A Five-Phase Linear Workflow for Geothermal Power Project Development

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Keywords

Project Development, Workflow, Geothermal Exploration, Geothermal Drilling, Conceptualization, Pre-Feasibility, Feasibility, Confirmation, Completion, Flowchart, Power Generation Projects

ABSTRACT

This paper details a five-phase linear workflow to develop a geothermal greenfield power project from an initial conceptualization phase, through multiple exploration phases, a confirmation phase, and ending with the completion of a geothermal field development. The purpose is to provide investors and stakeholders with a critical path for multiple project scenarios, allowing transparency, highlighting risk management, and creating decision-making tools. Each of the five phases has key inputs, processes, results, and decision points. This workflow is compatible with current risk mitigation funding strategies and is suitable for non-greenfield scenarios such as O&G (Oil and Gas) transitioning to geothermal energy, or existing fields seeking expansion.

1. Introduction

This paper will present a five-phase linear sequence of actions required to advance a geothermal power project from an initial concept to a completed project. Modeled around key decision points, this workflow provides a full path of required inputs, processes, and results. Designed for power generation projects, the workflow incorporates industry standard data analyses and specialized resource testing and modeling. The five Phases are:

I. Conceptualization
II. Pre-Feasibility
III. Feasibility
IV. Confirmation
V. Completion

A flowchart using conventional shapes organizes the workflow where ovals represent a start or end, arrows show the path between actions, trapezoids symbolize an input or output, rectangles denote a process, rhombi signify decisions, and stacked-document symbols mean key multi-disciplinary reports or plans. This workflow commences at a point where some or no legacy data exists. The critical path iteratively gathers information through processes of data analysis, acquisition, testing, and modeling. Each process or set of processes will produce reports or plans that will provide the stakeholders with key information for go/no-go decision points before proceeding to the next Phase. It builds on the scheme set out by Hickson and Yehia (2014) based on their development experience. Figure 1 below shows the flowchart for the five-phase geothermal workflow.

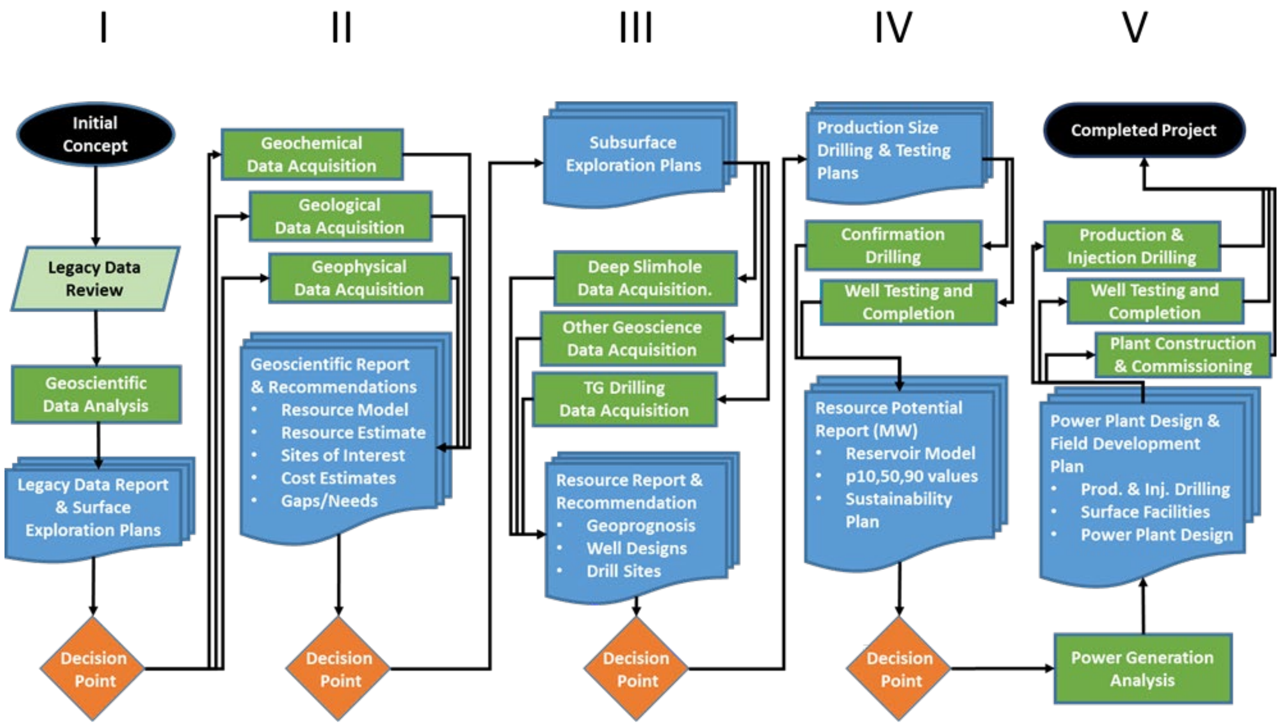

Figure 1: A five-phase linear workflow for geothermal power project development shows a process with only legacy data as an input, building iteratively from an initial concept to a completed project.

2. Conceptualization Phase

The first Phase, headed by Roman numeral I, is the Conceptualization Phase, which begins with an initial concept for a geothermal power project at a specific site that may or may not have associated data. Whatever data does exist goes through geoscientific analysis and into a Legacy Data Report, which includes a data-gap analysis section, the document also includes Surface Exploration Plans, which prioritize the data-gaps as objectives, and provide details of geoscientific studies with time and cost estimates.

2.1 Legacy Data Review

Existing data is the only key input assumed for this workflow—that would likely be the case for an unexplored, or "greenfield", project. Public and published data serve as a main source that does not require any field-related activities. If prior exploration or modeling has taken place at the site, the resulting documents may provide value after review for data quality and accuracy. Overall legacy data review vets, organizes, and selects key data inputs for the next step of baseline geoscientific analysis. Figure 2 shows Phase I.

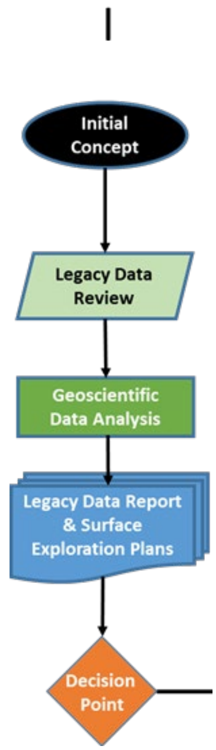

Figure 2: The set of actions for Phase I shows the path from initial concept to the first decision point.

2.2 Geoscientific Analysis

In this process, the summarized review of selected key inputs (if any) is analyzed by a multi-disciplinary team of geoscientists and engineers with experience in characterizing and assessing geothermal resources. Specialized personnel such as geologists, geochemists, geophysicists, environmental specialists, hydrologists, petrophysicists, review the data for quality and reliability. Geoscientists review maps, stratigraphy columns, chemical analyses, survey reports, and other studies to delineate areas of interest—areas that show evidence of a geothermal reservoir—and to highlight voids in data that need to be acquired in the next phase of development. Environmental specialists focus on existing conditions of the site and consider impacts of initial exploration for a subsequent formal Environmental Social Impact Assessment (ESIA). Hydrologists review meteorological data, watersheds, rivers, lakes, and collaborate with geoscientists and environmentalists to delineate areas of exploration interest. Petrophysicists and other wellbore-related specialists (engineers, drillers, etc.) focus on data such as offset well logs, drilling reports, and well schematics, to interpret subsurface characteristics.

2.3 Data Report and Surface Exploration Plans

This desktop study results in an initial geo-prognosis of the site area that can include but is not limited to, area(s) of interest, a conceptual model, or even first order resource estimate(s)—all depending on the breadth of available data. The analysis also identifies what is missing from the data set and prioritizes the gaps in order to formulate exploration operations designed to acquire the lacking data. These operations are typically the first set of data acquisition campaigns in geothermal development. Plans are recommended and budgeted in Phase I (Conceptualization) to execute in Phase II (Pre-Feasibility), if the developer agrees to move forward.

The Surface Exploration Plans are the least-invasive and least capital intensive, as they require limited personnel and equipment—when compared to drilling and power plant construction. Surface explorations include but are not limited to geologic field studies such as mapping, LiDAR surveys, rock sampling, and subsequent interpretation. Geochemical field studies include gas sampling, liquid sampling, air quality sampling, and laboratory analyses for interpretation. Geophysical field studies may include a magneto telluric (MT) resistivity survey, gravimetric survey, and a magnetic survey. Each data acquisition plan has a timeline, team, and cost, these provide the developer an idea of the commitments required to execute these plans.

2.4 Decision Point 1

This point of the workflow is the developer's opportunity to clarify interpretations in the Data Report or the Surface Exploration Plans. Typically, the key considerations for the developer are budget, security, logistics, and time; all development plans have inherent risk, and even the most thorough plans can incur delays or incompletion. If a "go" decision is given and the project moves forward, Phase II (Pre-Feasibility) commences, after completing the final version (after feedback and revisions) of the Surface Exploration Plans.

3. Pre-Feasibility Phase

The second Phase, headed by Roman numeral II, is the Pre-Feasibility portion of the workflow. Beginning with data acquisition processes for geology, geochemistry, and geophysics, the results lead to a Geoscientific Report with Recommendations, the guiding document for the developer at Decision Point 2. After Phase II is complete and the developer wants to continue delineating the resource by investing in Phase III (Feasibility) to reduce risk by in-situ data acquisition from the subsurface (drilling), Phase III (Feasibility) can commence. Figure 3 below shows Phase II.

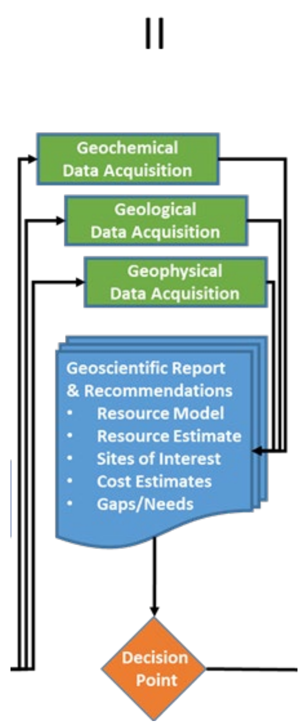

Figure 3: Phase II shows the path from geoscientific data acquisitions to the second decision point.

3.1 Data Acquisition Campaigns

Phase II workflow focuses on the resource investigation through surface campaigns planned at the end of Phase I (Conceptualization). The geological, geochemical, and geophysical studies are iteratively completed, or in parallel, depending on each plan's scope and the site's limitations. The assumption in these three data acquisition processes is that new field studies fill data-gaps; these studies can also confirm, update, or expand known data sets.

3.2 Geoscientific Report and Recommendations

The final product, after the completion of three geoscientific surface exploration processes, is a report with recommendations for Phase III (Feasibility). Given that the next Phase focuses on the first tranche of drilling activities, the report would highlight key items such as:

- Resource Model – a geothermal conceptual model that hypothesizes resource type, contextualizes major features, and integrates acquired surface exploration data to provide a first order estimate of area and depth.
- Resource Estimate – a first order revised estimate of the geothermal resource in MW, done via modeling such as a heat-in-place estimate.
- Sites of interest – locations for well sites along with target depths for Phase III exploratory drilling.
- Cost Estimates – key costs and time estimates for exploratory drilling in Phase III.
- Gaps/Needs – the identification of unattainable data in Phase II still deemed necessary to proceed with Phase III; acquisition either requires further investigation with changes in season (weather), methodology (un-manned equipment for safety), logistical obstacles (customs or permitting), or other parameters.

3.3 Decision Point 2

This go/no-go decision point for the developer is now well beyond the initial legacy data and integrates new surface exploration, with a delineated site or several sites to consider for Phase III (Feasibility Study). The conceptual model integrates geoscientific data (geology, geochemistry, and geophysics) for a revised dimension of the potential resource and an estimate of potential power generation (MWe). The costs associated with these three geoscientific campaigns are an order of magnitude less than a multi-site drilling campaign. Surface exploration studies (geology, geochemistry, and geophysics) run in the hundreds of thousands of dollars; Phase III Thermal Gradient (TG) drilling and deep slimhole drilling estimates are in the low (1-3) millions of dollars based on international disclosure-protected projects in the past 5 years.

Risk mitigation funding in certain regions—particularly emerging markets such as Latin America—provide reimbursable grant funding for Phase I and Phase II. The Geothermal Development Facility (GDF) is a particular fund that can provide up to 600,000 € or 40% of the budget in funding for the activities described in Phase II and drilling in Phase III. Although there is inherent risk in Phase III drilling, Phase II scientific campaigns reduce risk by assessing the site beyond legacy data with specialized teams and equipment.

4. Feasibility Phase

Where pre-feasibility studies are early-stage analyses of a project, (Phase II), feasibility studies build on those results and go into deeper study of many of the same subjects. In terms of geothermal resource identification, surface studies provide a regional to site-scale delineation of a potential reservoir, with a conceptual model of its possible behavior; feasibility studies aim to confirm this model by integrating in-situ (subsurface) data.

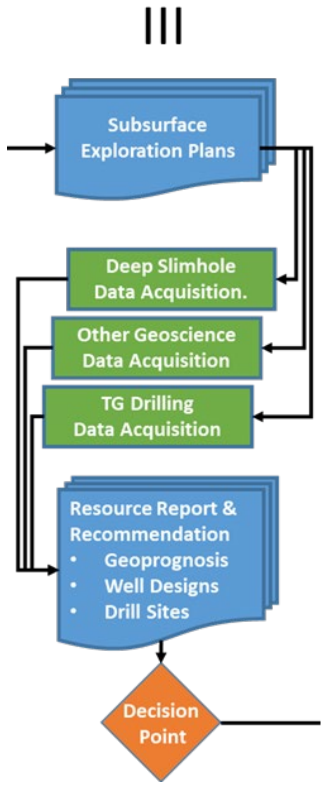

Figure 4: Phase III shows the path from Subsurface Exploration Plans to the third decision point.

4.1 Subsurface Exploration Plans

The Phase III exploration campaigns center around drilling plans which are focused on a specific set of goals laid out by the recommendations in the end of Phase II (Pre-Feasibility). Specifically, drilling targets are given for TG drilling, and a deep slimhole well(s) to acquire subsurface in-situ data gathered from coring, laboratory analysis, downhole logs (pressure, temperature, and flow), and formation tops and bottoms. These drilling plans consist of well schematics, well sites, target depths, drilling plans, and after initial engineering plans are completed, a final design document is used to lead the drilling campaign. These plans also go beyond typical drilling and logging and include downhole geophysical surveys such as gamma probes or resistivity. All plans are accompanied by cost and time estimates to guide the project; phases, tasks, and key milestones help measure progress against a set of expectations. Project management for drilling should be performed in a manner that acknowledges the importance of communication and given the complex and expensive nature of drilling provides an opportunity for input from beyond the drilling management team, e.g. Bailey et al. (2012). This input is often best acquired from project stakeholders whose specialized skills and knowledge can supplement the program and ease the path of change, as conditions dictate, during the life of the project, e.g., Bailey et al. (2012).

4.2 Drilling and Geoscience Follow-Up

Thermal gradient (TG) drilling is designed to construct vertical boreholes—typically between 200m and 800m true vertical depth (TVD) per McKenize et al. (2017)—for logging which can provide a geothermal gradient (temperature with depth, as shown below in Figure 5) and better calibrate subsurface modeling. TG boreholes are not pumped (production or injection), their casings are cemented and filled with water and multiple thermal gradients (from various TG boreholes) are spatially interpolated into subsurface modeling to delineate elevated gradients within a site. Deep slimhole wells can be as deep as 2,000m TVD and obtain similar information as TG holes but are designed to intersect the production zone using the same type of infrastructure associated with TG hole drilling, according to McKenzie et al., (2017). A discussion of the pros and cons of slimhole drilling can be found in White et al.

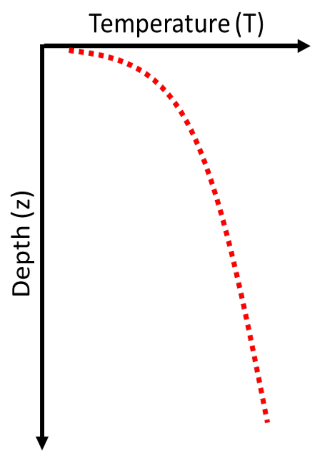

Figure 5: A conceptual graph of a temperature gradient, plotting temperature with corresponding depth.

4.3 Resource Report and Recommendation

The resulting Resource Report from this Phase refines the conceptual model with downhole parameters used in reservoir analysis such as temperature, pressure, lithological column (at the site), geochemical and geophysical properties from the subsurface. The resulting integration of these data is the foundation for a specialized geothermal expert team to provide recommended target sites for confirmation drilling. Per international risk mitigation funding developer requirements, such as the Geothermal Development Facility (2022), confirmation drilling is production size well construction suitable for reaching and confirming the geothermal reservoir potential, as well as power production. The well construction must abide by appropriate production zone casing diameters such as 6” to 10” e.g., Beckers and Young, (2018); similarly per GDF requirements > 5” diameter in the last casing or liner is considered apt for confirmation drilling (2022).

4.4 Decision Point 3

Completing Phases I through III takes anywhere from 12 – 24 months depending on the size of the area, logistical considerations, and permitting requirements; however, during this period from concept to feasibility, a robust geothermal reservoir model has been constructed and refined with various iterations of increasing accuracy, significantly de-risking any further involvement. This workflow model segments the pre-feasibility from the feasibility by dividing exploratory drilling from surface exploration; and then further divides drilling from smaller diameter less cost-intensive drilling from full-size more expensive production drilling. These distinctions allow the developer to invest in phases while maximizing reservoir model development, creating a cost-efficient path through exploration. This decision point is the go/no-go transition from investing less than 5 million dollars to investing tens of millions of dollars to confirm the resource. The developer now has 3-D subsurface modeling, refined power generation estimates based on reservoir parameters directly from exploratory drilling and can better assess their financial model (power generation market, return on investment, structured financing considerations, and other factors). When feasibility, both technical and financial, is confirmed, the developer signals the go-ahead onto Phase IV, the Confirmation Phase.

5. Confirmation Phase

Though feasibility studies have been completed, and a decision has been made to perform confirmation drilling, the idea of "bankability" is the key result for Phase IV. Drilling and well testing plans for productions size geothermal wells are created, followed by the actual drilling and long-term flow and injection testing of a few wells (depending on risk appetite and budget). The well tests are fed into geothermal reservoir engineering software (such as TOUGH—**T**ransport **O**f **U**nsaturated **G**roundwater and **H**eat—and its suite of programs) that can extrapolate potential power generation for decades and provide percentile values such as p10, p50, and p90. These percentiles represent 10%, 50%, and 90% levels of confidence in a statistical estimate—in this case MW generated from the reservoir. If adequate, and long-term power potential is established, a sustainability plan is provided in the Resource Potential Report at the end of Phase IV.

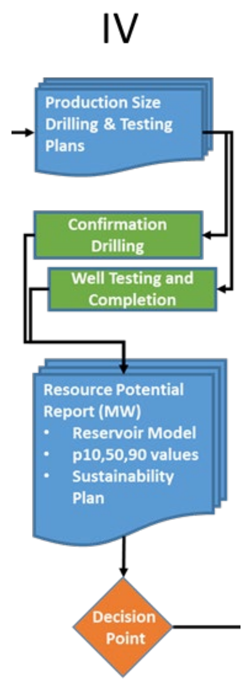

Figure 6: Phase IV shows the path from Production Size Drilling and Testing Plans to the fourth decision point.

5.1 Production Size Drilling and Testing Plans

Confirmation drilling is designed to drill down to the identified geothermal reservoir, then using the constructed well, perform long-term flow testing (typically 30 days) to analyze data and provide prognostication of 30-year generation potential. Detailed drilling plans are created to provide specifications of required personnel, rig equipment, wellheads, site designs, specialty equipment (blowout preventors, bottomhole assemblies, etc.). These plans are based on the recommendations from Phase III and have target depths, formations, or both. Drilling plans also include cost estimates, equipment lead times, and expected days versus depth charts as a preliminary progress baseline. According to Bailey et al. (2012), one of the greatest errors that an operator can make is failing to perform sufficient advanced planning which constitutes a trivial fraction of the total cost of drilling a well, but the failure to plan properly may result in wells that cost millions more than necessary.

Well testing plans have detailed procedures, equipment specifications and drawings, cost estimates, and timelines. According to the Energy Sector Management Assistance Program (ESMAP) Geothermal Handbook (2012), the long-term testing of productive exploration wells will define the expected productivity of future wells, as well as yield information on the pressure response (drawdown) of the reservoir to fluid production. Test results from several wells are integrated into numerical modeling software to produce probability percentiles that allow for risk mitigation of the reservoir’s performance.

5.2 Confirmation Drilling and Well Testing

Geothermal drilling is a significant investment with World Bank estimates from over a decade ago (2012) range from 2 to 6 million dollars per confirmation well. However, depending on the remoteness of the site, rig availability, and post-COVID supply chain cost increases can increase costs to 7 to 10 million dollars per well. This would make a 3-well confirmation drilling program cost between 20 to 30 million dollars; risk mitigation funding such as the GDF can provide contingency grants for up to 10 million euros or 70% of the total cost of drilling and related activities (2022). High enthalpy geothermal reservoirs (best suited for power production) with artesian conditions (self-flowing) provide cost savings with regards to pumping equipment, shallower depths, and have more cost-effective drilling campaigns with time savings and higher projected production estimates.

5.3 Resource Potential Report

All the resulting data from drilling and testing is summarized into a Resource Potential Report that explains lessons learned from the drilling campaign, final well designs (if they differ from the original design due to site conditions), final costs, well testing results and analysis (p10, p50, and p90 values), and an overall recommendation from the resource evaluation experts. The report is the key document that allows the developer to analyze the projects' performance with regards to confirming the resource dimensions, bankability, and attractiveness to acquire follow-on financial support to develop the geothermal field and construct a power plant, sized to the resource potential. This scale of investment—depending on the size of the project—can reach into the hundreds of millions of dollars for a 50 MW power project, per ESMAP (2012). Therefore, a detailed resource potential estimate based on long-term flow testing from confirmation wells that have reached and produced from the geothermal reservoir are the best tool available to integrate into a project's financial model and determine bankability.

5.4 Decision Point 4

The developer's fourth decision point is the final go/no-go before a project goes into full development and officially exits exploration. Though investment can be in the tens of millions of dollars after Phase IV, it is still much less than the hundreds of millions of dollars remaining in Phase V (Completion Phase) to complete the project. Using the Cost vs. Risk graph from the ESMAP Handbook (2012) as a guide, and then overlapping the Phases of this workflow, the inflection point in cost is shown in Phase V (Figure 7).

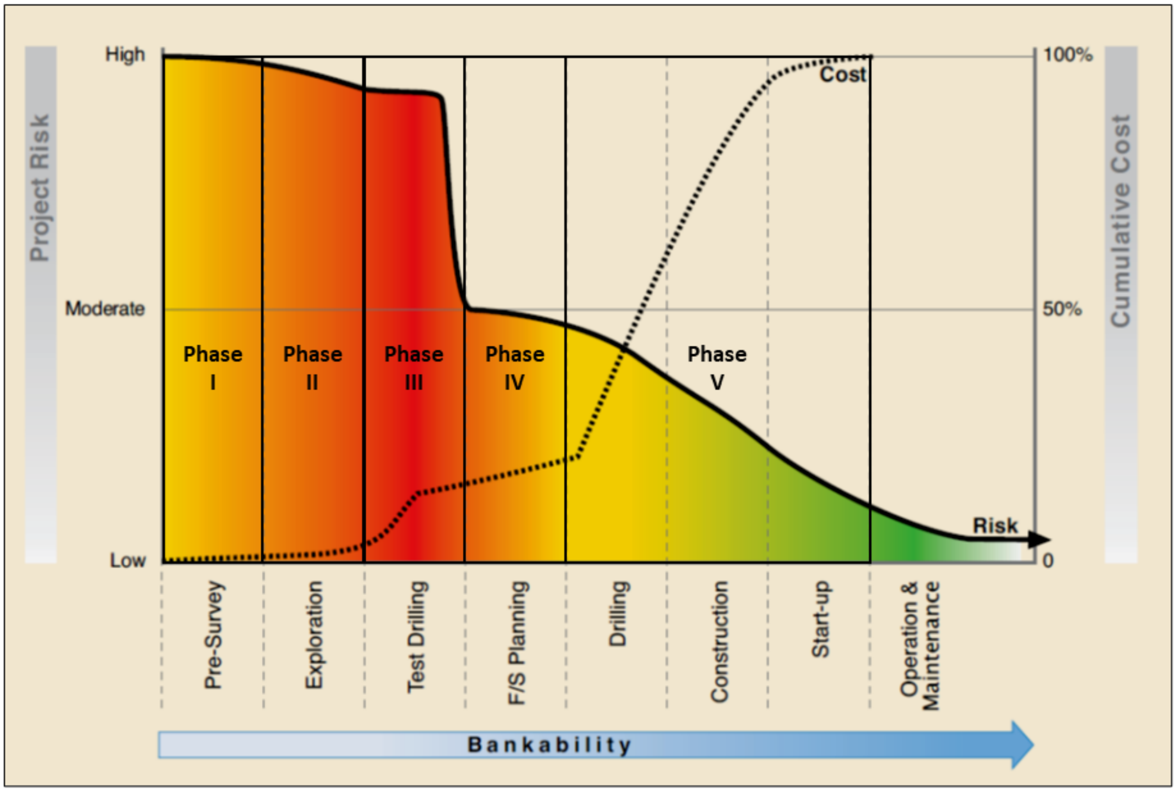

Figure 7: Phases overlapping World Bank/ESMAP's Cost and Risk Profile (modified from World Bank, 2012)

6. Completion Phase

The most cost-intensive phase in the development path, Phase V (Figure 8), entails power generation analysis followed by a guiding series of planning documents for production and injection drilling, surface facility design (steam gathering systems), and power plant specifications. The power estimates are revised as more drilling, testing, and modeling are completed throughout the development of the site; over time the specifics of the working fluid are better characterized, and the power plant design is updated. Whether a flash or binary system is installed, the working fluid produced from the geothermal wells must be properly understood for reservoir sustainability order to fulfill decades-long power purchase agreements (PPAs). These PPA contracts are the main source of revenue for typical power generation projects. However, in recent years other revenue streams are being integrated such as cascaded use of heat for district heating/cooling, agriculture, fish farming, and industrial processes. Geothermal working fluid itself can be used as a source for rare-earth minerals such as lithium in addition to power generation, yielding additional revenue.

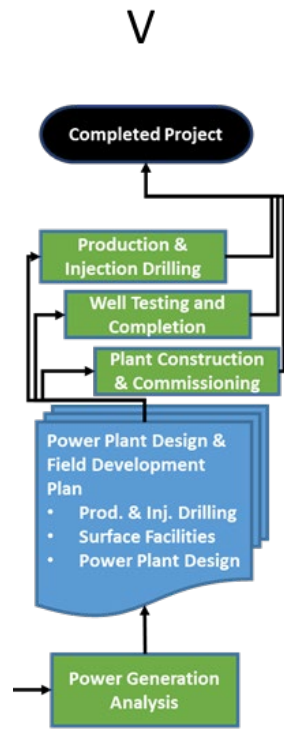

Figure 8: Phase V shows the path from Power Generation Analysis to a completed project.

6.1 Power Generation Analysis

Knowing what reservoir characteristics exist, including long-term well performance forecasts, a power generation analysis is performed. The analysis provides a secondary review of what reservoir engineering and modeling has concluded, from a team of power plant specialists. The power plant specialists use the modeling expectations and use that as the data inputs for modeling the appropriate power plant characteristics, size, generation type, surface facilities, scale (MW), etc. Other key aspects include a design to minimize impacts, maximize potential, and extend the life cycle of the system. A common method for studying impact and performance is a Life Cycle Analysis (LCA) which is a powerful approach to analyze systems overarching the complete life cycle of a system (from cradle to grave) which is necessary when considering the substitution of fossil fuels with renewables e.g., Basosi et al., (2020).

6.2 Power Plant Design & Field Development Plan

The design and field development are parallel documents that outline the well sites, designs, and estimated potential generation (individually per well, and overall, as a project). Each individual production and injection well will have its own design, drilling, and testing plan, and results of drilling will be integrated into the master plan for the field development. As each well is completed, the numerical model of the overall resource is updated, and these updates are integrated into the power plant design. When a confidence threshold—decided by the experts in reservoir engineering, power plant design, and drilling management—is crossed, construction contracting begins. In some cases, power plant construction is done in parallel with the latter stages of production and injection well drilling, which requires a high degree of confidence in the expectations of the geothermal field. It can also save time as power plant construction can take years depending on the size and site complexity of the project. The field development and power plant design plans are living documents that are adjusted accordingly. Logistic and supply chain delays, permitting obstacles, and even subsurface complications are factors that can change plans in real-time, to gage these risks, a risk register should be performed for the drilling phase and be coupled with iterative milestones. According to Bailey et al., (2012) an ideal drilling plan should incorporate the following inputs, tools, and outputs:

- Inputs
  - Well Proposal
  - Working drafts of the Drilling Procedure and Risk Registry
  - Service company-provided procedures for special operations
  - Iterative goals
- Tools and Techniques
  - Expert judgment
  - Delphi technique—per Cline (2000)
  - Drill-on-Paper exercise
- Output
  - Drilling Procedure(s)

Several drilling procedure documents for production and injection wells constitute a wellfield development plan.

Power plant design will incorporate temperature, flowrate (artesian or pumped), geochemistry of the fluid, ambient temperature, sustainable power generation estimates (MW), costs, times, dimensions, fluid gathering systems, substations, environmental impacts, PPA requirements, and other factors. Costs can range into the hundreds of millions of dollars, in fact a 2020 public estimate of a 110 MW power plant project was estimated at nearly 400 million dollars by the Asian Development Bank President and Board of Directors (2020). The locations were for 55 MW in Central Java (Dieng), and 55 MW in West Java (Patuha), Indonesia where geothermal power has been successfully developed for several decades using high enthalpy systems (Figure 9).

($ million)

Item	Amount[a]
A. Base Cost	
1. Geothermal power plants constructed and commissioned	399.51
2. Institutional capacity of GDE strengthened	1.00
3. Community development program enhanced	0.54
Subtotal (A)	**401.05**
B. Contingencies[b]	**55.75**
C. Financial Charges During Implementation[c]	**12.40**
Total (A+B+C)	**469.20**

ADB = Asian Development Bank, GDE = PT Geo Dipa Energi.
[a] In Q4 2019 prices. Includes taxes and duties of $12.48 million to be financed by ADB ($10.06 million), the Clean Technology Fund ($0.41 million), and a cash contribution from GDE ($2.01 million).
[b] Physical contingencies are 9% of base costs. Price contingencies use ADB's international and domestic inflation forecasts; includes provision for potential exchange rate fluctuation assuming a purchasing parity exchange rate.
[c] Includes interest during implementation and commitment charges.
Sources: Asian Development Bank and PT Geo Dipa Energi estimates.

Figure 9: Cost Estimate in Indonesia for two 55 MW geothermal plants from Asian Development Bank (2020).

7. Conclusion

The purpose of a workflow is to delineate key steps in a critical path. Geothermal power projects are inherently risky and are typically planned according to each site. This paper presents a common and critical set of inputs, processes, and documents that lead to key decision points for decision makers such as developers, financiers, and stakeholders all while adhering to industry standard practices and current international financing expectations. The five phases: conceptualization, pre-feasibility, feasibility, confirmation, and completion, are organized in a way that allows iterative investment of capital, while mitigating risk, in order to best delineate true reservoir performance and appropriate project design. This five-phase workflow can be applied and adjusted to projects that already have completed portions or entire phases, as well as sites that have had no prior research or exploration completed.

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REFERENCES

Bailey, A., Ohren, M., Balamir, O., and Hernandez J., “Cross-Functional Teams for Planning and Monitoring Drilling Projects”, *GRC Transactions, Vol. 36,* Nevada, USA (2012)

Basosi R., Bonciani, R., Frosali, D., Giampaolo, M., Parisi, M.L., and Sansone, F., “Life Cycle Analysis of a Geothermal Power Plant: Comparison of the Environmental Performance with Other Renewable Energy Systems”, *Multidisciplinary Digital Publishing Institute*, Italy (2020)

Beckers, K., and Young, K., “Technical Requirements for Geothermal Resource Confirmation” *GRC Transactions, Vol. 42, Geothermal Resources Conference,* Nevada, USA (2018)

Cline, A., “Prioritization Process Using Delphi Technique: White Paper Background and Motivation”, *for Carolla Development* (2000)

Dewhurst, W. “Geothermal Development Facility for Latin America Developer’s Manual, Version 25.0” *7th Call of the GDF*, Virginia, USA (2022)

Gehringer, M., and Loksha, V., “Geothermal Handbook: Planning and Financing Power Generation”, *Energy Sector Management Assistance Program (ESMAP) Technical Report 002/12,* Washington D.C., USA (2012)

Hickson, C.J. and Yehia, R. “The Geothermal exploration and development process: graphical representation path to optimal decision making” *In Geothermal Resources Council, Transactions, Volume 38, 2014, pp. 377-380.* Available from https://publications.mygeoenergynow.org/grc/1033563.pdf

K.M. Mackenzie, G.N.H. Ussher, R.B. Libbey, P.F. Quinlivan, J.U. Dacanay and I. Bogie, “Use of Deep Slimhole Drilling for Geothermal Exploration” *In Proceedings The 5th Indonesia International Geothermal Convention & Exhibition (IIGCE)*, Jakarta, Indonesia (2017)

Saeed A.M., Subramaniam, R., Jeffries, A., Wicklein, W., “Proposed Loan and Administration of Loan PT Geo Dipa Energi Geothermal Power Generation Project (Guaranteed by the Republic of Indonesia)” *Asian Development Bank (ADB) Report and Recommendation of the President to the Board of Directors-Project Number 52282-001*, Jakarta, Indonesia (2020)

Sulivan, J.L., Clark, C.E., Han, J., and Wang, M., “Life-Cycle Analysis Results of Geothermal Systems in Comparison to Other Power Systems” *Center for Transportation Research, Energy Systems Division, Argonne National Laboratory,* Tennessee, USA (2010)

White, P., MacKenzie, K., Verghese, K., Hickson, C.J. “Deep slim hole drilling for geothermal exploration” *In Geothermal Resources Council, Transactions, Volume 34, 2010, pp. 269-272. Available from* https://publications.mygeoenergynow.org/grc/1028656.pdf