ESMAP

PREPARING FEASIBILITY STUDIES FOR THE FINANCING OF GEOTHERMAL PROJECTS

An Overview of Best Practices

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The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and 18 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets.

EXECUTIVE SUMMARY

A geothermal feasibility study is a document, prepared by the project developer, that collects and presents information necessary to determine the technical and financial viability of a geothermal energy project and its compliance with environmental and social safeguards.

A feasibility study's role in overall project development is to review viability of a project and secure financing. A bankable feasibility study is finished when the developer achieves financial closure for the project, which means the remaining project activities are financed.

Detailed standards for the preparation of feasibility studies in the geothermal industry have not been published to date. Based on a review of feasibility studies from other sectors and industries, and the authors' personal experience in the geothermal industry, this document recommends that such studies include the following elements:

1. **Project concept and background:** A high-level overview of the project's scope, and a description of the relevant context in the host country
2. **Market concept and analysis:** A description of the energy market in which the project will operate, and an overview of the agreements prepared or in place for the sale of power produced over the project's lifetime
3. **Geothermal resource assessment and a field development plan:** An overview of the characteristics of the geothermal resource and its expected power generation capacity, and a detailed field development plan that indicates where the remaining production and reinjection wells are to be located, including makeup wells
4. **Location and site:** A description of aspects related to the project's geographical placement, and a summary of its critical characteristics
5. **Environmental and social safeguards:** A description of how the environmental and social impacts and risks necessarily associated with geothermal development will be managed, which are critical safeguards for a project's successful development
6. **Engineering and technology:** An outline of the functional aspects and physical layout of the proposed geothermal power plant
7. **Project execution plan and schedule:** A plan for the project's implementation, which starts with the decision to invest and is deemed complete upon the commencement of commercial production
8. **Financial analysis and investment appraisal:** A financial analysis showing that the project has a sound financial basis and considers both costs and revenues

Even though the focus is on geothermal projects for electricity production, most of the recommendations presented are equally valid for direct-use geothermal projects.

ABBREVIATIONS

AACE	American Association of Cost Engineering
CAPEX	capital expenditure
CO_2	carbon dioxide
EIA	Environmental Impact Assessment
EPC	engineering, procurement, and construction
ESF	Environmental and Social Framework
ESIA	Environmental and Social Impact Assessment
ESMAP	Energy Sector Management Assistance Program
ESMP	Environmental and Social Management Plan
ESS	Environmental and Social Standards (WB)
H_2S	hydrogen sulfide
Hg	mercury
IFC	International Finance Corporation
MWe	megawatts electric
NCG	non-condensable gas
OPEX	operating expenditure
PPA	power purchase agreement
PS	Performance Standard (IFC)
SEP	Stakeholder Engagement Plan
WB/WBG	World Bank Group
WBS	Work Breakdown Structure

All currency is in United States dollars (US$, USD), unless otherwise indicated.

1. PREPARING A GEOTHERMAL FEASIBILITY STUDY

This document offers guidelines for the preparation of feasibility studies for geothermal power projects in accordance with best industry practices. A geothermal feasibility study is a document, prepared by the project developer, that collects and presents information necessary to determine the technical and financial viability of a geothermal energy project and its compliance with environmental and social safeguards. In a broad sense, a feasibility study is a living document that evolves over the course of the project preparation phase. Such studies may also have specific purposes, such as to guide the internal business decisions of a project's owners or to demonstrate the economic viability of a project and its alignment with the country´s energy strategy to public stakeholders. The guidelines presented here refer, specifically, to feasibility studies prepared for the purpose of securing financing,[1] both debt and equity.

A project developer prepares a feasibility study using reliable data so that financiers can assess the risks associated with a project. A feasibility study should identify the main risks and describe how they will be managed. A necessary condition for receiving funding is that financiers can assess project risks and their magnitude and whether these are in a range they are willing to accept.

The guidelines offered in this document have two purposes. The first is to help project developers understand the required content and structure of a feasibility study. The second is to suggest how financing entities may assess whether a feasibility study is of adequate quality and scope.

The topics addressed in a feasibility study for any power generation project are quite similar irrespective of the energy conversion technology. However, several aspects of geothermal projects set them apart from other power generation projects. For example, geothermal projects need significant investments in drilling relatively early in the project lifetime to reduce resource uncertainty.

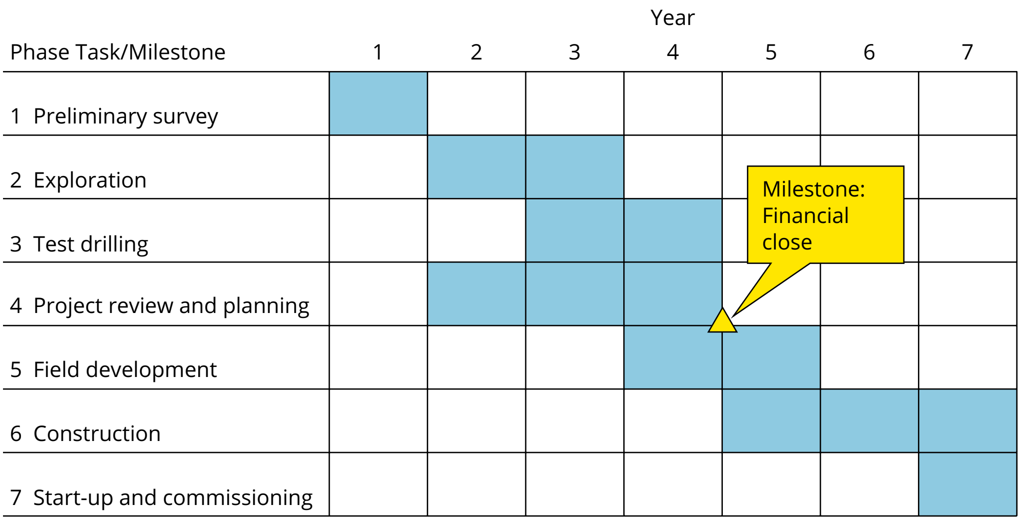
Even though the focus here is on geothermal projects for electricity production, most of the recommendations presented are equally valid for direct-use geothermal projects.

THE FEASIBILITY STUDY IN THE CONTEXT OF GEOTHERMAL PROJECT DEVELOPMENT

Before the operation of a geothermal project commences, its development can be divided into a series of phases. These may include preliminary surveys, exploration, test drilling, project review and planning, field development, and construction, as well as start-up and commissioning, and operation. In Figure 1.1, an arbitrary schedule depicting the development phases of a typical 50-megawatt electric (MW_e) project is shown.

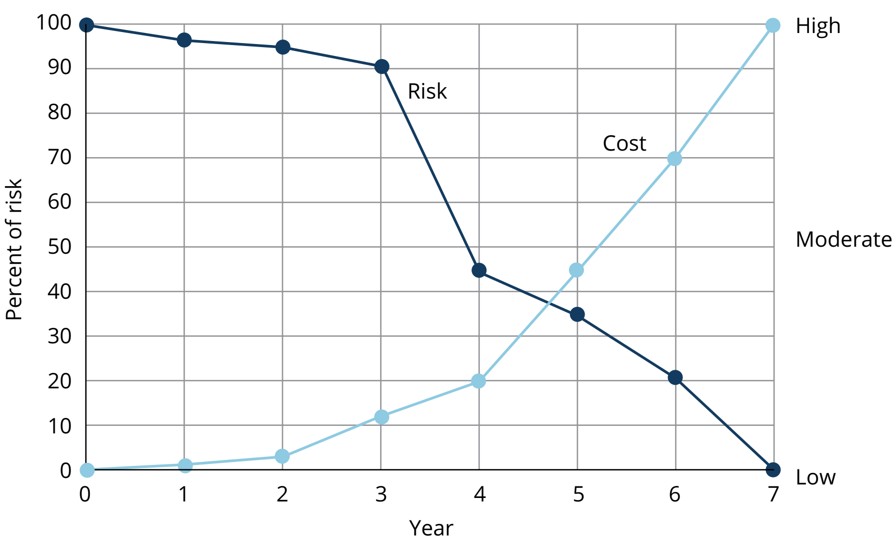
Figure 1.2 shows a project's risk profile and cost, as well as how the level of risk is reduced as the project advances. The highest risks are seen early on (during the preliminary survey, exploration, and test drilling), when there is considerable uncertainty regarding the characteristics and capacity of the resource. This uncertainty makes it difficult to estimate the cost of extracting the geothermal energy and reinjecting the heat-depleted brine back into the reservoir.

FIGURE 1.1: THE DEVELOPMENT PHASES OF A GEOTHERMAL PROJECT



Source: ESMAP 2012.

FIGURE 1.2: PROJECT'S RISK PROFILE AND COST AT EACH DEVELOPMENT PHASE



Source: ESMAP 2016.

Uncertainty is reduced by the end of the test drilling phase. Test drilling and subsequent production drilling[2] progressively confirm resource availability. At some point, the developer has enough information to decide on the field and project development strategy,[3] which in turn provides the premises for the feasibility study.

Two factors decide the size of a geothermal power plant: the geothermal resource itself and the financing capacity. The exact conditions required for financing a project vary by finance entity. For example, some commercial banks require confirmation of proven generation capacity before financing a project.[4] Together, the developer and finance entity in question set up a funding plan that addresses the required capital structure.

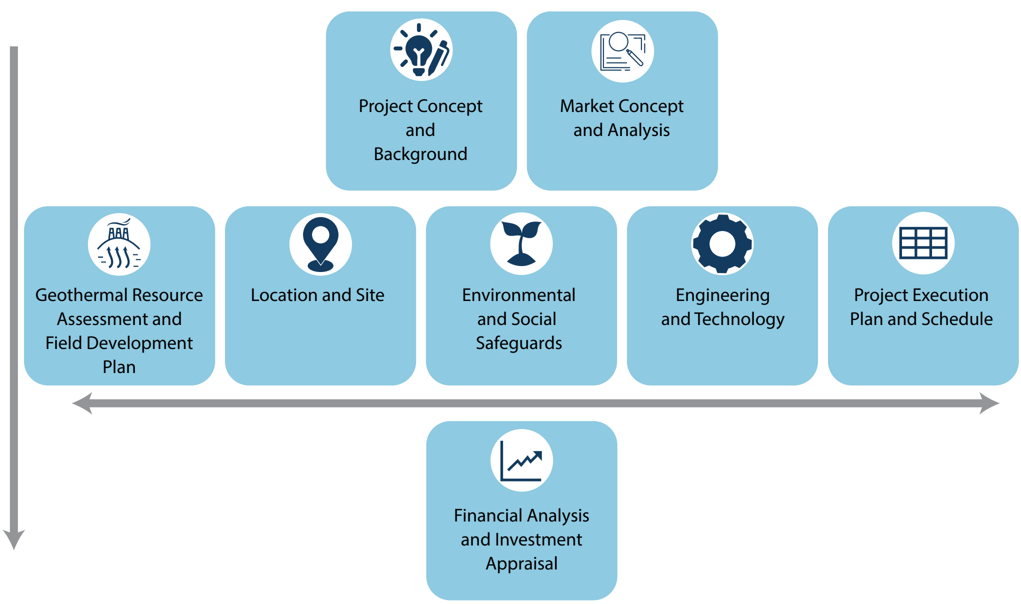
The feasibility study plays a critical role in a project's development and is used to secure financing when risks are low enough that finance/banking institutions consider funding the project. A study is finished once a project achieves financial closure, meaning that any remaining project activities are financed (Figure 1.1). These activities are typically those required to complete the field development phase, that is, the remaining production and reinjection well drilling, and the construction of a fluid disposal and collection system[5] and the power plant itself.

RECOMMENDED CONTENTS OF GEOTHERMAL FEASIBILITY STUDIES

Detailed industry standards for the preparation of feasibility studies in the geothermal industry have not been published.[6] The following recommendations are based on the authors' experience in the geothermal industry and a review of feasibility studies from other sectors and industries (e.g., Behrens and Hawranek 1991). Figure 1.3 illustrates a study's proposed contents.

The subsequent chapters will discuss each item in Figure 1.3 in detail.

FIGURE 1.3: CONTENTS OF GEOTHERMAL FEASIBILITY STUDIES



Source: Original figure for this publication.

Credit: Theistarevkir Geothermal Power Plant. © Mannvit.

2. PROJECT CONCEPT AND BACKGROUND

Most geothermal feasibility studies start with a high-level overview of the proposed project's scope, history, and relevant aspects (economic, social, and environmental) of the prospective host country's context. The topics typically addressed in this overview include:

- **Project concept.** The scope of the project should be exactly defined, including the project's size (in megawatts) and investment requirements. If the project is to be developed over multiple phases, this also must be explained. This is to be followed by an overview of the project's main systems and components, such as the turbine-generator unit, cold end, fluid disposal and collection system, and transmission lines, along with a brief description of the geothermal resource to be utilized.
- **Project objectives.** The principal objective is the production of power, but the project may have other objectives as well (social, economic, environmental, technical), such as a reduction in carbon dioxide (CO_2) emissions from the host country, job creation, and/or stabilization of the electrical grid in a specific region of the country.
- **Country objectives.** A brief description of how the project's objectives align with national and subnational objectives should be given. It is important that these are in harmony. Government policies (economic, social, financial, and environmental) that specifically support the project should be explained.
- **Country or regional support.** Outline whether government or regional policy supports renewable energy generation in the form of incentives, risk mitigation mechanisms, favorable energy tariffs, or guarantees. Also, indicate if nonrenewable energy generation is penalized in any form (e.g., taxes, fees, etc.) due to CO_2 emission and other gases causing "greenhouse effects."
- **Economic benefit.** A description of how the project benefits the country and region in question such as less CO_2 emission, reduced imports of fossil fuels, fewer imports, more stable economy, and indirect affect, such as support to industries, job creation, local production, export increase, etc., should be provided.
- **Purpose of the study and its intended audience.** This may be outlined in the introduction, along with the author(s) and their titles within their respective companies.
- **Geographical location.** The project location should be shown on maps at international, regional, and local levels.
- **Permits and developer licenses.** It is essential that all required licenses and permits be presented, along with their status. If any are missing, the study should outline how they will be acquired.

- **Project developer description and organization.** The names and addresses of the project developer, sponsors, partners, parent companies, and other key stakeholders should be listed. Also, the technical and financial capabilities of the developer and key stakeholders, relevant to project development, should be described. Basic information on the project's organization, financing structure, and other relevant characteristics (joint venture, project funding, etc.) should be included.

- **Brief project history.** The historical development of the project, including the dates of development milestones, can be summarized. The main studies and work performed to date should be listed, as well as key decisions made on the basis of existing studies and investigations.

3. MARKET CONCEPT AND ANALYSIS

A geothermal feasibility study needs to include a description of the energy market in which the project will operate, and the agreements prepared or in place for the sale of power produced over the lifetime of the project. It should identify potential issues that could affect the commercialization of the energy generated by the project—that is, the market risk. This is the risk that financial requirements will not be met during the financial horizon of the project due to market-related reasons. In other words, the project's revenues are lower than expected, not due to less production but because the developer does not get paid for the production as originally planned. Any risk that can influence revenue streams is important to address here.

The review needs to detail the system of energy generation and delivery, indicating whether there is a competitive energy market or only one buyer and distributor of electricity (monopoly). It also needs to explain the roles, energy and delivery prices, terms and agreements of each entity, and who has control of the generation company and grid.

The feasibility study considers the market's current status, presents data on the past 5 to 15 years (as appropriate), and provides a forecast for the length of the proposed project's lifetime. The exact nature of the analysis depends on the project's revenue structure, but common topics include the following:

- **An overview, relevant regulations, the main stakeholders (generation, transmission, distribution, and regulatory entities), and how the project fits into current conditions.** This may include, for example, projections of electricity demand, changes in regulations, and generation expansion plans. These will help clarify whether the electricity generated by the project can be absorbed by the market and to what extent the project can complement generation from other technologies (e.g., providing grid load balancing services), thereby providing added value in the generation mix beyond electrical generation. How the local grid connects to other countries and or markets is also relevant.
- **Conditions under which the energy will be sold.** A feasibility study outlines all contractual agreements related to the transmission and sale of energy.
- **Risks due to possible technical or contractual issues** that can impede power sales from the developer, such as transmission faults or power grid congestion, are important to outline. It is always assumed that a power system study has been performed that analyzes the technical compatibility of the power plant in relation to the electrical infrastructure to which it will be connected (see Chapter 7 for further discussion).
- **Fees and costs related to the generation and sale of power,** including all costs incurred by selling electricity (such as the costs of transmission, system operation, and licensing), taxes (value added, sales, corporate, and so on), and possible subsidies.
- **Currency risks.** If the developer needs to transfer currency to meet obligations outside the host country, currency fluctuation, convertibility, and transfer risks need to be considered, as well.

The section of a feasibility study focused on the market concept also outlines the revenue structure over the project horizon.

Utility Owned

In some cases, the developer is the same entity as the off-taker of power. In these cases, it is important to demonstrate (e.g., via a sales agreement) how revenue of the project is secured.

Long-Term Energy Sales

The most common way for the power plant developer to deal with market risk is to sell the energy at pre-defined rates under either: (i) a power purchase agreement (PPA) with an off-taker or (ii) a feed-in tariff set by authorities. These two options may be described as follows:

- **Power purchase agreement.** In a PPA, the off-taker can be a utility, an industrial user, or another entity in the country's energy market. The agreement converts the market risk into the contract risk of the PPA and the off-taker risk of defaulting. The PPA sets the contractual obligations of both the power seller and the off-taker such as prices, billing, payment, and performance terms. It defines dispatch, operating, and metering procedures; penalties for under delivery; and procedures and treating *force majeure*.
- **Feed-in-tariff.** Many governments in countries with abundant renewable energy resources encourage the development of renewable energy by offering guaranteed prices to developers based on a feed-in tariff. Such a policy requires a strong, long-term commitment from the government and an elaborate legislative framework. Mandatory off-take of renewable energy by the power utility is a key element of a feed-in tariff, and guaranteed energy prices are set for a predetermined number of years. Market risk is eliminated, provided the country risk profile is adequate, since energy purchases are backed by the government.

Short-Term Electricity Markets

Another approach is to sell the energy on short-term markets such as the energy spot market—assuming such a market exists in the country where the project is located. This approach is unusual for geothermal projects as the feasibility often relies on the constant sale of electricity. If a short-term market will be used, a detailed risk analysis of possible market fluctuations over the project's financial horizon must be presented in the feasibility study. Also, a sensitivity analysis must be carried out to assess how price fluctuations in the short-term market might affect the project's revenue stream. The possibility that these energy sales might also influence the market is to be considered, as well. Short-term market prices can be influenced by a wide variety of factors, including the general economic situation of the country or the world, or fuel prices (which can influence the marginal cost of other generating units in the market).

Thermal Projects, Sales of Heat and/or Goods

When the revenue stream is not electricity but heat or other goods, it is important to demonstrate how the revenue of the project is secured (e.g., sales agreement, comprehensive market study).

4. GEOTHERMAL RESOURCE ASSESSMENT AND FIELD DEVELOPMENT PLAN

RESOURCE ASSESSMENT

Among the most critical roles of the feasibility study are summarizing the characteristics of the geothermal resource in question and estimating its expected power generation capacity. Relevant data include the results of resource exploration and drilling, along with any production tests carried out to date. If the developer envisions that the project will proceed in several phases, then relevant plans beyond the time horizon discussed in the feasibility study should be described. The resource assessment should address the following elements:

- **The exploration history of the geothermal system.** The bulk of the surface exploration occurs before the feasibility study is written, though some additional exploration may be conducted throughout the development of the resource. The feasibility study should demonstrate that the methodology followed has been consistent with industry best practices.[7]

- **The exploration drilling and preliminary testing phase.** This phase is completed when the project's feasibility is assessed and typically some of the production drilling and testing has been completed.[8] The feasibility study reviews the drilling performed in the field, including basic well design information, well location and drilling targets, well success (including reservoir temperature and permeability), and well productivity based on production testing data.

- **Conceptual model.** The results of surface exploration and the results of exploration drilling and testing are normally presented as a comprehensive conceptual model of the geothermal system (Box 4.1). Such a model is then used as the basis for realistic development plans (to define drilling targets for remaining production and injection wells), and as the foundation for energy generation capacity assessments.[9] The conceptual model reflects the uncertainty inherent in various parameters (e.g., reservoir volume, temperature conditions, etc.) that will affect the resource assessment.

The size of the power plant to be developed in a given geothermal project is based on the estimated generation capacity of the geothermal resource. This estimate, therefore, is of central importance in the feasibility study. The methods most commonly used to estimate geothermal resources are volumetric methods and detailed numerical models.[10] Two principles apply when assessing production capacity:

- The generating capacity can be considered proven if predicted by an accurate and reliable detailed numerical model (calibrated using correct and comprehensive data), supported to some extent by the testing of existing exploration and/or production wells.

- If a reliable numerical model cannot be created, the P90 outcome[11] of a volumetric assessment can be used, largely relying on the output testing of existing wells.

The resource assessment must focus on the part of the resource that is physically accessible for development, considering constraints posed by terrain, permits, environmental aspects, and drilling depth, etc. This accessibility is addressed, for example, through an accessibility factor in volumetric assessments.

BOX 4.1: CREATING A CONCEPTUAL MODEL

The key to the successful exploration, development (including drilling), and utilization of any type of geothermal system is a clear definition and understanding of the nature and characteristics of the geothermal system. This is generally achieved through the development of a conceptual model, that is, a descriptive (qualitative) model incorporating and unifying the essential physical features of the system.

Conceptual models are mainly based on an analysis of geological and geophysical information, temperature and pressure data, and information on reservoir properties, as well as the chemical and gas content of reservoir fluids. Monitoring data reflecting reservoir changes during long-term testing and exploitation provide input into revising conceptual models once they become available. Conceptual models should explain the heat source for the reservoir and the location of recharge zones, the location of the main flow channels, the general flow patterns within the reservoir, reservoir temperature, and pressure conditions. A comprehensive conceptual model also estimates the size of the reservoir involved. Conceptual models are developed through interdisciplinary cooperation between geologists, geochemists, geophysicists, and reservoir engineers involved in the geothermal project.

Conceptual models form the basis of field development plans, that is, for selecting drilling sites and establishing the targets of wells to be drilled. They serve as the foundation for all geothermal resource assessments, particularly volumetric assessments and geothermal reservoir models, used to determine the energy production capacity of a geothermal system.

Initially, a conceptual model is largely based on surface exploration data. The model is updated once the first wells have been drilled into a system and subsurface data becomes available. The most important information obtained from drilling includes the locations of the feed zone, temperature profiles, and well test data. As more data becomes available, conceptual models should be revised and improved continuously throughout the exploration, development, and utilization of a geothermal system.

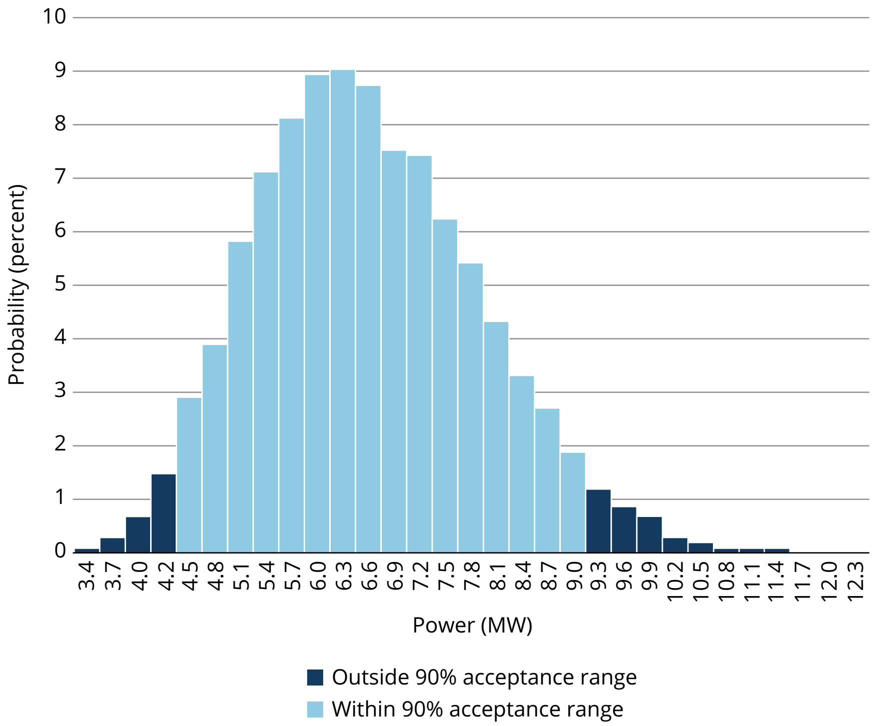
Volumetric Methods

Volumetric methods are more suitable for providing a first-order estimate of resource capacity when production history is limited, whereas detailed numerical models are more appropriate when historical production data are available. Volumetric methods using the probabilistic distribution of reservoir parameters and supported by observed well outputs are most commonly used for greenfield developments. The feasibility study describes the rationale behind the selection of those reservoir parameters used as inputs and demonstrates how these are supported by direct observations from the field and the drilled wells. When volumetric resource assessments are used to determine the size of a geothermal power plant, the P90 result is generally considered appropriately conservative (Figure 4.1).

Detailed Numerical Models

Detailed numerical models result in more reliable estimates of generation capacity, provided that they are calibrated using comprehensive data on well tests and reservoir responses (e.g., pressure decline and interference). Numerical modelling, in such cases, is much more reliable than volumetric methods. Calibration is location specific and usually requires testing for several months (6–12 months or more). Since

FIGURE 4.1: EXAMPLE PROBABILITY DISTRIBUTION FOR THE RESULTS (ELECTRICAL GENERATION CAPACITY) OF A MONTE CARLO VOLUMETRIC ASSESSMENT



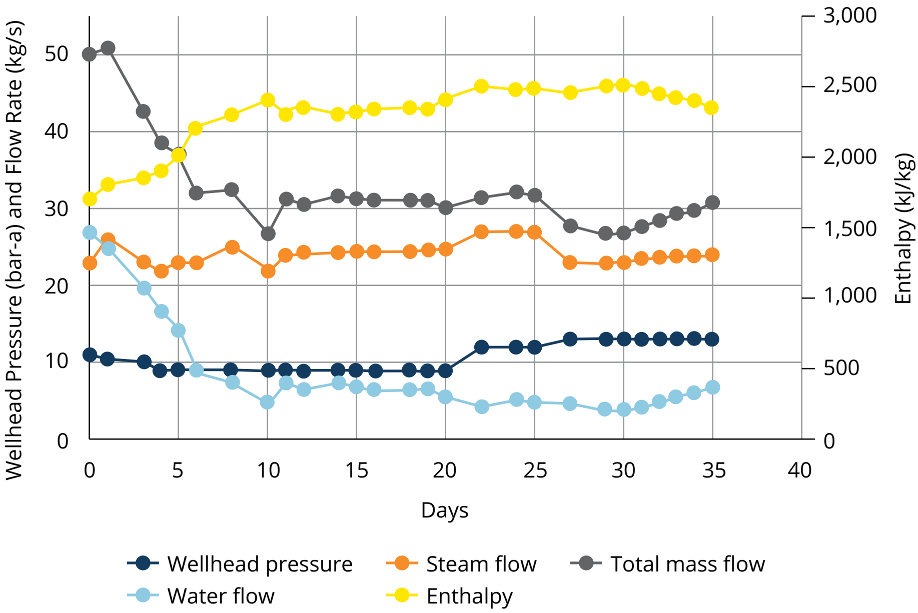
Source: Example prepared by Iceland GeoSurvey (ISOR).

well testing is generally not practical for such extensive periods in greenfield developments, numerical models are more commonly used to determine the appropriate power plant size in expansion projects.

The production capacity of geothermal reservoirs is controlled by reservoir pressure decline (see Appendix B), which must be within manageable limits within the time frame of the feasibility study. The following criteria are suggested in the initial development of a geothermal field (greenfield). If a numerical model predicts that the geothermal resource in question can sustain the planned capacity (i) without vast pressure changes (<10–30 bar, depending on thermodynamic conditions), (ii) with manageable temperature changes, and (iii) with a decline in well output that would result in a financially viable need for makeup wells, then the utilization can be maintained throughout the time frame of the feasibility study. For geothermal fields where some development and production has already taken place, somewhat greater predicted changes (mainly in pressure) may be acceptable.

It should be noted, however, that during utilization, some high-enthalpy geothermal systems develop steam zones due to a localized pressure drawdown greater than that referred to above. This results in the increased production enthalpy of wells and, hence, in maximized energy extraction. Such a utilization scheme is difficult to forecast before large-scale utilization commences.

FIGURE 4.2: EXAMPLE OF DATA COLLECTED DURING DISCHARGE TESTING OF A HIGH-ENTHALPY PRODUCTION WELL



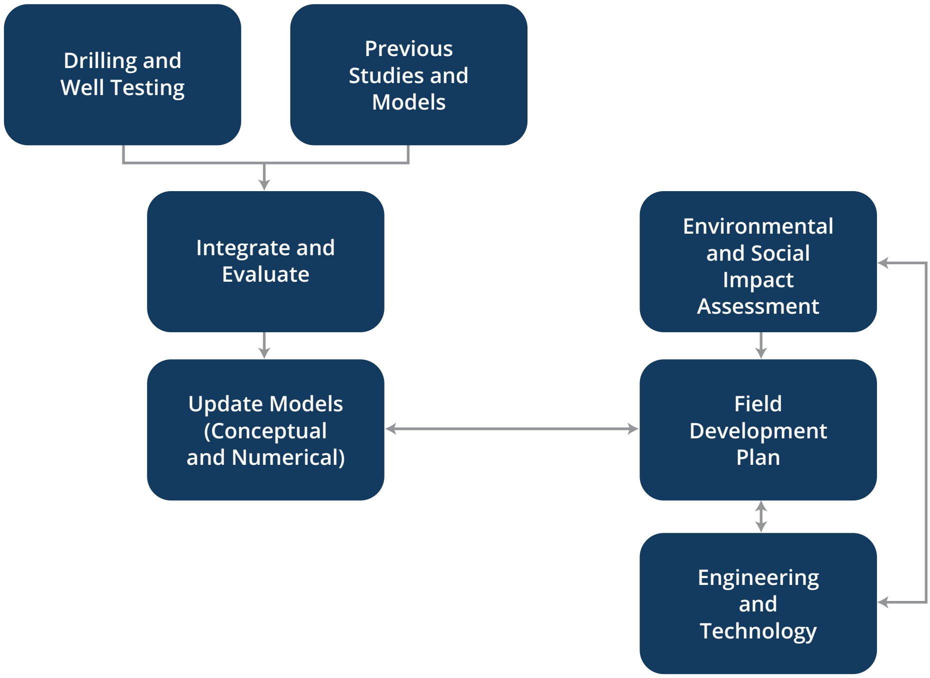
Source: Modified from source in the geothermal literature.

Note: kg/s = kilograms per second; kJ/kg = kilojoules per kilogram.

Beyond the volumetric method, the capacity of geothermal resources is also sometimes assessed using the power density method, which is based on estimates of geothermal fields' capacity per unit area (megawatts/square kilometer; see Wilmarth and Stimac 2015).[12] This is useful to verify the results of both volumetric methods and numerical models.

A key component of a geothermal feasibility study is an explicit statement of the proven generation capacity of the wells drilled to date. Lenders typically have specific requirements regarding how much planned generation capacity must be proven by well tests at the time of financing. These requirements vary across lenders and market conditions. A commonly cited value is 50 percent of the planned generation capacity, but the value is known to vary between 25 percent and 80 percent (Salmon et al. 2011). The proven capacity is typically presented as the cumulative output, either in kilograms per second (kg/s) of steam at a specific wellhead pressure or in megawatts electric (MWe), determined through discharge tests (see Figure 4.2 for example of date presentation for single well testing). The feasibility study would do well to describe the discharge tests and show the results. It is particularly important to demonstrate to lenders that the wells reached a stable or semi-stable condition during testing. This may be supported by a resource assessment report prepared by external experts.

FIGURE 4.3: GEOTHERMAL RESOURCE ASSESSMENT AND INTERACTIONS WITH OTHER DELIVERABLES



Source: Original figure for this publication.

FIELD DEVELOPMENT PLAN

The feasibility study also lays out plans for the drilling of remaining wells. These plans are linked with environmental and social safeguards (Chapter 6), well design and engineering (Chapter 7), an implementation schedule (Chapter 8), and capital and operating cost estimates (Chapter 9) (Figure 4.3).

A detailed field development plan shows where the remaining production wells and reinjection wells for the planned power plant will be drilled based on the conceptual model for the geothermal system. The plan should also explain the reinjection strategy in detail. Reinjection of the geothermal fluid is not only a requirement of environmental permits but is also key to the long-term operation of the geothermal field. The reinjection strategy is often developed through a trial-and-error approach involving comprehensive investigations (e.g., tracer testing), and is site specific because it depends on the reservoir structure. The reinjection strategy should be part of the exploitation plan from the project's onset. Options for reinjection should refer to the conceptual model and explain how the reinjection strategy will provide pressure support without causing premature cooling of production wells.

Once the utilization of a geothermal system commences, operating conditions (such as the reservoir pressure) usually change. This will result in declining well output, which will eventually require the drilling of makeup wells or installation of submergible pumps in water dominated fields. Similarly, changes in the reinjection strategy may also require drilling of reinjection makeup wells. An estimate of the likely number of makeup wells (or installation of pumps) over the operating period is an important part of the field development plan. This estimate is difficult to know before operation starts, but informed decisions can be made based on worldwide averages, local experience, or numerical modelling results.

Failed wells are to be expected when drilling into a geothermal reservoir; the field development plan must assume a drilling success rate less than 100 percent (see IFC 2013). A reasonable number of unsuccessful wells and their estimated drilling costs should be included in the project implementation budget (Chapter 8) and forecasted in the schedule.

As the locations of new wells become known, the locations of subsequent wells can be changed. Coupled with the need for makeup wells, a field development plan is a dynamic document that is updated throughout the development and utilization of a resource.

Phased Projects

A common strategy in geothermal development is to tap the resource and build up generation capacity in phases. This can reduce risk, since experience is gained during the partial exploitation of a resource before a decision is made to add generation capacity. For example, multistage development substantially reduces the risk surrounding future capacity estimates, as data from the ongoing exploitation of the reservoir will be available to calibrate numerical models set up to estimate reservoir generation capacity. If the project presented in the feasibility study will proceed in phases, this must be carefully explained in the field development plan.

5. LOCATION AND SITE

A feasibility study outlines the location and site of a project and describes their critical characteristics. A distinction is made between location and site. A location can refer to a wide geographical area where it is expected that the geothermal resource can be found. A site, on the other hand, refers to a specific place within the location where infrastructure, such as wells and power plants, will be placed. The site is usually selected after several options have been evaluated within the project location (Figure 5.1).

The location of a geothermal project is linked to the resource. Such projects are often located in remote places that are difficult to access and have little infrastructure. For this reason, it is important to explain carefully how the location affects a project.

Environmental, social, and legal questions related to the location are treated specifically in Chapter 6.

FIGURE 5.1: LAYOUT AND LOCATION OF OLKARIA IV AND V AND WELL PADS

Source: Google Maps.

Issues related to a project's location and site that must be included in the feasibility study include the following:

- **Natural environment** such as temperature, rainfall, humidity, wind, snow, dust, and solar radiation.
- **Natural hazards** such as floods, earthquakes, volcanic eruptions, and hurricanes impacting the project. Relevant information is often presented through maps showing distinct zones of higher and lower risk.
- **Geotechnical aspects** such as soil conditions and subsoil water levels can drive up costs if not carefully investigated.
- **Existing infrastructure conditions and access:** Since geothermal projects are sometimes located in remote places, it is important to explain the conditions of roads needed to carry heavy equipment to the site and harbor infrastructure needed for sea transport. The distances between transport hubs and plans for access to water and electricity at distinct project phases should be indicated. The availability of human resources must be guaranteed, as well as of critical services (such as civil construction, equipment installation, and maintenance) at each distinct project phase.
- **Maps** are important in clarifying information regarding both project location and site issues. These might include nearby population centers and/or other landmarks, as well as existing and future infrastructure.

If any specific risk is forecasted to be of significance, efforts to mitigate harmful effects should be described, as well as cost and time implications. The costs involved in site preparation are also necessary to estimate here.

6. ENVIRONMENTAL AND SOCIAL SAFEGUARDS

All geothermal projects have associated environmental and social impacts and risks. Management of these impacts and risks is critical for projects' successful development. The feasibility study demonstrates that environmental and social impacts are assessed and managed in a way that reduces these risks to an acceptable level during all stages of development. Inappropriate handling of these issues can result in the termination of a project, delays, and/or costly mitigation measures down the road.

Best Practices

Developers seeking international financing are advised to adopt international best practices to identify and address environmental and social impacts and risks.[13] Requirements in host countries must be followed as well, and a gap analysis (that systematically lists local and international requirements and highlights the differences, or gaps, between the two) should be presented in the feasibility study to demonstrate the project's compliance. The most widely accepted best practices—the International Finance Corporation (IFC) Performance Standards (PS)[14] and the World Bank Environmental and Social Framework Environmental and Social Standards (WB ESF ESS)[15]—are applied to projects financed by the World Bank. A separate study addressing environmental and social impacts and risks associated with the geothermal development should be conducted in accordance with the abovementioned best practices. Engaging with all stakeholders identifies their issues and concerns in an effort to incorporate as much of their input as possible into the design. These studies need to incorporate the findings of this study (basic design), as well as provide input into the risk, timeline, and cost of the project.

Project Maturity

By the time a feasibility study is being prepared, all necessary processes to obtain licenses should be finished and most, if not all, permits should have been obtained for the power plant. The study should include a list of any missing permits or licenses and present a clear, low-risk path to obtaining them to be incorporated into the project execution plan. A typical geothermal project, sometimes referred to as a Category A project,[16] has significant environmental and social impacts. As such, an Environmental and Social Impact Assessment (ESIA) (for more information, see Box 6.1), covering all important aspects required by WB ESF ESS1, PS1 in the IFC Performance Standards, must be submitted to relevant stakeholders, including the local community, project affected persons, the environmental authority, and other issuers of authorization or licenses.

Because geothermal reservoirs are dynamic resources, it is difficult to forecast all project aspects and their impacts at the feasibility stage. Several wells will still need to be drilled, and it is not unusual for their locations to be unknown at the time the feasibility study is being prepared. The design of the fluid

BOX 6.1: ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

The standard mechanism used globally to identify and manage environmental and social impacts and risks is the Environmental and Social Impact Assessment (ESIA). The developer sponsors the ESIA, which is generally carried out by an independent party with appropriate expertise. Most countries require only an Environmental Impact Assessment (EIA) to be prepared for infrastructure investments. The scope and breadth of the ESIA are wider and deeper than most national EIA requirements.

An ESIA also identifies the extent and complexity of potential social impacts and the socioeconomic characteristics of the project area. Beyond fulfilling the requirements of a national EIA, it comprises some additional components that reflect the policy requirements of various international agencies: (i) an Environmental and Social Management Plan (ESMP), specifically prepared for managing the risks and impacts of the project; (ii) a Stakeholder Engagement Plan (SEP); (iii) a grievance redressal mechanism; and (iv) a series of sub-management plans to manage site specific risks, including but not limited to community health and safety, waste management, occupational health and safety, emergency preparedness and response, and water management.

If the ESIA is carried out to supplement or update a previous EIA/ESIA, it will include an Environmental and Social Action Plan that assesses the content and implementation of previous efforts to identify deficiencies and plan actions that bring the process up to international standards. Finally, stand-alone land acquisition and resettlement documents and/or a development framework or plan for local indigenous communities may also be required.

Source: ESMAP 2018.

disposal and collection system cannot be finalized before the final well locations have been decided. Therefore, while the location of the project is clear, the exact layout of all the field facilities may not be defined at this stage. Further production drilling may have to be carried out on the resource before all location-specific impacts can be described and assessed. In projects where this is the case, an Environmental and Social Management Framework may be appropriate.

However, it must be emphasized that the ESIA should be as comprehensive as possible. If the project's layout, location, or design are uncertain, then a strategy for managing the changes with respect to environmental and social impact assessment should be provided, at minimum, outlining how the ESIA/Environmental and Social Management Plan (ESMP) will be updated once relevant information exists.

Environmental and Social Risks and Impacts

Typical environmental and social risks and impacts may be grouped into 11 principal categories (described in Box 6.2).

BOX 6.2: EXAMPLES OF TYPICAL ENVIRONMENTAL AND SOCIAL IMPACTS AND RISKS

Environmental

1. **Land and habitat loss.** Much new geothermal development occurs in remote areas with volcanic characteristics, while some occurs in populated areas with through traffic. The challenges of a remote location include: (i) the presence of small indigenous communities who are using the land, (ii) a need to construct new or improved access roads, and (iii) an increased likelihood of being either near or within critical habitats or protected areas. Despite having a limited footprint, a new facility can disrupt local livelihood patterns that are dependent on crop or animal production. Fears (not always founded on scientific evidence) that geothermal development may cause landslides, seismicity, and disturbances from natural hydrothermal manifestations may cause local populations to resist it.

2. **Water risks.** If not managed carefully, well drilling, stimulation, and testing require surface and underground water that may pick up dissolved minerals and can pollute surface waters and groundwaters. Similarly, water used to clean facilities and leaks from breaks in well casings can contaminate groundwater. Surface and underground water requirements vary at different stages of development and operation, from drilling to managing the geothermal resource to cooling. The relative abundance of nearby water sources and the level of competition for their use determines the level of risk.

3. **Solid discharge and waste.** Drilling muds are generally recycled and reused, but the cuttings can contain hazardous components such as sulfides, arsenic, mercury, nickel, and other heavy metals, which can leak into the environment if not managed and disposed of properly. Holding ponds constitute a public hazard if not protected from unauthorized access.

4. **Gas emissions.** The principal non-condensable gases (NCGs) encountered in geothermal development are carbon dioxide (CO_2) and hydrogen sulfide (H_2S). In some cases, mercury (Hg) can be present in low to significant amounts. NCGs are released at well sites during and after site development. During operation, NCGs are carried with the steam from the well, passed through the steam turbine or heat exchanger, where the water vapor is condensed, and released through venting. NCGs can be captured and treated for commercial purposes or injected back into the subsurface. But injection of NCGs back into the subsurface is not a common practice, as H_2S, in particular, has an obnoxious smell even at low concentrations and poses a health hazard if concentrations are high. Some jurisdictions require that H_2S and Hg be removed from geothermal NCGs through chemical treatments.

5. **Dust and noise.** Noise pollution occurs usually during the well drilling, stimulation, and testing phases and during construction of the powerhouse and related facilities. The operation of the transformer, powerhouse, and cooling towers can create noise, depending on their design. Construction machinery and trucks also increase noise and dust in the project area.

6. **Occupational health and safety.** Employees at geothermal drilling and operation facilities face various occupational risks to their safety, ranging from well blowouts to pipeline failure and seismicity issues and impacts. Some of the impacts and risks can be mitigated by having a robust regulatory framework that requires geothermal companies to adopt good international industrial health and safety standards or requirements. Other risks, such as the risk of encountering toxic fumes in a closed area, can be addressed by risk management plans that include emergency response measures.

(continued)

BOX 6.2: CONTINUED

Social

7. **Livelihood and ecosystem services.** Land acquisition or loss of access to land due to geothermal development can impact the livelihoods and everyday lives of local people. Regardless of whether the land is owned by individuals, communities, or even the state, if people are dependent on it for their livelihoods or for resources that they use consistently, the loss can be difficult to overcome, even if they are compensated through relocation, monetary settlement, or land swaps. The severity of the risk varies, with vulnerable (including women) and indigenous peoples most at risk.

8. **Disruption.** Drilling, testing, construction, operation, and decommissioning can disrupt family and community life with increased traffic, influx of labor, and damage to assets and resources. This can have consequences for health and safety, as well as peace of mind.

9. **Conflict.** New facilities and investments, including land purchases, bring new opportunities to communities, but also disruptions and competition over access to employment, commercial opportunities, and ownership of new resources. These changes can renew long-standing kinship or clan conflicts or create new ones based on gender, age, or other factors.

10. **Cultural heritage.** New geothermal developments can take place in or near sites that are protected or prized for their cultural significance or aesthetic aspects, threatening or compromising the physical or visual status of the site. Nationally or internationally recognized cultural assets generate much interest, but even sites of local importance require special attention.

11. **Apprehension and opposition.** Local people may be apprehensive or suspicious of geothermal investments, based on real information about poorly managed developments in other areas or on rumors, misunderstandings, or fear of the unknown. Such apprehension can generate local opposition, which may be nurtured and amplified by external interests.

Source: ESMAP 2018.

Environmental and Social Safeguard Topics

The feasibility study should outline a clear plan for mitigating all environmental and social risks, such as:

- **Legal framework, processes, and institutional capacity.** An overview of the legal framework in the host country should include information on institutional and regulatory frameworks and licensing procedures. Information on the issuers of licenses and the institutional capacity of expert agencies will provide further insight into the regulatory environment of the project.

- **Gap analysis.** For internationally funded projects, it is important to provide a comparison between national legal requirements and international best practices, such as the World Bank ESF and EES and the IFC Performance Standards, and of how any gaps are to be addressed.

- **Current status and previous work.** Environmental licenses are required in both the (i) exploration phase(s), and (ii) development/construction and operational phase. If the resource is being developed in phases, information on the processes already conducted and the licenses and permits obtained should be provided.

- **Relation to other project activities.** It is important to demonstrate that the project's environmental and social assessment has been carried out in parallel with its technical development, and that all critical technical and/or economic aspects are considered in this assessment.

- **Key results of the ESIA.** This necessarily includes a description of the physical, biological, socioeconomic, and cultural contexts of the site and areas of influence. Based on this information, an assessment of the possible impacts of the project and actions to avoid, reduce, or compensate for—and, importantly, monitor—should be provided. The ESIA should cover all relevant aspects of the physical environment, biodiversity conservation, and sustainable management of living natural resources, indigenous peoples, other vulnerable groups, and cultural heritage sites. Cumulative impacts should also be considered in the impact assessment and mention infrastructure (e.g., transmission lines, access roads, etc.), which may not necessarily be in the developer's scope. All environmental and social risks and impacts associated with the geothermal development projects should be described based on the sectoral risks and impacts and those having specific interventions on the baseline characteristics of the project area of influence. The respective mitigation measures to eliminate/minimize/reduce such risks and impacts, including cumulative impacts and impacts related to associated facilities and adopting the mitigation hierarchy, should also be clearly described in the ESIA. A monitoring plan should also be established, which would include parameters to be monitored—location, frequency and responsibility, and costs of the monitoring.

- **Access to land.** An overview of land ownership and use (including information on land acquisition processes, land use restrictions, and status of land use zoning, if relevant) should be provided. According to the World Bank ESF, ESS 5, and IFC PS5 on Land Acquisition, Restrictions on Land Use and Involuntary Resettlement, project affected persons who do not hold a formal legal title to land are also eligible for benefits. This is, in many cases, beyond local requirements regarding eligibility for benefits.

- **Stakeholder engagement.** It is important to provide information on past, ongoing, and planned stakeholder engagement, that is, Stakeholder Engagement Plans (SEPs) and community development frameworks, if relevant to the project. According to World Bank ESF, EES 10, and IFC PS the developers need to engage with all stakeholders and set up a systematic approach to identify and inform stakeholders.

- **Tasks and timelines.** The study should show the estimated time frames for the ESIA's ongoing and remaining tasks. These can include: landowner negotiation and acquisition of land (resettlement policy frameworks and resettlement action plans, if applicable); some remaining aspects on environmental and social baseline research; ESMPs, SEPs, sub-management plans and community development frameworks, statutory presentation and review periods; licensing processes; and monitoring programs.

- **Responsibility for the implementation of mitigation measures, monitoring, and associated costs.** Information on who is responsible for the implementation of mitigation measures, monitoring responsibilities to whom progress will be reported to, and the estimated costs should be provided, including the costs of the development and operational phases.

Credit: Workers entering a well head separator, Olkaria, Kenya.

7. ENGINEERING AND TECHNOLOGY

A feasibility study presents the functional aspects and physical layout of the geothermal power plant, as well as related infrastructure, including the fluid disposal and collection system, wells, transmission lines, and substation infrastructure. Importantly, it also discusses the choice of technology being selected for power generation, the basic engineering design, and an estimate of capital costs to be used in the financial analysis. The work should explore different engineering and technology options (e.g., drilling technologies, plant sizing, direct utilization) to identify the most economical options.

The *Geothermal Handbook* (ESMAP 2012) of the World Bank's Energy Sector Management Assistance Program outlines the power generation technologies commonly chosen by the geothermal industry. This handbook can be used to compare project-specific technology choices with industry benchmarks.

This section of the feasibility study should demonstrate the following:

- **The power plant will be designed and built according to the project criteria,** adequate standards, and good practices.
- **The capital and operational cost** of the proposed power plant.
- **The power plant will operate reliably,** enabling the owner to meet contractual obligations in terms of power sales.
- **The power plant will efficiently and effectively** use the geothermal resource as defined during geothermal exploration and development.

Project Maturity

A project's maturity level is intrinsically related to the required accuracy of the cost estimates provided in the study. The American Association of Cost Engineering (AACE 2005) offers guidelines for the level of maturity of the cost estimate and design needed for a feasibility study;[17] its recommendations are in accordance with those for feasibility studies in other industries (e.g., Behrens and Hawranek 1991).

At the time of preparing the feasibility study, the engineering design should include basic engineering in accordance with the AACE. After the financing is secured, typically the detailed design phase would begin.

The topics and the deliverables of the engineering design that should be included in the feasibility study report are discussed below.

Main Technical Parameters

It is important that the feasibility study clearly states the main technical parameters and boundary conditions of a power plant. This includes the plant's capacity, especially since many of the studies related to the feasibility study (regarding the resource or grid, for example) are performed with a fixed capacity in mind. A description of the boundary conditions for the plant should be included. The assumed geothermal fluid chemical composition, its NCG content, and any other aspect that might influence the choice of technology should also be outlined.[18] These factors can introduce risks to projects, and the feasibility study should identify and demonstrate how these risks will be mitigated. For example, the scaling and corrosion potential of the geothermal fluid can be analyzed based on its chemical content.

Technology Choice and Equipment Selection

The choice of technology will depend on the resource characteristics and should be clearly presented. It is important to demonstrate that the technology selected is not risky and that it will perform with adequate efficiency for the designated resource. This can be done by identifying the available and commercially accepted power cycles for the main technical parameters. Technical proposals from known vendors of geothermal power generating equipment may be obtained to demonstrate the expected power output, given the likely resource parameters, such as flow (i.e., steam and/or brine) and enthalpy. These numbers can then be compared with publicly available data (as presented in the *Geothermal Handbook*, ESMAP 2012).

Since resource characteristics, such as enthalpy and well productivity, can change with time, it is important to forecast how these changes will influence plant operation and efficiency.

As with technology options, it is also important to clarify the choice of the required equipment. The main suppliers should be mentioned and important aspects, such as the procurement lead time, should be summarized.

Basic Engineering

By the time a feasibility study is being prepared, the basic engineering of a project is usually complete, while the detailed design phase has not yet been reached.

The basic engineering should be presented for the technical systems entailing the highest project costs. This includes for the power plant, fluid disposal and collection systems, wells, and transmission infrastructure. A set of design documents is typically attached to the feasibility study, which outlines the necessary design elements (Figure 7.1).

The basic engineering description and documents define the scope of the project and clarify related areas of responsibility. A summary of the most common design criteria should also be presented. Factors include the environment (such as natural hazards) and other relevant conditions at the plant location, design codes with respect to earthquakes, wind load, and more. Scaling, corrosion, and NCG content also pose special risks that should be addressed in the basic design description and documents. Figure 7.2 shows equipment at a Nesjavellir Geothermal Power Plant, the world's second largest geothermal plant located in Iceland.

Maintenance and Operation

The feasibility study outlines key elements of the project's operation—namely the level of automation required, number of personnel present during typical operations (night and day), and typical availability

FIGURE 7.1: DESIGN DOCUMENTS TO ACCOMPANY FEASIBILITY STUDY

- ☐ **Process flow diagrams** with heat and mass balances
- ☐ **Utility flow diagrams**
- ☐ **Preliminary piping and instrument diagrams** showing the main pipe diameters and the material selection for pipes
- ☐ **Layout drawings and plot plans**
- ☐ **A single line diagram** showing the plant and connection to existing grid infrastructure
- ☐ **Process and utility lists** of main equipment
- ☐ **A preliminary drilling program**
- ☐ **A concept design for the wells,** including a casing program

FIGURE 7.2: MIST ELIMINATORS AT NESJAVELLIR POWER PLANT (ICELAND)

Source: © Mannvit. Used with the permission of Mannvit. Further permission required for reuse.

(counting planned and unplanned stops for maintenance or other reasons). The availability of the power plant is an important input parameter in the financial modelling.

Power System Study

To connect a power plant to existing electrical infrastructure, a power system study (sometimes called a grid connection study) is performed to analyze and simulate grid behavior once the plant is added to the grid. This demonstrates the feasibility of the power plant in relation to existing electrical infrastructure. A summary of results should be included in the feasibility study.

Civil Works

The feasibility study should provide plans and cost estimates for civil works related to the project, including site preparation and development, buildings, civil engineering works relating to utilities, transport, emissions and effluent discharges, internal roads, fencing, and security.

Cost Estimates

The purpose of a cost estimate is to demonstrate that the project's cost is reasonable. Cost benchmarks from, for example, ESMAP's *Geothermal Handbook*,[19] and any major divergence from industry benchmarks should be outlined.

Cost estimates become obsolete with time. Therefore, a common practice when using older cost estimates for comparison is to use capital cost indices, such as the Chemical Engineering Plant Cost Index (www.chemengonline.com), to update estimates.

The capital expenditure (CAPEX) should be presented in itemized lists showing the main quantities and unit costs, including cost estimates for main items such as the power plant, fluid disposal and collection system, and wells. Transmission lines and substations should be included when they are part of the project scope. These itemized lists are best presented in a way that makes it easy to perform a consistency check between them and the basic design documents, and to verify that all important items included in the scope of the project are accounted for in the cost estimate.

The cost estimate methods and experience from other projects should be specifically denoted. For high-cost items, preliminary tendering may be performed to obtain estimates, including delivery times from key suppliers.

Both direct and indirect costs should be included in the cost estimates. Engineering and supervision costs should be counted separately.

Similarly, the operating expenditure (OPEX) should be clearly presented in itemized lists. It is particularly important to present assumptions regarding drilling of makeup wells during the project financial horizon. All costs incurred during the operation and maintenance of technical systems over the horizon of the financial modelling should be compared with the technical descriptions of these systems. This includes the cost of the human resources needed to run the plant and the cost of spare parts.

Assumptions regarding cost contingencies (including for unsuccessful wells) should be explained in a clear and concise manner.

8. PROJECT EXECUTION PLAN AND SCHEDULE

The project execution plan covers the period from the decision to invest to the start of commercial production. The plan should outline how implementation will be managed by the project developer, including responsibility matrixes and organizational charts that describe the management structure.

The project time schedule shows how project tasks are positioned over time. This demonstrates that the project has been carefully planned, thus minimizing risks related to the budgeted costs and schedule.

Professional project management is key to a project's optimal execution. Such management involves effective preparation, planning, an analysis of risk aspects and risk management, procurement, execution, project control, and contract management. Several competing best practices in project management have been suggested (see Project Management Institute 2017). Effective project management considers all stages of preparation and execution, and makes it more likely that individual project components and the project in its entirety remain within the defined time and cost frame. The project execution plan should describe the project management methodology that will be applied during project execution.

Work Breakdown Structure and Schedule

The project execution plan should above all include a description of the work breakdown schedule (WBS) and the project stages, all combined in a project schedule[20] that includes:

- **A description of the scope** of the tasks in the WBS, with clearly defined milestones and deliverables
- **Determination of the logical sequence** of tasks and milestones
- **Demonstration of the critical path** of the schedule, clarifying which tasks will directly influence the project timeline if delayed
- **Large tasks** that might be best broken down into engineering, procurement, and construction (EPC) phases (these include, for example, the power plant and fluid disposal, collection field engineering and construction, and engineering and drilling of the geothermal wells)

Project Implementation Budget

An implementation budget, among other things, shows the project's cash flow as a function of time during the project execution phase. This clarifies the link between the WBS and cash flow and demonstrates that adequate funds will be available throughout the project's execution phase. Importantly, this includes not only CAPEX but also the cost of the project during development. The implementation budget is an important input into the project's financial analysis.

Project Execution Issues

Other important aspects of project execution listed in a feasibility study include the organizational chart and personnel involved in the project execution and operation phases, and the overhead costs of the project execution company. Relevant human resources may be outlined according to categories and functions. The execution of a complex project requires an experienced and competent team.

A procurement and contracting strategy should be presented in the study. This includes a description of the scope of the main procurement packages, what packages will be procured locally and internationally, and the tender process that will be applied to guarantee competitive bids. Contracts regarding drilling and the plant equipment's should be in place (Salmon et al. 2011). It should be noted that most international financing institutions require formal and open procurement processes.

9. FINANCIAL ANALYSIS AND INVESTMENT APPRAISAL

Essential parts of any feasibility study are a financial analysis of the project and an appraisal of its investment needs. Critically, the decision of whether to finance a project is based on these elements. A detailed feasibility study that is complete and transparent in its assessment of the project and facilitates financial evaluation will reduce the project risk assessment of the financier. Financiers will consider information beyond the feasibility study in their decision to finance projects, such as country risk and the level of experience of a project's development team and partners. It is also essential to demonstrate how cost outflow is monitored and its link with the project development and schedules, as well as to specify how the developer will secure prudent financial management and proper and timely action in case of delays or cost increases.

The objective of the financial analysis is to demonstrate that the project will deliver acceptable returns to the developer and service the debt of the lending entity while meeting all commitments of the developer. Financial institutions use various measures to evaluate the capacity that needs to be proven before a project can be commercially funded. These can, among other criteria, be based on the type (greenfield/expansion) or size of the project (in megawatts electric, MW_e), its structure (phased-in development) and location, the capacity of the developer, and the risk appetite of financiers.

The financial analysis of a geothermal project follows the same principles as for other energy projects. However, the high up-front development costs and resource risks associated with geothermal development (ESMAP 2012) has implications for the financial structuring.

FINANCIAL MODEL

A financial model forms the backbone of the calculations used in the financial analysis. It uses inputs in the form of data and assumptions about variables and parameters defining the project and produces outputs from which financial viability can be assessed (see Box 9.1 for a description of key elements). It is critical to validate (often through a third party) the data, information, and assumptions used for the model (i.e., capital structure, interest rate, cost items, and time frame).

Outflows include the sum of the project's implementation budget, which in turn includes capital expenditure (CAPEX), operating expenditure (OPEX), and production losses, if any. Cash inflow is the sum of the sales revenue, revenue from selling assets, if any, and the recovery of salvage value (at the end of a project).

Financial model inputs. Inputs to the financial model include the CAPEX and OPEX and their distribution over the financial horizon.

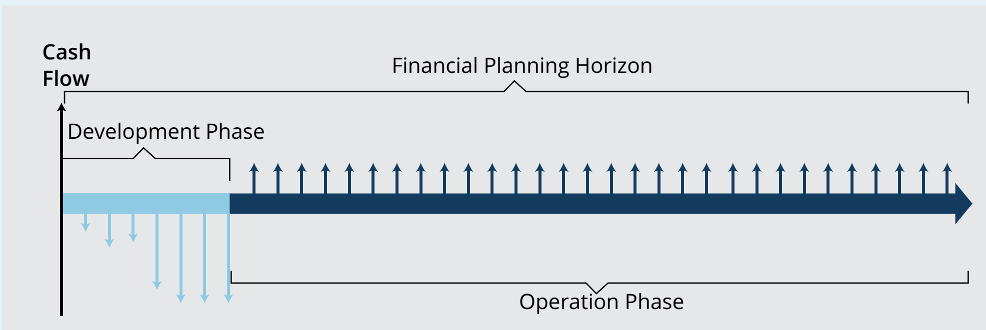
Assumptions made when creating the financial model and the accounting methods used—including those not in line with the generally accepted accounting principles—must be explained in detail.

BOX 9.1: FINANCIAL MODEL

A financial model's main inputs are cost, revenue (including support and risk measures), and the time horizon of the financial planning process. The outputs are the parameters of the financial return, which are calculated using formulas based on the discounted net cash flow of the project.

Financial modelling based on the discounted cash flow concept is generally accepted as a methodology for investment appraisal. The cash inflows and outflows over the financial planning horizon are estimated, yielding a typical net cash flow (as shown here). This is negative during the development phase, but positive in the operation phase as the plant generates revenue through power sales. A typical financial planning horizon for a geothermal energy project is 30 years (5 years for the development phase and 25 for the operating phase).

CASH FLOW OVER A TYPICAL 30-YEAR FINANCIAL PLANNING HORIZON



Source: © Mannvit.

The following aspects should always be included in the financial model:

- **Finance and loan structure:** the financial sources used to fund a project and the finance structure should be explained in a transparent manner showing amounts, covenants, payment conditions such as grace period(s), and interest rates
- **Depreciation and amortization schedule**
- Review of all **taxes and tax credits,** if any
- Review on all **support, incentives, and risk mitigation** available
- The way **inflation** is treated in the model
- **Weighted average cost of capital**
- **Insurance structures** used to transfer risks
- **Exchange rate assumptions,** if applicable

Financial model outputs. Typical financial model outputs—calculated using the cash flow over the financial planning horizon—are the net present value (NPV) and internal rate of revenue (IRR). Several others that are common in the financial appraisal include return on investment (ROI), return on equity (ROE), and the debt service coverage ratio (DSCR).

Financial model presentation. The financial model is typically presented in tables. It is important to detail how individual items are calculated. These include accounting statements for the financial planning horizon presented in the form of a:

- Balance sheet
- Income statement
- Cash flow statement

The financial model output values, and how they are calculated, should be clearly demonstrated.

SENSITIVITY ANALYSIS

How uncertain parameters of financial inputs affect those of financial outcomes may be investigated by performing a sensitivity analysis. The objective is to demonstrate that the project's financial outcome is robust toward these uncertainties. This means that even in the presence of uncertainty, the values of the financial output parameters will always be acceptable. The sensitivity analysis should demonstrate the degree of closeness to the hurdle rate, which is the rate at which the investment gives unacceptable returns to the developer or funding entities.

Several factors can cause uncertainty in the financial input parameters. For example, the cost of drilling production wells to reach target plant capacity is always uncertain due to the unpredictable drilling success of geothermal wells. Schedules are uncertain, and delays can cause financial parameters to deteriorate. Revenue can be lower than planned if target capacity is not achieved during the production drilling or if a reservoir declines faster than expected, calling for more frequent drilling of makeup wells than planned.

The sensitivity analysis should present graphs depicting how the financial output parameters (i.e., net present value, internal rate of return, debt service coverage ratio) vary as estimated variables (i.e., CAPEX, OPEX, revenue, and delayed project execution) vary within reasonable intervals. The sensitivity analysis can also include analysis of likely project development scenarios that can affect the financial outcome and options for the project's financial structuring.

ECONOMIC ANALYSIS

In some situations, for example when investors are the public sector or development banks, an economic assessment of the project may be requested in addition to the financial assessment. As with a financial model, an economical model is established with inputs in the form of data and assumptions about variables and parameters defining the project. From these, a stream of costs and benefits is constructed by which economic viability can be assessed relative to a counterfactual scenario where the project was not developed. They key differences are that: (i) the scope of the analysis is broader, typically at national level, considering sector wide impacts of the project on energy generation, transmission, distribution, jobs, etc.; (ii) costs and benefits are economic ones, including external costs (such as greenhouse gas [GHG] emissions that are displaced relative to the counterfactual scenario) and excluding taxes, duties, and transfer payments; and (iii) an economic discount rate is used that reflects the economic opportunity cost of capital. As with a financial analysis, it is critical to validate (often through a third party) the data, information, and assumptions used for the model (i.e., structure, revenue, cost items, and time frame) and to conduct a sensitivity analysis on the assumptions.

FUNDING PLAN

A funding plan is a framework agreement between the developer and providers of external funding. It sets the key parameters for developing the project and the milestones needed to unlock external funding. Projects should have a sound funding plan in place, in line with how much geothermal resource needs to be proven when external funding is to be acquired.

As discussed in Chapter 3, the financier often requires more than 50 percent of proven steam (or MW) and once 50 to 80 percent of the generation capacity is proven, the financing risk is considered comparable to that of gas-fired power plants (Salmon et al. 2011). This means that initial steps of geothermal development (exploration, concept design and part of production, and reinjection drilling) have to be funded by the developer with equity or soft finance. The funding plan is set in cooperation with the providers of external debt as they will require a predetermined share of the energy resource to be proven when external funding is provided as either debt or equity.

ENDNOTES

[1] Project developers preparing a feasibility study aim to make it “bankable.” This means that the study is able to secure loans from banking institutions. The exact point of bankability cannot be universally defined. Requirements for bankability vary between financing institutions and with market conditions. For example, the risk appetite of banking institutions fell sharply after the global financial crisis of 2008 (see Salmon et al. 2011). As a result, the required proven generation capacity for lending increased significantly, as well as the required equity/debt ratio.

[2] Production drilling is also sometimes referred to as confirmation drilling, delineation drilling, or appraisal drilling.

[3] The field development strategy includes decisions on how to develop the resource, that is, its generation capacity, whether it should be developed in phases, and how many wells to drill and their location. The strategy also outlines the capacity of the power plant and transmission lines.

[4] As observed in Latin America and the Caribbean, some commercial banks will consider offering financing for plant construction only once at least 50 percent of the geothermal fluid required to fulfill the plant generation capacity is available (ESMAP 2018).

[5] This phrase can apply to all types of fluids. For medium to high enthalpy power plant, it is usually called: Steam Gathering Systems or Steam Above Ground System.

[6] The International Renewable Energy Agency (IRENA) has published a bankability checklist—IRENA Project Navigator: Technical Concept Guidelines for Geothermal Power—accessible at https://navigator.irena.org/. This checklist is broadly consistent with the more detailed guidelines presented here.

[7] A guide to best practices in geothermal exploration has been presented by IGA Service GmbH and the International Finance Corporation (IGA and IFC 2013).

[8] Drilling that immediately follows exploration drilling is sometimes referred to as appraisal drilling, confirmation drilling, or delineation drilling. Typically, the wells drilled during this phase are designed to be used as production wells.

[9] Volumetric resource assessments, numerical models, and other simpler models should be based on the conceptual model.

[10] These, and other assessment methods (modelling methods), are described in Appendix B.

[11] A probabilistic volumetric model offers a probability density function that represents the range of possible generation capacities. P90 means that a particular generation capacity estimate equals or is exceeded by 90 percent of all the various generation capacities estimated by the model.

[12] The accuracy for this method for hydrothermal systems is not well documented and my not apply to certain cases.

[13] This chapter draws from ESMAP (2018), which presents international best practices for mitigating environmental and social risks in geothermal projects.

[14] http://www.ifc.org/performancestandards.

[15] https://www.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-standards.

[16] Category A projects are those likely to have significant adverse environmental impacts that are sensitive, diverse, or unprecedented. These impacts may affect an area broader than the sites or facilities subject to physical works (see ESMAP 2018).

[17] The association recommends a “class 3” estimate, which has an accuracy range of –20% to –10% on the low side, and +10% to +30% on the high side. The accuracy range of a cost estimate for a geothermal feasibility study depends heavily on the number of wells that have to be drilled to reach full plant capacity, and should therefore be evaluated on a case-by-case basis (AACE 2005).

[18] The characteristics of the resource that must be defined in order to design a plant are sometimes referred to as resource design criteria. Typically, these include the total mass flow at a given pressure, enthalpy, and fluid chemistry.

[19] Country-to-country cost variations should be considered in this comparison.

[20] It is recommended that the schedule achieve a class 3 or 4 ranking within the Association for the Advancement of Cost Engineering’s schedule classification system.

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APPENDIX A. GEOTHERMAL PROJECT RISKS

Many of the risks of geothermal development occur in other grid-connected power generation projects: completion or delay risk, off-taker risk, market demand or price risk, operational risk, and social, environmental, political, or regulatory risks (based on ESMAP 2012). However, there are some risks unique to geothermal energy development. Most notably, the test drilling phase is often considered to be the riskiest stage as it is capital intensive and fraught with high uncertainty about the reservoir's generation capacity. Before the test drilling phase, significant investment is required in surface exploration to determine whether the exploitation of the geothermal resource will be economically viable.

As explained in Chapter 4, when the project reaches financial closure, the field development phase has not yet concluded. The geological drilling risk, which involves the risk of drilling the remaining production wells and reinjection wells to meet the planned capacity of the power plant, is still present.

One of the main purposes of a feasibility study is to allow the financing entity to assess the project risk. For a financing entity, the primary concern is the probability of the developer repaying the loan. The developer is likely to repay the loan if the project is free of (unexpected) obstacles (showstoppers) and if the financial outcome of the project remains acceptable to the developer. Other risk factors in the project include, for example, poorly managed social and environmental risks can damage the financing entity's reputation.

Risk Handling

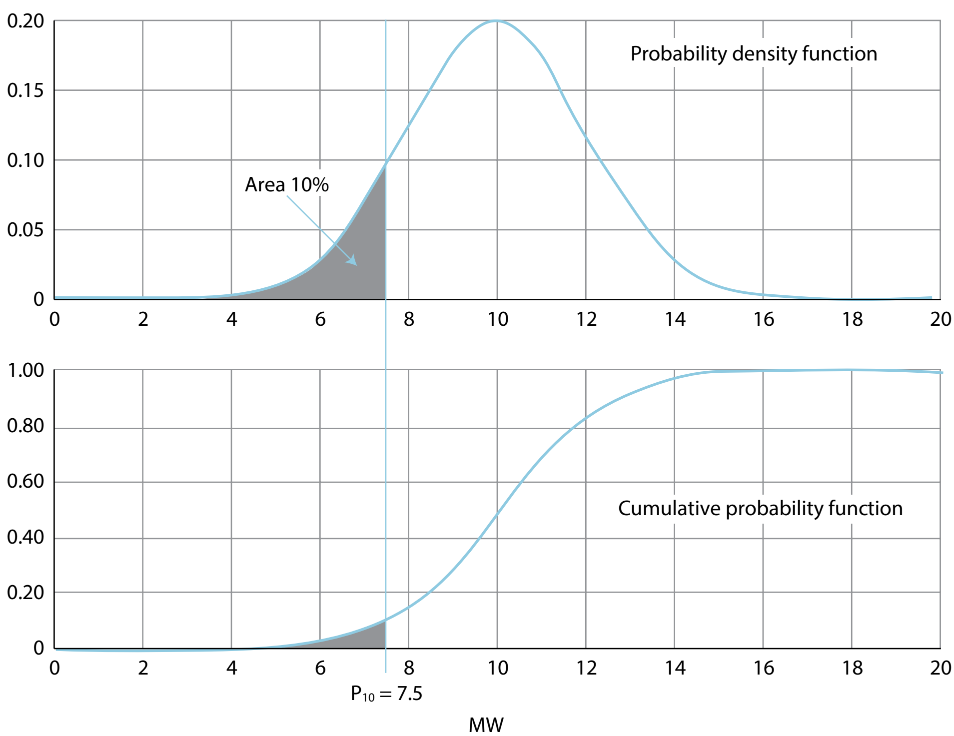
A feasibility study should disclose the main risks and a strategy for how they will be handled. The following are typical approaches to handling risk:

- **Avoid risk** by selecting approaches that circumvent potential problems. This can include an analysis of alternative approaches, for example, the risk of landslides can be avoided by moving the plant to a site where landslides do not occur.
- **Control/mitigate risk** by reducing its likelihood or, if the event cannot be avoided, the impact is offset through a series of predetermined measures/actions resulting in beneficial effects. The likelihood of cost overruns in plant construction can be reduced by furthering the maturity of the engineering design, as the cost estimates' accuracy depends on this.
- **Transfer risk to a third party** through contract agreements such as engineering, procurement, and construction (EPC) contracts for the erection of the power plant transfer construction risk, and a power purchase agreement (PPA) for market risk. Financial instruments can include political risk guarantees from regional financial institutions. Private finance institutions offer instruments such as convertible loans, bonds, and derivatives to hedge financial exposure to specific risks such as currency changes. Risks can also be transferred to insurance companies, such as through an all-risk insurance contract.
- **Accept risk** but include an appropriate budget for the possible cost overruns. The risk of cost increases associated with failed wells cannot be avoided when drilling production wells to acquire steam/brine for the full plant capacity. It is therefore prudent to include the cost for failed wells in the budget for production well drilling.

Risk and Probability

Risks are often presented as a probability; a risk probability is the likelihood of occurrence. To present risk probabilities quantitatively is with percentiles. The implicit assumption is then that the risk variable has a probability density distribution. The percentile of the distribution is a value Pα such that the probability of getting a value smaller than or equal to P_α is α/100. Typical values used in a feasibility study are P_{10}, P_{50}, P_{90}, P_{95}, and P_{99}. As an example, consider a variable with a probability distribution as shown in Figure A.1. Here, P_{10}, P_{50}, and P_{90} equal 7.5 megawatts (MW), 10 MW, and 12.5 MW, respectively. The relation between percentiles and the probability distribution function is that P_α is the value, and the area under the probability distribution function is α. In Figure A.1, the gray area is 0.1 of the total area under the probability density function. It defines the value of P_{10} = 7.5. Percentiles are often given for reservoir capacity. If the P_{10} of proven generating capacity of a reservoir is 50 MW, there is 90 percent probability that the generation capacity of the reservoir is above 50 MW. Percentiles are often the results of quantitative analysis using Monte Carlo methods, where repeated random sampling is used to create distributions of calculated variables based on probabilistic distributions of input variables.

FIGURE A.1: PERCENTILES, PROBABILITY DENSITY FUNCTIONS, AND CUMULATIVE DISTRIBUTION FUNCTIONS



Source: Original figure for this publication.
Note: MW = megawatt.

Risk Identification and Risk Classification

Integral parts of risk management are risk identification and risk classification. To assess risk exposure, risks are often classified according to impact (changes in cost, schedule, revenue, or other) and probability of occurrence. In Table A.1, typical geothermal project risks and risk categories are listed. The list is not exhaustive (and the division in categories is not always crisp) but it gives a good overview of the risks present in a typical geothermal project.

TABLE A.1: TYPICAL RISK CATEGORIES

TYPE OF RISK	DESCRIPTION	EXAMPLES OF RISK MANAGEMENT	RELATED RISKS
Market	Risk that the revenue of the project will not be as expected, not due to lower production, but because the developer does not get paid for the production as originally planned.	Transfer risk to an off-taker by signing a power purchase agreement (PPA). The market risk is then converted to the off-taker default risk.	• Off-taker credit risk • Price risk
Geothermal Resource	At the time of the feasibility study, the risk of the production drilling campaign fails to reach the required capacity, or does so with cost overruns. Second, the risk of decline in the resource due to exploitation that cannot be maintained for the duration planned. In this case, the resource is not as productive as originally estimated and the reservoir cannot sustain production to the power plant according to planned capacity.	Reduce the likelihood of occurrence by performing further exploration of the resource using experienced specialist consultants. Transfer the risk through risk mitigation facilities, if available. Develop the resource in phases with partial utilization/generation during the first phase and then stepwise increase in utilization. This can lead to a better understanding of the geothermal system, and a more accurate capacity estimate, before further exploitation is decided. Resource data management on a country level or sharing data with other developers.	• Exploration drilling risk (often mitigated with risk sharing mechanism), e.g., Turkey, Indonesia, and Armenia • Reservoir capacity risk • Reservoir decline risk • Reservoir sustainability risk
Location and Site	Risks associated with the project location include natural hazards (earthquakes, hurricanes, and volcanos) and security risks. Risks associated with the project site include landslides and floods.	Select site to avoid natural hazards. Design infrastructure to withstand natural hazards.	• Natural hazard risk • Security risk

(continued)

TABLE A.1: CONTINUED

TYPE OF RISK	DESCRIPTION	EXAMPLES OF RISK MANAGEMENT	RELATED RISKS
Technical	Risks associated with technical problems during drilling, plant construction, or plant operation, which can include quality problems, abandonment, and noncompletion. Impacts may include increased costs, delays, or revenue losses due to less energy generation.	Invest more in the engineering of the project. Transfer risk to equipment suppliers and engineering, procurement, and construction (EPC) companies. Contracts with these companies may include guarantees and penalties for delays.	• Construction risk • Technical drilling risk
Social and Environmental	Risks of: • Environmental damage caused by the geothermal power plant, including any liability following such damage. The environmental risk assessment shall include, for example, forest and habitat conservation. • Delays and even project cancellation due to adverse social impacts of the power plant. • Apprehension and opposition to the geothermal power plant by the local community.	Conduct investigations according to internationally accepted standards for environmental and social impact assessments. Hold stakeholders meetings and consultations. Make sure all stakeholders have been identified. Stakeholders' consultation should consider audience (e.g., indigenous people, women, etc.) to ensure appropriate participation. Incorporate environmental and social requirements into the design and site selection (e.g., well pads, power plant location, visual impacts, noise). Identify opportunities (e.g., employment, business development, direct use) and gender equality.	• Security risk

(continued)

TABLE A.1: CONTINUED

TYPE OF RISK	DESCRIPTION	EXAMPLES OF RISK MANAGEMENT	RELATED RISKS
Project Execution	Risks due to: • Delays in project execution • Management problem • Poor planning and an inadequate budget that does not consider cost uncertainties • Difficulties in the procurement process	Follow scheduling classification systems. Increase efforts in project planning. Follow procurement plans. Use advanced engineering.	• Company risk • Procurement risk
Financial	Risks of: • Cost increase • Delays • Revenue loss • Changes in financing conditions such as interest rate change or currency changes	Base the financial planning on proper financial analysis, including sensitivity analysis.	• Credit risk
Legal	Risks related to the business transactions and contractual relationships in the project.	Engage experienced legal counsel.	• Contract risk • Credit risk
Regulatory	Risks related to regulatory authorities whose decisions can impact the project either in the development or operation phase.	Contract expert consultants with knowledge of the regulation environment. Evaluate past performances and practices in the sector.	
Political	Risk of project termination or delay due to political instability, causing, for example, civil unrest and labor strikes.	Mitigate risk with social outreach programs and political risk insurance.	
Operation and Maintenance	Risk of unscheduled generation outages due to equipment failure or lack of resources for maintenance.	Assign adequate funding during the operation phase and hire experienced operators or an operation company.	

Source: Original figure for this publication.

APPENDIX B. RESOURCE ASSESSMENT

The energy production capacity of hydrothermal systems is predominantly controlled by reservoir pressure decline caused by hot water/steam production, which is, in turn, determined by the size of the geothermal reservoir, permeability, storage capacity, fluid recharge, and geological structure. More generally, the capacity of geothermal systems is controlled by their energy content and dictated by their size and temperature conditions (e.g., enthalpy). A thorough understanding of the nature and properties of geothermal resources via comprehensive interdisciplinary research, as well as reliable and accurate assessments of their production capacity, through modelling, are prerequisites for the successful long-term utilization of geothermal resources.

Modelling plays a key role in understanding the nature of geothermal systems and is the most powerful tool for geothermal resource assessment, or for estimating their production capacity, which is mainly based on predicting the response of the systems to future production (see Axelsson 2016). Models are an indispensable part of geothermal resource management during utilization.

The volumetric method is the simplest reservoir modelling and resource assessment method used in the geothermal industry and is classified as static modelling. Different methods of dynamic modelling, including simple analytical modelling, lumped parameter modelling, or detailed numerical modelling, are also used. The volumetric method using Monte Carlo calculations, supported by the testing of drilled wells, is how resources are typically assessed in feasibility studies for greenfield systems, while dynamic numerical models can be applied in the case of expansion projects, if data coverage is sufficient.

The volumetric method is presented and discussed in detail by Sarmiento, Axelsson, and Steingrimsson (2013). It is often used for first-stage assessment, when data are limited, and still widely used in many countries. It is increasingly being used through application of the Monte Carlo method, which enables the incorporation of overall uncertainty in the results. The main drawback of the volumetric method is the fact that the dynamic response of a reservoir to production is not considered, such as the pressure response and the effect of fluid recharge. Reservoirs with the same heat content may have different permeabilities and recharge and, hence, very different production potentials.

The volumetric method estimates the total heat stored in a volume of rock (referred to some base temperature), both thermal energy in the rock matrix and in water/steam in the pores. In the volumetric method the likely surface area and thickness of a resource are initially estimated from geophysical and geological data, and later from well data. Consequently, likely temperature conditions are assumed based on chemical studies and well temperature data, if available. Based on these estimates of reservoir porosity and the thermal properties of water and rock involved, the total energy content is estimated. The reservoir temperature can be assumed to be approximately constant, variable between different reservoir parts, or a certain fraction of the boiling point curve at prevailing pressure conditions, in the calculations. The reference temperature used is the base temperature of the energy production process involved (space heating, electricity generation, etc.).

Only a relatively small fraction of the total energy in a system can be expected to be extracted, or recovered, during the several decades' long utilization period. This fraction is estimated by applying two factors. First, so-called surface accessibility (A) describes the proportion of the reservoir volume can be accessed through drilling from the surface. The recovery factor (R) indicates how much of the accessible energy may be feasibly recovered. The recovery factor is the parameter in the volumetric method, which is most difficult to estimate. The results of the volumetric assessment are also highly dependent on the factor. The recovery factor depends on the nature of the system: permeability; porosity; significance of fractures; recharge; mode of production, that is, whether reinjection is applied; and, to some extent, the utilization time. Williams (2007) provides a good review of the estimation of the recovery factor, which is often assumed to be in the range of 0.05–0.25. In recent years, researchers have become more conservative in selecting the recovery factor, based on the experiences of numerous geothermal systems worldwide.

To estimate electrical generation capacity (total energy or power potential) on the basis of the recoverable energy, an appropriate conversion efficiency should be used. It should incorporate the conversion of thermal energy into mechanical energy and mechanical energy into electrical energy. The efficiency depends on resource temperature, the generation process used (conventional steam turbine, binary fluid generation, etc.), and the reference temperature.

The volumetric method can be applied to individual geothermal reservoirs, to whole geothermal systems, or to a whole country, that is, on a regional scale. For individual systems, the Monte Carlo method is commonly applied. It involves assigning probability distributions to the different parameters of the equations above and estimating the system potential with probability.

It must be emphasized that the volumetric method is not suitable for the estimation of the long-term (sustainable) production capacity of geothermal systems. This is because of its limitations mentioned above, mainly the fact that it neglects the dynamic response of geothermal systems during utilization. Thus, the results of a volumetric assessment should only be considered indicative. It is also important to put emphasis on the lower limit of the Monte Carlo outcome, often referred to as the P_{95} or P_{90} value, rather than the average outcome or upper limit.

As the volumetric method is not sufficient to estimate the ultimate capacity of a geothermal resource, the results should be combined with the cumulative capacity of wells already drilled to plan the first development step. Detailed numerical modelling, performed once relevant data become available, will provide a much more accurate capacity estimate.

ESMAP MISSION

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