by fluids moves from the interior of the earth's crust to the surface levels to form geothermal reservoirs.

The energy stored in the form of heat in the rock and aquifers located near the surface can be exploited by drilling wells of up to 3000 or 4000 m depth. The geothermal reservoirs are sometimes visualized on the surface in the form of mud volcanoes, fumaroles, geysers, hydrothermal springs, etc.

The meteoric water that infiltrates through permeable rocks at great depths is heated directly or indirectly by the flow of heat generated by the magmatic chambers, reaching high-, medium-, or low-enthalpy geothermal reservoirs. A geothermal field susceptible of exploitation by steam production for the purpose of electric generation or only hot water (low enthalpy) must present the following characteristics:

- A thermal anomaly
- A reservoir constituted by permeable rocks where the geothermal fluid circulates at economically exploitable depths
- An impermeable cover that prevents the loss of heat by circulation of the geothermal fluid to the surface

In the exploration of a geothermal region, to locate a thermal anomaly (heat source) near the earth's surface, volcanological, structural, and petrological methods are applied. These methods help to distinguish volcanic centers within the regional structural framework estimating their age. Morphological, stratigraphic, and radiometric methods are also applied, which allow the geometry of the geological units in the subsoil to be reconstructed in broad strokes.

The elements that favor the existence of geothermal areas are the persistence of volcanic activity and the frequent eruptions of products that need for its formation a long stay of magma in a chamber. In most cases the chambers are large deposits of magma that feed central volcanic complexes.

Most of the geothermal fields are located in areas of volcanism constituted by clearly identified products (andesite, rhyolites, or dacites) related to an igneous intrusion with depth between 10,000 and 15,000 m representing the magmatic chamber of recent or active volcanic centers.

The five main countries of installed capacity for generating electricity, in the world, using geothermal resources [1–3] are shown in **Table 1**. This classification includes the statistics of production in these five countries between 2005 and 2015.

However, recent additions in 2017 show an increase of 792 MW around the world [4]. Such new additions are as follows:

- Turkey: 325 MW.
- Indonesia: 359 MW.
- Chile: 48 MW.
- Iceland: 45 MW.
- Mexico: 25 MW.
- United States: 24 MW.

	Installed capacity (MW)			Growth rate (MW)
	2005	2010	2015	
United States	2564	3098	3450	886
Philippines	1930	1904	1870	-60
Indonesia	797	1197	1340	543
Mexico	953	958	1017	64
New Zealand	791	843	1005	214

**Table 1.** Classification of the first five countries with the largest installed capacity for generating electricity, from geothermal resources, in the world, in the period 2005–2015 [1–3].

- Portugal (Azores): 3 MW.
- Japan: 5 MW.
- Hungary: 3 MW.

It can be seen from **Table 1** that in 2005 Mexico was in the third place among the countries with the highest installed capacity for electricity generation; currently in 2015 it is located in the fourth position. In this period the United States of North America had an increase in its installed capacity of 886 MWe, Indonesia with 543 MWe, New Zealand with 214 MWe, and Mexico with 64 MWe. The Philippines showed a decrease of 60 MWe in its installed capacity to generate electricity with geothermal resources.

A geothermal reservoir must contain a volume of fluid large enough to ensure prolonged exploitation to recover the investment made. It must also be located within a hydrological system that allows the hydraulic recharge of the area in operation. When the balance between exploitation and recharge is maintained, it is possible to consider geothermal energy as renewable and sustainable.

## 2. Stages of a geothermal project

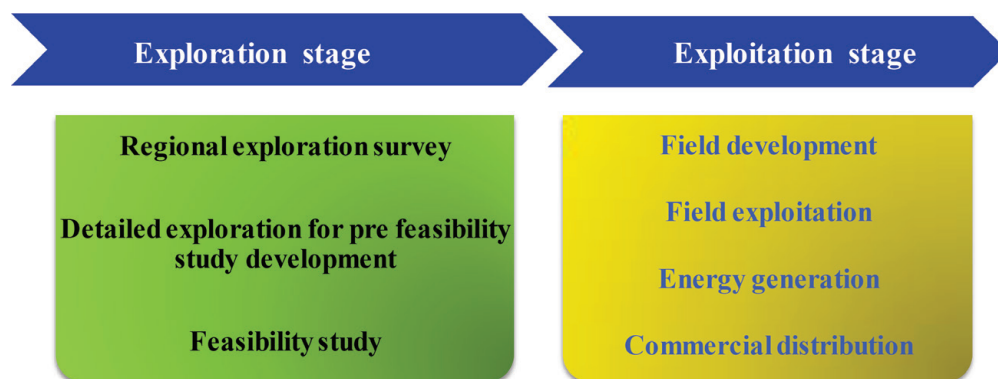
In general, the execution of a typical geothermal project is divided into two main parts: (a) exploration and (b) exploitation. The first is considered high uncertainty whose objective is the reservoir identification, including a study of its possible use. It also implies significant levels of economic risk that must be faced with progressively increasing but relatively low-cost investments. The exploitation stage involves minor risks but requires high investments.

The Latin American Energy Organization (OLADE) [5] drafted a guidance document for recognition studies of a geothermal project, applicable to Latin American countries. The document states that from a practical point of view, a geothermal project can be divided into the stages, appearing in **Figure 1**.

According to the experiences obtained in the world, it has been identified that for areas of research coverage of a thermal source, during the exploration the following ranges can be referred:

For the survey study, the area to be covered could be  $\geq 1000 \text{ km}^2$ .

- For the prefeasibility study, the area could have a coverage between 400 and 500  $\text{km}^2$ .
- The area for a feasibility study is reduced to between 10 and 100  $\text{km}^2$ .



**Figure 1.** Two main stages (exploration and exploitation) of a geothermal project described by [5], with its corresponding particular tasks.

To develop a project in a geographically understudied region, it is necessary to start the exploration with a reconnaissance study that covers an area of 1000 km<sup>2</sup> or more. This recognition will make it possible to formulate the first hypotheses about the geothermal possibilities of the region and select one or several favorable areas to carry out prefeasibility studies. Likewise, a detailed exploration program applicable to areas of geothermal interest will be designed.

The objective of prefeasibility tasks is to identify, with field studies, the possible existence of underground reservoir under conditions such that if the process continues with deep perforations, the risk will be minimal. Based on the survey area, prefeasibility investigations are usually carried out in areas ranging from 400 to 500 km<sup>2</sup>.

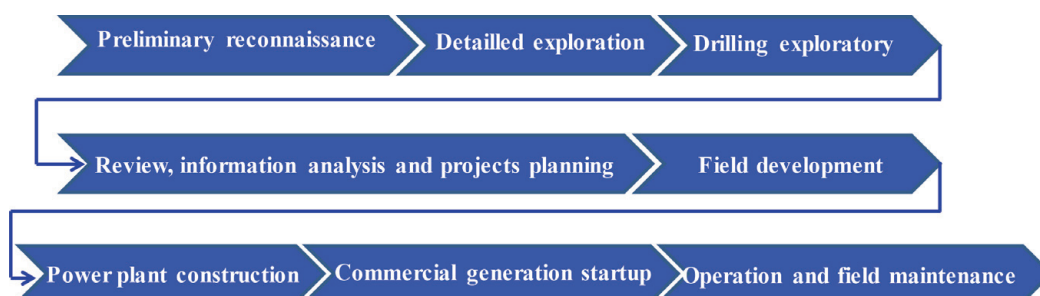
After a geothermal project positively exceeds the prefeasibility stage, it evolves to the feasibility stage. The verification of the existence of a reservoir in an area between 10 and 100 km<sup>2</sup> is carried out by drilling deep exploratory wells. Likewise, the probable reserve of the prospective area is evaluated, and the preliminary design of the systems to be used in the following stages is developed.

The development stage includes the continuation of well drilling, the execution of geoscientific studies in detail, the evaluation of the probable reserve, the extraction of the fluid, the design of the project, and the construction of a power plant generation.

The exploitation process of the resource involves the management of the geothermal fluid from its extraction to its exploitation through the production of electrical energy or any direct use of heat. Techniques are applied during the exploitation to optimize the use of the fluid and its transport to the generation plants, guaranteeing the continuous operation of the field and observing and controlling the reservoir evolution.

At the international level, there is currently no guide available that contains the most recommendable practices for the development of a geothermal project. Alone, with the experience acquired by the different countries, geothermal projects have been executed. The International Geothermal Association (IGA) [6] configured some ideas regarding the practices applied in different geothermal projects on the planet. Even though there are differences in methodologies and techniques between the different countries, the general guide establishes a seven-stage process for the development of these projects. This guide is known as ESMAP Geothermal Handbook and basically contains the stages mentioned by [5, 7], with the exception that in the exploitation stage, it adds two more stages: (1) construction of the generation plant and (2) start-up and operation. The seven-stage process proposed by the [6] is shown in **Figure 2**, adding at the end of seventh, the corresponding operation and field maintenance.

Both documents [5–7] coincide in the preliminary survey study as the basis for initiating a geothermal project. This document describes this stage in a specific way, considering the influence of the exploratory stage in a geothermal project.



**Figure 2.** Process stages of a geothermal project suggested by [5–7] and adding the operation and field maintenance stage.

## 2.1 Geothermal survey study

The preliminary reconnaissance stage involves a work program to evaluate the available evidence of the geothermal potential within a specific area. This stage is usually at the regional or even at the national level, where reviews of the literature on geology, hydrology, thermal manifestation data, well data, remote sensing data (if available), and even anecdotal information from the communities are included.

The studies that are carried out are the geological, geochemical, and hydrological exploration; using the available geophysical information also correlated the satellite images. A preliminary geological scheme of the geothermal system of the area or areas of interest is elaborated, and the geothermal possibilities of each are determined. The parameters to be determined are:

- The existence of an anomalous high-temperature zone in the subsoil based on the volcanological conditions and the result of chemical geothermometers.
- The degree of permeability of the rocks in which it is inferred the reservoir is nested. This determination will be based on the degree of tectonic fracturing suffered by the rocks.
- The extension and depth of the probable reservoir, which is used to estimate the volume of the deposit and is the sustenance to evaluate the energy capacity of the area, as well as the cost of the wells to be drilled.
- Estimate the possibility of recharging the aquifer that may sustain the reservoir exploitation during its operational life.

The analysis of the areas studied in this stage will allow to evaluate its energetic potential and a preliminary hierarchy of those that are considered of geothermal interest. Subsequent socioeconomic and political evaluations may help to define priority areas to continue prefeasibility studies.

In general, the geological studies are summarized:

- Develop regional cartography and define the preliminary geovolcanological scheme of the area.
- Define the relationship of regional geodynamics with tectonics and volcanism in the area.
- Determine thermal anomalies.
- Define the regional stratigraphic sequence and the lithological characteristics of the formations.
- Prepare the geovolcanological cartography of the geothermal areas identified.
- Identify the elements that could integrate the geothermal systems (heat source, reservoir, sealing system).
- Define, classify, and select geothermal areas of interest.
- Preparation of a preliminary structural geological plan of the region to be investigated.

From the specimens of collected rocks, thin sheets were prepared for petrographic and petrological analyses. The petrographic analysis is useful for determining the type of rock and classifying it. The petrological analysis allows to determine the nature of the magma and its degree of acidity.

Analysis of hydrothermal alteration will allow to determine the paragenesis of minerals and a thermal zoning of the possible geothermal system. The rock samples are subjected to chemical analysis for determining major elements such as SiO<sub>2</sub>, AlO<sub>3</sub>, FeO, Na<sub>2</sub>O, CaO, MnO, TiO<sub>2</sub>, P<sub>2</sub>O<sub>3</sub>, and MgO, among others, and also trace elements such as Ni, Cr, Rb, Sr., Ce, La, Zr, and Nb. By isotopy, the Sr<sup>16</sup>/Sr<sup>37</sup> ratio will be determined.

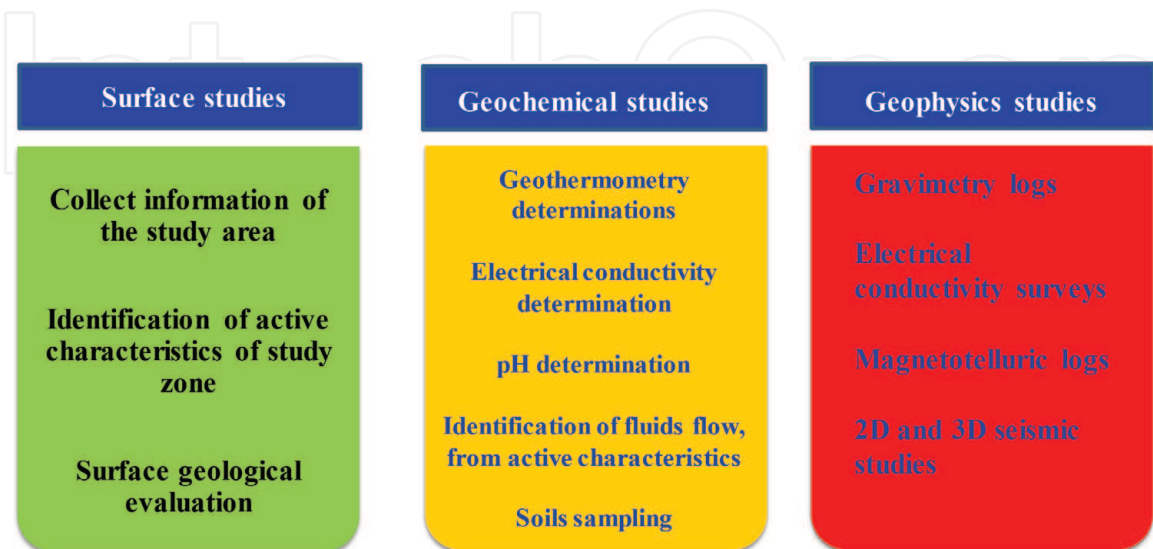
At this stage, the reservoir temperature could be estimated from the geochemical samples, using geothermometers or also taking into account the mineralogical studies of the hydrothermalized xenoliths, the petrology of the expelled products, and their radiometric age. The stratigraphic sequence of the studied zone will also contribute to define the hydrological characteristics of the formations.

Regardless of the studies to be carried out at this stage, it is highly recommended to visualize the project in a global manner, covering aspects such as infrastructure of the area (access roads, water availability, communication, and transmission systems) and property rights (water, legal permits for drilling, commitments to environmental legislation, legal framework of the geothermal laws, etc.). The consideration of these factors allows to identify possible obstacles that could influence the successful development of the project in general. Taking into consideration the results of the review and evaluation, the developer is in a position to decide to move to the prefeasibility stage. This stage could be developed in about 4 to 5 months; however, if there are many potential sites and if the processes of environmental approvals and permits are complex, it could last up to a year.

## 2.2 Prefeasibility studies

The basic studies of this stage are summarized in **Figure 3**.

The time duration for the recognition and prefeasibility stages, corresponding to the exploration stage [6] assigned in its document, is estimated to be 10 months. **Table 2** shows the breakdown of the activities of each stage using a Gantt chart for distribution over time.



**Figure 3.**

*Summary of the studies carried out through the three basic disciplines that intervene in this stage of superficial recognition of a geothermal project.*

Stage	Activities	Time (months)									
		1	2	3	4	5	6	7	8	9	10
Preliminary reconnaissance	Review of updated literature	█									
	Access and land domain	█									
	Review and environmental and social problem identification	█	█								
	Attention to legal regulations	█	█								
	Inventory of active geothermal zones		█								
	Field general exploration program		█	█							
Exploration	Environmental study program according to regulation		█	█							
	Field works of geology and geochemical exploration		█	█							
	Geophysical surveys			█	█						
	Data interpretation by correlating geological, geophysical, and geochemical				█	█					
	Drilling of temperature gradient wells					█	█				
	Integrated analysis of information (geological, geophysical, geochemical, and thermodynamic)						█	█			
	Conceptual model development		█	█	█	█	█	█	█	█	█
	Site selection for drilling exploratory of deep well								█	█	
	Prefeasibility report								█	█	█

**Table 2.** Sequence of the activities that are carried out in the stages of preliminary recognition and exploration, each with their duration times.



The main activities of each one of the disciplines that are executed throughout the exploration stage are the following:

Location of the source (lat/long or UTM coordinates).

1. For active geothermal characteristics

- Temperature
- Electric conductivity
- pH
- Flow
- Presence of gas bubbles and their composition
- Presence of odors (sulfides or others)
- Presence of precipitates in fluids
- Local or detailed area map with the thermal characteristics clearly indicated

2. Geological data

- Geological maps of the area or areas
- Cross-sectional geological sections of the study area or areas
- Description by means of stratigraphic and lithological columns
- Description of regional and local structures accompanied by maps
- Identification and characterization of the potential of the reservoir units
- Presence of mineralization associated with hydrothermal systems

3. Geochemical data

- Location, name, and characteristics of the sampling points
- Temperature, electrical conductivity, pH, and approximate flow during sampling
- Preservation of the sample for transfer to laboratories
- Chemical analysis of the samples collected
- Characteristics of the laboratories that develop the analyses
- Information on calcite inhibitors (if the sample comes from a producer well)
- Names, descriptions, and locations of the incrustations or minerals deposited

- Geothermometry estimates
- Interpretation and/or graphs of geochemical data
- Referral data from wells and neighboring projects

#### 4. Geophysical data

- Gravity logs
- Electrical resistivity
- Seismic surveys
- Heat flow and temperature gradient records
- Geomagnetic studies
- Other records

#### 5. Subsurface temperature data

- Rock formation temperature from measurements
- Temperature to flow conditions, at manifestations as in wells
- Maps of temperature contours at different depths of the reservoir
- Transverse sections of temperature distributions

#### 6. Reservoir conceptual model that incorporates all the previous concepts.

All the data integration will allow the project developers to understand and explain the three-dimensional composition of the project area including its geological structure, stratigraphy, geophysical properties, location of the thermal sources, and geochemical characteristics. The model's fundamental result is the location of the heat sources and the possible sources of geothermal fluids as well as the nature of the trajectories that allow the movement of the fluids from the source to the system through the reservoir and to the discharge points.

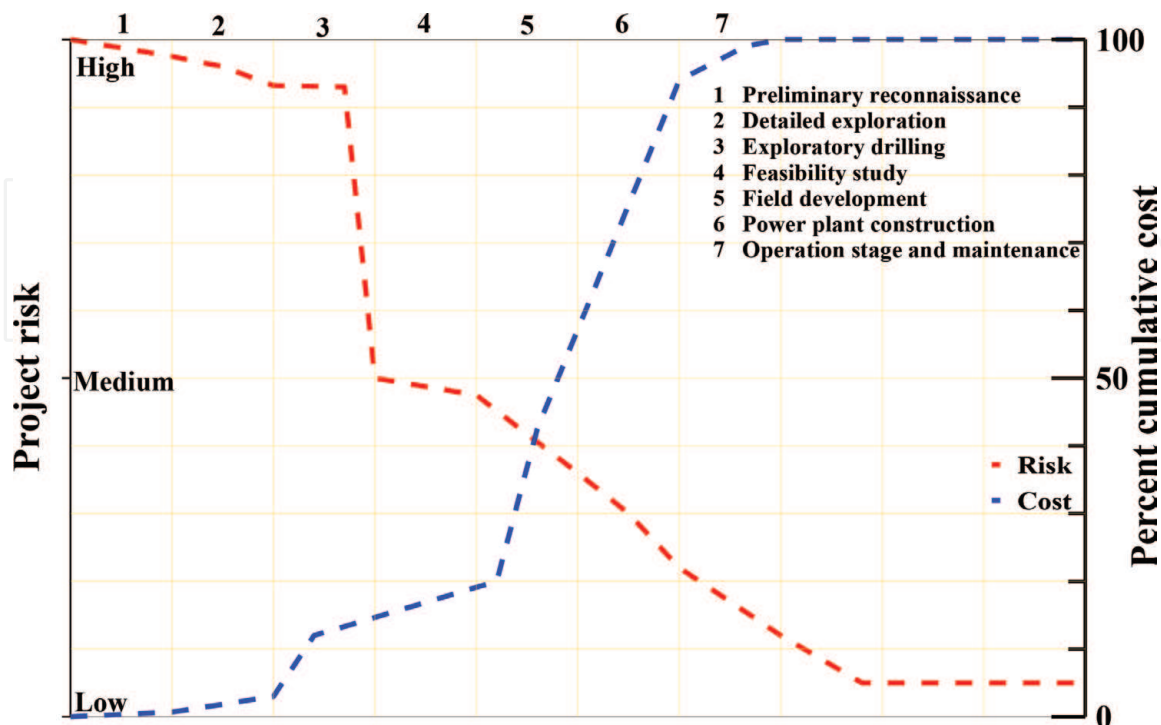
Based on the understanding of fluid flow, the conceptual model is used for programming well drilling to reach specific targets on its lithology and structures. A robust conceptual model allows determining the feasibility of a project, the ideal locations, and depths to drill in the wells. The basic focuses of this type of models are oriented to:

- Determine temperature thermodynamic conditions for the generation of electrical energy.
- Determine the distribution of the temperature surfaces in the reservoir and its relationship with the fluid flow.

- Determine the adequate porosity and permeability existing in the rocks of the reservoir, as well as its extension and orientation.
- Determine the existing relationship between geology and geothermal characteristics.
- Determine the degree of influence of faults and stratigraphic units on the flow of fluids.
- Determine the most attractive places and their depths to succeed in drilling wells.

The final process of the exploration consists of the evaluation of all the data, technical and nontechnical, before committing the decision of a location to start the drilling of a deep well. This is an important decision because it involves large financial commitments for the project.

A geothermal project presents risks of success in its early stages, because geochemical studies, geological exploration, and geophysics are developed from the surface. Even though these studies are of very good precision, there is always the uncertainty of their validation. The previous is achieved with the drilling of a well, which represents a direct view of the formation of rock and its thermodynamic characteristics, confirming the veracity of the preceding studies. Conversely, the first stages do not involve large costs until the drilling begins. However, drilling influences the decrease in project risks. **Figure 4** shows a graph of the behavior of risks in a geothermal project [1, 8] and its relationship with investment costs according to the stages of the same. Ref. [9] developed an estimate of installed capacity costs for plants from 20 to 50 MWe in New Zealand.



**Figure 4.** Typical profiles of risks and costs in a geothermal project, taking into account each stage of its development [1, 8].

## 2.3 Well drilling

The drilling of the first wells in any project represents the period of greatest risk. It is usually recommended to drill three or four deep wells to obtain certainty of the commercial feasibility of the exploitation of the resource. Likewise, the drilling of at least one injection well must be considered jointly. It is important to consider that drilling wells, their logs, and their tests significantly improve the understanding of the available resource.

In this stage, they represent a reliable basis for preliminary estimation of the energy reserve, the identification of the production thicknesses, the petrophysical characteristics of the formation, and an approximate evaluation of the system area. The basic information that must be carefully collected at this stage is the following:

- Drilling speeds.
- The inlet and outlet temperatures of the drilling fluids.
- Chemical sampling of fluids and gases that come out with the circulation of the drilling fluid.
- Sampling (meter by meter) of the perforation cuttings for further analysis.
- Mineralogical control.
- Lithology control of the well (each meter), for the construction of its column.
- Record of circulation losses of drilling fluids.
- Series of records of temperature and pressure profiles approximately every 400 m, using resting times of 0, 6, 12, 18, 24, and 30 h to determine the profiles in undisturbed state and the static pressures and temperatures to be used in the numerical models of the reservoir.
- Injection tests when the target depth is reached in the well, to analyze them by means of pressure transient techniques and determine the petrophysical characteristics of the reservoir area.
- If the well presents thermodynamic characteristics of production, enable it with its surface facilities, valves, pipes, silencer, and measuring instruments (manometers, thermometers, and sampling holes) to make a discharge test to different openings and build the initial characteristic curve of the well production.
- During the production test, take samples of the fluid produced at each orifice change, for its chemical characterization.

The series of pressure-temperature logs, together with all the parameters that have been determined, allow to identify the characteristics of the well to make an appropriate definition on the presence of the appropriate range of exploitation. After the well drilling reaches the intervals of interest, transient pressure tests are carried out. The decision on well completion is taken after the permeable zones and

thermodynamic conditions suitable for exploitation are found. During well completion, design of production pipes that are going to be introduced into the well is carried out. The next step is to proceed to conditioning the facilities on the surface of the well, giving a period of heating for their pipes and even measuring their elongation on the surface.

Performing daily measurements on the pressure and temperature at the well head, it is possible to determine if the heating has been uniformed in the pipes, in order to decide the appropriate moment to carry out the initial discharge test and obtain its production characteristic curve. The parameters of the characteristic curve (pressure-flow-enthalpy) are the basis for the well characterization.

Taking all previous considerations, the results of the first wells are aimed at:

- Making a better approach to the heat source
- Determining the average productivity as well as the probability that the same trend will continue in future drilling
- Selection of new sites, target depths, and construction of road infrastructure
- Mechanical designs of the subsequent exploitation and reinjection wells
- Development of a preliminary design of the power plant and the steam transport system

## **2.4 Project planning**

The first drilled wells in an area allow locating and confirming the existence of a viable project, and from the information recovered, their risks are substantially reduced. With all the information obtained, it is feasible to prepare a report. At this point the developer is able to figure out the general plan of the project. The incorporation of the risk analysis in the economic models of the project provides support for the request of the financing that was necessary.

The feasibility report is designed in order to provide confidence on the viability of the project and facilitate its financing. From this stage and in the subsequent ones, a constant monitoring of the behavior parameters of the wells must be maintained, such as:

- Production behavior (pressure, flow, enthalpy, production hole diameter, etc.)
- Fluid and gas sampling (chemical and isotopic analyses)
- Production tests (according to the possibilities in each well)

The feasibility report should include the following elements:

- Location of wells to be drilled, design for completion, and civil works necessary (access roads, leveling, possible locations of the generation plant, etc.)
- Design of field development wells
- Design of the electric power generation plant

- Construction of the main access roads
- Budgeting
- Terms of agreements for the sale of electric power
- Projections of the income-expenditure budget

## **2.5 Field development**

Field development corresponds to its growth through production wells for increasing production flow until the supply requirement to the generation plant is satisfied. Also the environment-friendly eviction must be sought, of the brine produced, through reinjection wells.

The data and useful information that project partners must analyze may include the following:

### *2.5.1 Information related to drilling equipment, work crews, and supervisors*

- Detail specifications of the drilling equipment for the subsequent wells
- Analysis of the experience, in geothermal wells, of the drilling company
- Design of drilling programs for the subsequent wells to be drilled (depths, thicknesses, casing pipes, production liners, surface installations, etc.)
- List and classification of possible specialized service providers
- Knowledge and classification of the work teams for the project and the technical support of their advisors

### *2.5.2 Information on the commercial aspects of the project*

- Plan for the sale of electric power and its sale wholesale or retail
- Description of the project structure
- Analysis of financial projections including expenses for unforeseen contingencies during drilling or costs of maintenance operations and/or stimulation
- Description and value of the goods and equipment to be insured

### *2.5.3 Information of the company responsible for the project*

- Basic information of the company (type, organization, owners, financial movements, related companies, etc.)
- Experience of managers in the management of drilling projects and the development of natural resource projects

	Exploration			Exploitation		
Phases	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
	Recognition	Exploration	Exploratory drilling	Feasibility	Field development	Construction
Generic activities	Licenses acquisition	Geology detailed	Drilling and evaluation of exploration wells	Financing analysis	Well drilling	Construction of the plant
	Regional surface geological exploration	Geochemistry	Parameter evaluation	Conceptual design	Exploitation designs	Drilling and evaluation of wells
	Geochemical exploration	Geophysical studies	Static reservoir characterization	Reservoir evaluation	Plant design	Construction of vapor ducts and surface equipment
		Location of sites to drill	Delimitation of the exploration area	Feasibility report	Design of steam transport and equipment	Admission tests and turbine treading
Main objectives	Surface recognition	Confirmation of geothermal conditions	Geothermal reservoir confirmation	Techno-economic feasibility	Techno-economic infrastructure	Commercial operation start-up

**Table 3.** Activities and their likely duration of the various stages of a business plan for a geothermal project [1, 5].

- Experience of the work team
- Number and type of support staff

## 2.6 Construction of the power generation plant

Based on the construction designs of the generation plant, at the end of this stage, civil works, access roads, and steam collection and transport systems are completed. During this stage, the development of the transient pressure tests to the wells that are finishing drilling is continued as far as possible. These tests are useful for reservoir characterization under its undisturbed state.

## 2.7 Start-up and operation

After finishing the construction of the plant, the start-up and operation phase of the plant begins. Having assured the supply of the resource (with the drilling of wells) for the start of operation of the plant, the main objective is aimed at optimizing production. The above is achieved through appropriate designs, applying criteria for reservoir engineering and well production.

Likewise, it is necessary to emphasize the drilling of injection wells for the clean evacuation of the brine, preserving the environment and seeking reservoir recharge. During the operation, it must seek to minimize its costs and ensure reliable delivery of the resource to the generation plant.

A timeline on the likely total duration of the project and each of its stages is shown in **Table 3** [1, 5]. It should be emphasized that the quality of the information during the first two stages is the basis for obtaining a location for the first well to be drilled and, if necessary, ensuring its success and therefore the continuity of the project. However, in the case that the first well drilled is not a producer, it is recommended not to discard the project and try to drill up to three or four exploratory wells, always applying the best technical criteria to select their locations.

After the exploitation stage comes the operation and maintenance stage. This stage involves the operation and maintenance activities of the electricity generation plant, as well as the maintenance of the wells, the transport systems, and the accessory equipment for the operation of the plant.

## 3. Costs

According to the Department of Information and Energy Administration of the United States of America (EIA, 2016), the costs that generally prevail at present for a geothermal plant are the following:

The estimated cost of the KW installed in a geothermal plant fluctuates between 1500 and 2500 dollars. The cost of operation and maintenance of a plant can be considered between 0.015 and 0.020 dollars per KW installed hour. The cost per KW hour installed for the operation and maintenance of the field is estimated between 0.035 and 0.040 dollars. However, the magnitude of generation plant type is a factor for investment projection, because the initial drilling exploration increases the costs. **Table 4** shows the investment costs for power plants of different generation capacities. From cost balance, it can be seen that the cost of generated MW for small plants (5 MW) is major than for bigger plants (30 MW).



Plant capacity	Stage	High-enthalpy fluid	Medium-enthalpy fluid
Plants with capacity lower than 5 MW	Exploration (USD)	400–800	400–1000
	Production (USD)	100–200	300–600
	Operation (USD)	1100–1300	1100–1400
	<b>Total (USD)</b>	<b>1600–2300</b>	<b>1800–3000</b>
Plants of medium capacity between 5 to 30 MW	Exploration (USD)	250–400	250–600
	Production (USD)	200–500	400–700
	Operation (USD)	850–1200	950–1200
	<b>Total (USD)</b>	<b>1300–2100</b>	<b>1600–2500</b>
Plants with capacity upper than 30 MW	Exploration (USD)	100–200	100–400
	Production (USD)	300–450	400–700
	Operation (USD)	750–1100	850–1100
	<b>Total (USD)</b>	<b>1150–1750</b>	<b>1350–2200</b>

**Table 4.**

*Estimated values of investment of a complete geothermal project from exploration to operation and maintenance stage, with generation plants of 5 up to 30 MW and for fluids with high and medium enthalpy [10].*

The useful life of a geothermal project is estimated between 25 and 30 years. The considerations were made based on a 50 MW plant generating electricity using geothermal fluid.

#### 4. Direct uses

The direct uses of geothermal energy are considered among the oldest, most versatile, and most common ways to use it. Since the Roman Empire, there are records of using water for thermal spas [11–13]. Other applications were for space heating, and then techniques were introduced to use it as a greenhouse effect; recently it has also been applied for refrigeration, for fruit drying, and with the advancement of technology in heat pumps.

**Table 5** shows the use of geothermal energy applied to direct uses in the last 20 years on the planet [13]. It can be seen that the greatest growth has occurred due to the technological development.

In addition to this table, a growth in the application of geothermal energy for heat pumps, heating and greenhouses, thermal baths, and swimming can be observed (**Table 5**). However, the drying of fruits, vegetables, and woods, as well as applications for refrigeration and industrial uses, shows moderate progress.

The geothermal fluid used for direct applications has low enthalpy, and the decision to operate under this modality is based on two of the basic stages of the project:

1. At the end of the exploration stage, when the prefeasibility study indicates the geothermal project is not viable so that the wells can be subjected to commercial exploitation.
2. During the stage of commercial exploitation, the use of the geothermal resource makes the process interesting to take advantage of the remaining energy in each stage.

Direct uses of geothermal heat	Utilization TJ/year				
	1995	2000	2005	2010	2015
Heat geothermal pumps	14,617	23,275	87,503	200,149	325,028
Heating of spaces	38,230	42,926	55,256	63,025	88,222
Air conditioning of greenhouses	15,742	17,864	20,661	23,264	26,662
Heating of aquaculture ponds	13,493	11,733	10,976	11,521	11,958
Drying of fruits, vegetables, and woods	1124	1038	2013	1635	2030
Industrial uses	10,120	10,220	10,868	11,745	10,453
Thermal baths and swimming	15,742	79,546	83,018	109,410	119,381
Refrigeration	1124	1063	2032	2126	2600
Others	2249	3034	1045	955	1452

**Table 5.**  
*Description of the uses of geothermal energy for direct applications on the planet during 1995–2015 [13].*

That is, if you have an electric generation plant with an intake pressure of, for example, 8 bars, when you leave this first process, the steam still has pressure, and naturally there is water condensed at high temperature, resulting from the first “flash.” The steam can be channeled to a second “flash” to a plant that requires lower intake pressure, and again there is condensed water at high temperature. After this second stage, the steam still has energy and can be channeled to a binary cycle plant to take advantage of its remaining energy. The water produced by the consecutive “flashes,” in the generation processes at different intake pressures, can be used to heat spaces in residential areas. When the water cools, it can be conducted to the injection systems to recharge the reservoir.

As can be seen, the direct uses of geothermal energy have a variety of applications during the operation of the field, which leads to make the most of the heat of the earth while preserving the environment. For this reason, the geothermal energy is renewable and can be considered sustainable.

## 5. Conclusions

Geothermal energy is a natural resource whose characteristics make it renewable and sustainable.

The exploration, geological, geochemical, and geophysical stages allow us to delimit the regional area to a focused area where we can locate the first exploratory wells to be drilled.

The quality of the information obtained, its analysis, and interpretation support the technical bases of the stages of recognition, prefeasibility, and feasibility of a geothermal project.

The risks in the exploration stage are high due to the uncertainties of not yet having direct information from the subsurface; however, the costs are low, which may be 15 or 20% of the total cost of the project.

The costs of the project increase during the well drilling stage for the development of the field, as well as in the construction of the plant; however, the risks decrease noticeably.

The characterization of the productivity of the wells allows to establish the appropriate designs of their exploitation and in this way increase their efficiency and useful life.

As of the start-up of the plant, costs are minimized, because the working fuel is a natural resource; only operating and maintenance costs are considered for wells and facilities. It is necessary to maintain a balance between the extracted mass and the recharge input to increase the efficiency in the operation.

In a geothermal process, particularly a hydrothermal of high temperature, the energy can be fully utilized by sequentially using its discharges from the different stages, to generate electricity at lower acceptance conditions of the plants in a second and third “flash.”

Direct uses of geothermal heat are recommended for low-enthalpy systems.

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