# A Global Perspective on Aligning Resource Assessment, Technological Evaluation, and Financial Analysis for Geothermal Project Development

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## ABSTRACT

Geothermal energy plays a pivotal role in the renewable energy landscape by providing reliable baseload power and a consistent heat source, unlike other renewable technologies that are affected by seasonal fluctuations and market variations. This paper explores the diverse applications of geothermal resources, highlighting their potential to create new economic sectors and boost existing markets. It analyzes and compares project development factors in geothermal power generation and direct-use heat application, such as techno-economic assessment, risk management strategy and economic outcome, which focuses on conducting comprehensive geothermal resource assessments and evaluating system compatibility based on temperature, depth, and permeability. It also addresses the financial considerations between geothermal power and direct-use projects, emphasizing the importance of pre-feasibility and feasibility studies to inform decision-making. Furthermore, it discusses the unique risks associated with legacy and next-generation geothermal power generation technologies, which persist throughout the project lifecycle.

This paper draws from a selection of projects in the Asia-Pacific, Africa and Europe regions for geothermal direct-use applications such as heating for chicken broiler sheds, barramundi aquaculture, greenhouse, wellness bathing, malting plants, space heating and cooling, and heat storage in aquifers. These are presented as a comparative case study with the global geothermal power industry experience, offering a decision-making framework for practical and actionable insights to stakeholders seeking geothermal energy solutions.

**Keywords:** Geothermal resource assessment, project development, geothermal applications, decision-making, geothermal energy solutions

## 1. INTRODUCTION

Geothermal energy is a reliable resource that can be economically installed and indefinitely maintained as proven by legacy geothermal fields located in various regions worldwide. It is currently an emerging contributor to the global energy transition initiative due to its exceptional ability to provide baseload power generation and direct-use heat applications, whether the resource is situated in a volcanic or sedimentary geothermal system (Figure 1).

However, geothermal project development is unique as the diversity of geothermal resources require extensive studies to integrate technical and commercial considerations in concluding feasibility for sustainable and renewable geothermal energy exploitation (DiPippo, Gutiérrez-Negrin, & Chiasson, 2025).

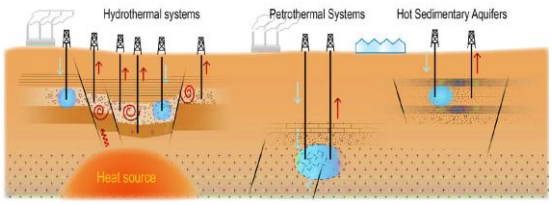



**Figure 1: Representation of geothermal systems according to resource temperature, depth and permeability (Buijze, et al., 2019).**

Though specified for geothermal power projects, the recommended framework of the World Bank Group's Energy Sector Management Assistance Program (ESMAP) in 2021 for conducting a holistic feasibility study is based on documented global industry experience that can also be applied with geothermal direct-use projects. It emphasizes the use of reliable data to identify a project's potential and strategy, minimizing risks and maximizing opportunities for return of investment.

While the geothermal direct-use projects mentioned in this paper are specific to JRG Energy Consultants, the objective is to provide a comparative case study with the global experience in geothermal power project development. This will align geothermal resource assessment, technological evaluation and financial analysis, which are critical steps for stakeholders to make informed decisions in investing to advance geothermal deployment.

## 2. METHODOLOGY

This paper adopts a comparative case study approach using geothermal projects across multiple regions, particularly in Asia-Pacific, Africa, and Europe. The study starts with a review of project documentation to check available information, followed by a comparative analysis highlighting the commonalities and differences in the expectations for techno-economic assessments, risk management strategies and economic outcomes. Lastly, the case study involving a diverse range of geothermal applications derives insights to conclude best practices and a decision-making framework aimed at aligning resource assessment, technological evaluation and financial analysis for geothermal project development (Figure 2).

For the purpose of conducting the comparative case study, geothermal direct-use projects of JRG Energy Consultants are selected and analyzed. While kept anonymous for confidentiality, these projects are compared with the global geothermal power industry practice referencing ESMAP (2021), IRENA and IGA (2023), and DiPippo, Gutiérrez-Negrin and Chiasson (2025).

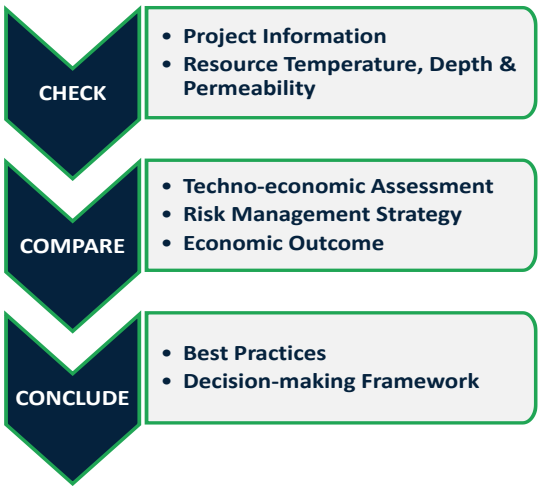



**Figure 2: Approach for comparing resource assessment, technological evaluation and financial analysis in geothermal projects.**

## 3. CASE STUDY

Geothermal power and direct-use projects should meet some criteria, which vary depending on the intended application or utilization based on key factors such as geothermal resource temperature, depth and permeability (Table 1). In general, geothermal energy project development starts with exploration and confirmation of the potential resource. These are the stages where risk levels are considered significant against the costs, which could either slow down or halt the project.

Even with a proven geothermal resource, risks and uncertainties could still be passed on during production if these were not addressed during the early development stage. A discussion on this can be referenced from the dissertation of Brémaud (2025), wherein a global database of hot sedimentary aquifer geothermal projects was studied for de-risking future projects by determining key success and failure criteria. Results of the study show that substantial risks could still remain during the production period, particularly for hot sedimentary aquifer projects.

Whether the geothermal project is for power generation or direct-use heat application, resource risk mitigation can be approached by the following – (1) involving the public sector to help absorb drilling costs, (2) adopting a risk insurance mechanism to motivate validation efforts toward increasing the success rate of geothermal wells, and (3) implement early-stage fiscal incentives to promote geothermal development (Sanyal, Robertson-Tait, Jayawardena, Huttrer, & Berman, 2016).

**Table 1: General criteria for geothermal utilization.**

| Parameter | Power | Direct-use |
|---|---|---|
| Temperature | Suitable for commercial-scale utilization | Sufficient to reach the system's required process temperature and acceptable performance |
| Depth | Accessible by drilling rig to reach the target temperature | Accessible by drilling rig to reach the host reservoir |
| Permeability | Available to produce economical flow rates at a given fluid temperature | Conducive to fluid flow without requiring excessive consumption of electricity as parasitic load |

### 3.1 Geothermal Power

Various technologies have been made available for converting geothermal energy to electricity, including subsurface innovations that can successfully extract heat from different types of geothermal systems. According to a global geothermal market and technology assessment report in 2023, resource temperature as low as 150°C can be considered for commercial-scale power generation but may be found in deep sedimentary basins if not within areas where tectonic and volcanic activities are present. Figure 3 shows a map of geothermal areas within the Pacific Ring of Fire, the mid-Atlantic ridge, some parts of Europe and the East African Rift, which are expected to have resource temperatures favorable for geothermal power development.

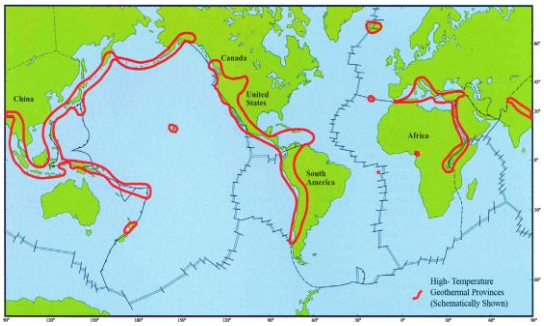



**Figure 3: Regions with high geothermal resource temperatures (DiPippo, Gutiérrez-Negrin, & Chiasson, 2025).**

Conventional or legacy geothermal power generation technologies, such as Dry Steam Plant, Flash Steam Plant and Binary Cycle Plant, utilize geothermal energy by directly producing geothermal fluids from the reservoir and converting the heat to electricity. Emerging or next-generation technologies, such as the Enhanced Geothermal System (EGS), Advanced Geothermal System (AGS) and Supercritical Geothermal System, to improve geothermal energy extraction from the subsurface are currently being evaluated with various studies and pilot projects implemented, proving the concepts towards commercial geothermal energy extraction (IRENA and IGA, 2023).

Though the development and application of both legacy and next-generation geothermal power generation technologies are attracting investments worldwide, the risks unique to the geothermal resource like uncertainty in productivity, potential constraints in scalability and challenges in long-term sustainability are still imminent.

In spite of being able to access depths where both temperature and permeability

are economical through global experts, modern technology and capable drilling rigs, the overall financial viability of geothermal power development remains dependent on resource productivity and how it can be utilized relative to the capital investment. These are driven by the number of wells and the capacity of each well attributed primarily to the flow rate and enthalpy of the geothermal fluids that can be produced from the reservoir. Potential constraints in scalability and the challenges in long-term sustainability are related as there is a need to eliminate first the resource uncertainties. Developing large-scale without thorough understanding of the reservoir's limits may result to pressure drops and reservoir depletion earlier than forecasted, making a geothermal field unsustainable (Gehringer & Loksha, 2012).

### 3.2 Geothermal Direct-use

In some cases, geothermal direct-use applications can present a more economical business case even when power generation is viable. The main applications include space heating and cooling, aquaculture, industrial process heat, and health, recreation and tourism (IRENA and IGA, 2023).

In this paper, the direct-use geothermal applications are represented by some of the projects undertaken by JRG Energy Consultants worldwide (Table 2). Most of these projects are in sedimentary geothermal systems with resource temperatures varying from 15°C to 92°C, except for those identified to be in the volcanic geothermal systems such as New Zealand and Kenya where the resource temperatures could be as low as 150°C.

Based on the scope of work, critical tasks delivered were geothermal resource assessment, technology evaluation, reservoir modelling and financial analysis. In some projects, the scope of work specified by clients includes social, environmental, market and legal aspects as part of the factors to consider with the resource assessment.

**Table 2: Selected geothermal direct-use projects.**

| Application | Location | Scope of Work |
|---|---|---|
| Heating for Chicken Broiler Shed | New Zealand | Feasibility study |
| Barramundi Aquaculture | Australia | Detailed feasibility study supported by reservoir modelling |
| Heating for a Malting Plant | Australia | Detailed feasibility study |
| Greenhouse and Aquaculture | Australia | Feasibility study |
| Wellness Bathing | Kenya | Detailed feasibility study |
| Technology Appraisal for Space Heating and Cooling | London | Feasibility study |
| Aquifer Thermal Energy Storage (ATES) | France | Detailed feasibility study supported by reservoir modelling |

## 4. RESULTS

The project development factors, such as techno-economic assessment, risk management strategy and economic outcome, are rather similar and different for geothermal power generation and direct-use heat application projects (Table 3). They are similar because the primary consideration is the geothermal resource, which directly relates to future risk mitigation measures and financial requirements. The difference is attributed to how the geothermal resource is accessed to produce at commercial level.

**Table 3: Comparative analysis of project development factors between geothermal power and direct-use.**

| Factor | Power | Direct-use |
|---|---|---|
| Techno-economic Assessment | Geothermal system conceptual model, reserves estimate, reservoir model, market forecast | Geothermal installation conceptual model, wellbore model, energy loads analysis |
| Risk Management Strategy | Well drilling and testing, reservoir modelling, feasibility study | Hydro-geological assessment, reservoir modelling, system modelling, feasibility study |
| Economic Outcome | Payback period from electricity sales | Payback period from energy sales (e.g., heating); or<br><br>Savings vs. existing or alternative energy source (e.g., natural gas) |

For example, geothermal direct-use projects usually require pumping to extract more fluids with a relatively lower temperature to attain the energy demand requirements while geothermal power projects generally require drilling to greater depths where both the temperature and permeability are economical. With this comparative analysis, a general decision-making framework that can be adopted for both geothermal power generation and direct-use heat applications when conducting techno-economic assessment, planning for the risk management strategy and predicting the economic outcome is proposed (Figure 4).

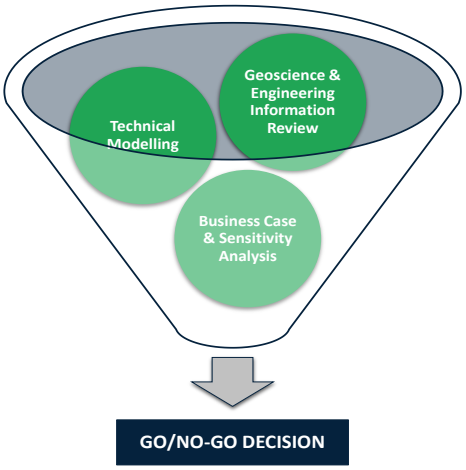



**Figure 4: Decision-making framework for geothermal project development.**

Elements of the proposed framework are described below:

- The **Geoscience & Engineering Information Review** facilitates a thorough understanding of the geothermal field, including the resource parameters and site settings to assess a suitable geothermal technology that can be installed (e.g., flash plant for power generation, ground source heat pump for direct-use).
- **Technical Modelling** refers to either creating a reservoir model or geothermal system model. The former is applicable to both power

and direct-use projects, while the latter is more targeted to direct-use heat applications wherein an integrated model of the borehole and surface system is built to understand compatibility and operational scenarios for optimum efficiency.

- Before a final decision is made, **Business Case & Sensitivity Analysis** is done to forecast the potential return on investment and payback period considering various scenarios and financial factors (e.g., taxation, incentives, funding).

## 5. CONCLUSIONS

Geothermal resource assessment, technological evaluation and financial analysis are key elements of geothermal project development, both for power generation and direct-use heat applications. Though power generation is the forefront of geothermal energy utilization, direct-use heat applications have the potential commercial value that can also be realized worldwide by applying the same project development principles. The difference in approach between these projects can be streamlined with a general framework outlining the decision-making requirements. It can be summarized to – (1) understanding the geothermal resource, (2) simulating the operational possibilities from various scenarios, and (3) predicting the future financial benefits given the potential risks that may be encountered throughout the project lifecycle.

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