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# A Screening Methodology for the Optimal Selection of AL Methods for Geothermal Wells

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## ABSTRACT

Well-flow rates significantly influence the economic viability of geothermal projects. Geothermal wells targeting natural fractures typically yield high flow rates; however, the production performance of these wells can substantially decline over time. Artificial lift (AL) methods, including gas lift (GL) and downhole pumps such as Electrical Submersible Pumps (ESPs) and line shaft pumps (LSPs), are effectively used to compensate for production losses in geothermal wells. This study presents a screening and decision-making methodology to determine the most suitable AL method for geothermal wells with different characteristics, considering a techno-economic analysis of the various lift methods. A Python script was developed to automate the selection of an optimal AL method using a structured decision-making approach including Boolean logic analysis and Multicriteria Decision Analysis (MCDA) methods.

## 1. INTRODUCTION

Geothermal energy is considered a clean and renewable energy resource. Especially geothermal energy usage for electricity generation and heating are two main applications worldwide. In terms of electricity generation and heating, its usage might increase by 100 to 210 TWh and 880-1050 TWh by 2050, respectively (Khanmohammadi et al., 2025). USA, Indonesia, Philippines, Turkiye, and New Zealand are the leading countries with installed geothermal power generation capacity (3937 MW, 2653 MW, 1984 MW, 1734 MW, and 1207 MW, respectively according to the 2024 data) (Cariaga, 2025).

Geothermal projects rely on high flow deliverability and the sustainability of flow rates over the production period. A decline in production naturally occurs in all hydrocarbon and geothermal reservoirs. To compensate for this loss, artificial lift (AL) methods have become essential in geothermal fields. Various techniques are employed to enhance the extraction of hot water and steam from geothermal wells, ensuring that the plant operates at its full potential. Among the most commonly used AL systems as shown in Fig.1 are line-shaft pumps (LSP) and electrical submersible pumps (ESP), which help maintain the required production rates by lifting geothermal fluids from deep underground. Additionally, gas lift (GL) methods can be utilized to improve flow by injecting gas into the wellbore, reducing the fluid density and facilitating upward movement (Aydin et al., 2021; Kaya and Mertoglu, 2005; Niewold, 2017; Prabowo et al., 2021). Implementing these AL technologies allows geothermal power plants to optimize resource utilization, prolong reservoir lifespan, and maintain steady energy production, ultimately supporting the long-term sustainability of geothermal energy.

Drilling make-up wells is typically preferred at the beginning of field exploitation when reservoir energy is sufficiently high to support production wells with artesian flow. As reservoir energy decreases due to the decline in reservoir pressure, temperature, and non-condensable gas (NCG) content, the production performance of the wells is significantly reduced, and they eventually become non-artesian (Malatinszky and Marcu, 2022). Drilling new wells is costly and technically risky, particularly in heterogeneous geothermal reservoirs where uncertainty is significant. On the other hand, AL is an engineering solution that involves minimal risks and offers a higher likelihood of successful results.

LSP, ESP, and GL systems are different than each other in many aspects as shown in Figure 1. LSPs are powered by a long shaft connected to a motor at the wellhead (Figure 1-a), whereas ESPs use an electric motor and pump assembly installed inside the well (Aksoy, 2007; Kaya and Mertoglu, 2005). An ESP system consists of an electric motor, motor protector, pump sections, power cables, and gas-handling equipment (Figure 1-b), working together to lift geothermal or oil reservoir fluids to the surface (Takacs, 2009). Recent advancements, such as permanent magnet motors (PMMs) with heat-resistant components and improved motor cooling techniques, enhance ESP reliability in high-temperature geothermal wells, offering increased efficiency and durability (Aydin and Merey, 2021). GL systems (Figure 1-c) use compressed gas injected through the casing-tubing annulus or coiled tubing to aerate and lighten the fluid column, reducing its density and facilitating its flow to the surface. The system includes a gas compression unit, tubing string, unloading, and operating valves, and a downhole chamber, with continuous or intermittent gas injection controlled by strategically placed valves to optimize lift efficiency and well performance (Aydin and Merey, 2024; Erwandi et al., 2019; Guo et al., 2007).

Each AL technique has its advantages and disadvantages. As technology advances, some of these drawbacks may be eliminated. For instance, ESPs in geothermal wells previously struggled with high temperatures and short-run lives. However, over the past five years, ESPs have become much more viable for geothermal applications, offering higher temperature tolerance and longer operational lifespans compared to five years ago. For example, Aydin and Merey (2021) investigated the application of ESP systems in a geothermal well in the Alasehir field, Western Turkey, using Python-based ESP design and WELBOR wellbore simulations to analyze production sensitivities, ultimately finding that the ESP increases production by 165 tons/hour and remains economically viable for at least eight months. The primary motivation in this field was to enhance steam production to meet the capacity of the Alasehir geothermal power plant after declining reservoir pressure, and non-condensable gas % (NCG). Alternatively to ESP, the GL option in the Alasehir geothermal power plant was also investigated by Aydin and Merey (2024) and they concluded that GL might be an alternative to downhole pumps for enhancing production in geothermal wells with low gas content and pressure, analyzing the influence of design parameters such as injection depth, rates, tubing size, and gas type on production performance. The electrical submersible pump (ESP) plays a crucial role in transporting hot geothermal brine in low-enthalpy geothermal wells, but its reliability often falls short due to suboptimal design, installation, and operation, leading to failures and shorter-than-expected lifetimes. Omrani et al. (2021) discussed typical conditions and reliability challenges in low-enthalpy geothermal systems, particularly in the Netherlands, and emphasized the need for further research, improved monitoring, and testing to enhance the reliability and design of geothermal ESP systems. According to Yearsley (2023), in pumped-well geothermal projects, LSPs are commonly used in shallower wells, while ESPs are needed for deeper wells where LSPs cannot be applied. Both pump types increase pressure to maintain the geothermal fluid in a single phase and provide the necessary flow rate, with pump depth and design influenced by factors such as temperature, productivity index (PI), and preventing cavitation by maintaining pressure above the fluid's vapor pressure. Erwandi et al. (2019) applied the nitrogen ($N_2$) lift method for discharging a deviated (43.1°) geothermal well. While coiled tubing $N_2$ lift is a widely used method for discharging geothermal wells (Aydin and Merey, 2024; Buiiing et al., 1998), the use of GL with a valve system, as shown in Fig. 1-c, is not typically applied in geothermal applications. GL with a valve system is more commonly seen in oil and gas operations but has not yet become a standard practice in geothermal wells due to the unique challenges and conditions associated with geothermal reservoirs. However, its potential for improving well performance and enhancing production makes it an interesting area for further exploration and application in the geothermal industry.

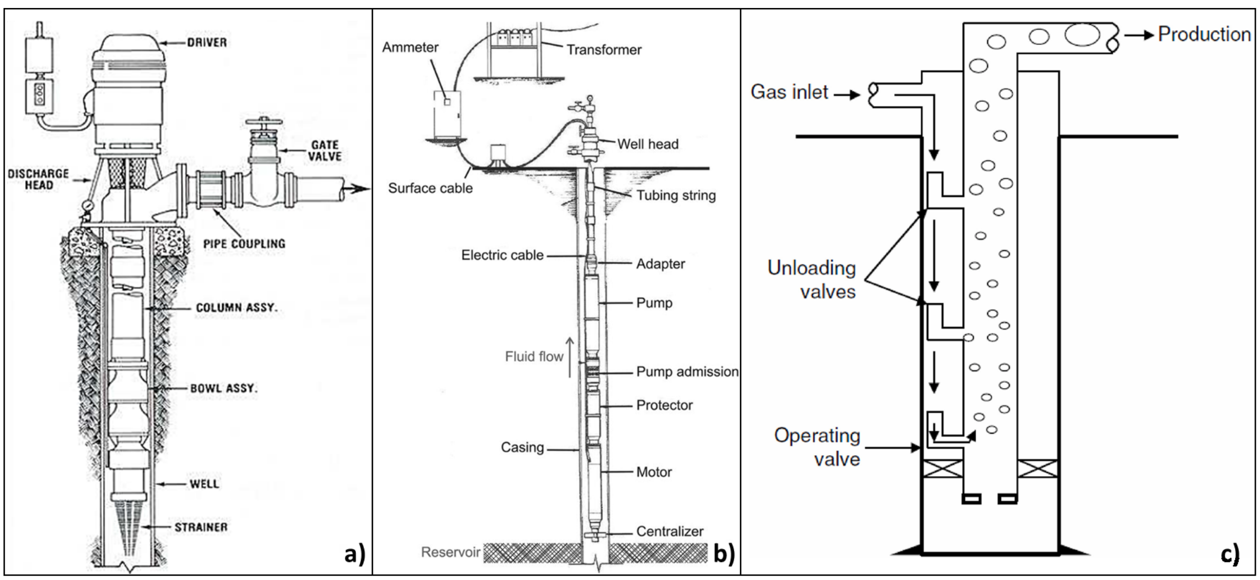


**Figure 1: Configuration of a typical a) LSP well (Kaya and Mertoglu, 2005) b) ESP well (Romero and Hupp, 2014) c) GL well (Guo et al., 2007)**

The pump selection and design process require several crucial data sets, including the production history of the field, casing, and tubing sizes, perforation depth, planned pump setting depth, desired wellhead pressure, target production rate, non-condensable gas (NCG) percentage, reservoir and pump setting depth temperatures, fluid properties, pump costs, and other related costs for a comprehensive feasibility study. Pump screening criteria were constructed oil and gas industry many decades ago. However, especially for the geothermal energy sector, there is a need for AL screening. Malatinszky and Marcu (2022) proposed a Boolean logic-based application that quickly screens and selects the optimal lift technique by comparing well data, displaying results with method advantages and disadvantages for the oil industry. A screening process evaluated AL methods for a declining reservoir, concluding that only ESP and GL were feasible, with integrated modeling predicting their long-term performance. Sarvestani and Hadipour (2019)'s AL screening study in the field (in the south-west of Iran near Persian-Gulf) found that GL achieved the highest oil recovery (134 MMSTB in 10 years), followed by ESP (112 MMSTB), while natural depletion yielded the lowest recovery (13 MMSTB). Ejim and Xiao (2020) review and rank 19 AL methods for unloading liquids in unconventional gas wells, identifying GL variants and plunger lift systems as the most effective solutions. Their screening process considered factors like depth, temperature, production rate, and economics, providing a guideline for field engineers to select the most suitable method. Mahdi et al. (2023) proposed a machine learning-based model for AL selection using Sudanese oil field data, achieving 93% accuracy and outperforming actual field selections. Valbuena et al. (2016) proposed a methodology for selecting the most suitable AL technique for horizontal wells by considering technical limitations, suitability coefficients, and economic analysis, using an attribute matrix and cost breakdown, with a field example demonstrating its application.

**Table 1: SWOT matrix (modified after Aziz, 2021)**

| | **Strengths (S)** | **Weaknesses (W)** |
|---|---|---|
| **Opportunities (O)** | Evaluation of internal strengths to take advantage of external opportunities (SO) | Addressing of internal weaknesses that prevent benefiting from external opportunities (WO) |
| **Threats (T)** | Evaluation of internal strengths to minimize the impact of external threats (ST) | Addressing internal weaknesses that will turn threats into a reality (WT) |

**Table 2: SWOT analysis of LSP, ESP, and GL (Aksoy, 2007; Aydin and Merey, 2021; Aydin et al., 2021; Aydin and Merey, 2024; Curkan et al., 2018; Kaya and Mertoglu, 2005; Mubarok and Zarrouk, 2017)**

| Method | Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|---|
| LSP | -Long-time experience in geothermal wells<br>-No electric part in the wellbore<br>- Higher efficiency<br>- Lower power loss<br>- Longer run life<br>- High flow rate capacity in large diameter-production casing (i.e., 13-3/8 in) | -Limited to shallow installation depths<br>-Cannot be installed in deviated wells<br>-Longer installation and workover time<br>-Less accessible for purchase and services<br>-Higher CapEx and OpEx than GL | -Technological advancements in materials and design<br>-Cost reduction with implementation of technological advancements (to decrease scaling/corrosion/wear/tear)<br>-Supplying auxiliary consumption from other renewable energy resources (i.e., solar, wind) | -Wear and tear (i.e., shaft, impeller) due to solids or gas production or harsh reservoir conditions.<br>-Scaling/ corrosion due to minerals/chemicals in geothermal fluids<br>-Competition from other technologies (such as ESP and GL) |
| ESP | -Installation to greater depths<br>-Can be installed in deviated wells<br>-Shorter installation and workover time<br>-Widely accessible for purchase and services<br>- High flow rate capacity in large diameter-production casing (i.e., 13-3/8 in) | -Complex infrastructure<br>-Sensitive to gas production<br>-Higher power loss<br>-Higher CapEx and OpEx than LSP and GL<br>- Immature technology for geothermal wells<br>- Shorter run life compared to other AL methods<br>- Power cable inside the wellbore<br>- Lower efficiency | -Technological advancements in materials and design<br>-Cost reduction with implementation of technological advancements (to decrease scaling/corrosion/wear/tear risks)<br>- Integration with other techniques (GL) to boost the production<br>- Supplying auxiliary consumption from other renewable energy resources (i.e., solar, wind) | -Significant energy consumption<br>-Wear and tear (i.e., impeller) due to solids or gas production or harsh reservoir conditions<br>-Scaling/corrosion due to minerals/chemicals in geothermal fluids<br>-Competition from other technologies (such as GL and LSP) |
| GL | -Suitable for wells with high gas-liquid ratios<br>-Tolerates high gas interference<br>- Cost-effective compared to ESP and LSP<br>- Can be applied to deep and deviated wells<br>-No mechanical moving parts downhole<br>-Proven success in geothermal wells using $N_2$ lift | -Requires continuous or intermittent gas supply<br>-Less effective in wells with low gas content<br>-Temporary intervention rather than a long-term solution<br>-High cost of nitrogen injection<br>-Success rate varies by well conditions | -Technological advancements in materials and design<br>-Integration with other techniques (ESP) to boost the production<br>-Supplying auxiliary consumption from other renewable energy resources (i.e., solar, wind) | -Risk related to gas impurity<br>- Risk of gas leakage<br>-Further increase in gas emissions<br>- Risk of corrosion and flow assurance problems<br>- Risk related to high pressure<br>-Competition from other technologies (such as ESP and LSP) |

The economic feasibility of geothermal projects is highly dependent on the flow rates of the wells. In geothermal systems, wells that target natural fractures often exhibit initially high flow rates due to the increased permeability in these areas. However, over time, particularly following the primary recovery phase and corresponding pressure decline periods, the production capacity of these wells tends to decline significantly, which can impact the overall efficiency and profitability of geothermal operations. To address this issue, AL technologies, such as GL, and various types of downhole pumps like ESPs and LSPs, are commonly employed, which help maintain or enhance flow rates to optimize the production lifespans. The implementation of the optimal AL method (LSP, ESP, GL) is of great importance, which, indeed, is a complex process that involves multiple factors, including technical considerations such as well characteristics, the capabilities and costs of the AL method, application feasibility, and the reliability of the chosen method. At this point, performing a SWOT analysis, which is used to analyze the strengths, weaknesses, opportunities, and threats of business/alternatives (Table 1), would be beneficial in refining AL options.

The SWOT analysis consists of two main components as the analysis of the internal or micro environment (Strengths and Weaknesses) and the external or macro environment (Opportunities and Threats) (Sammut-Bonnici and Galea, 2015; Alacali, 2023). To this end, the strengths, weaknesses, opportunities, and threats of LSP, ESP, and GL have been evaluated as tabulated in Table 2.

In the light of information previously discussed, this study presents a comprehensive screening methodology based on Boolean Logic to narrow down the suitable options for the candidate well. Subsequently, a SWOT analysis is incorporated into Multi-Criteria Decision Analysis (MCDA) to determine the best option, ensuring maximum efficiency from both technical and economic perspectives. A case study is presented from western Anatolia, Turkiye.

The comprehensive screening and decision-making framework is designed to identify the most appropriate AL method for geothermal wells with diverse characteristics. The methodology integrates a techno-economic evaluation of different lift techniques, weighing both their technical feasibility and cost-effectiveness. By considering factors such as well depth, fluid composition, pressure conditions, and economic considerations, this approach aims to guide operators in selecting the most efficient and economically viable AL solution for their geothermal projects. In geothermal companies, there is often a lack of experienced personnel with specialized knowledge in petroleum and geothermal production engineering. As a result, these companies may struggle to make informed decisions about the most appropriate technologies and equipment for their operations. The screening criteria presented in this study can be especially valuable for such organizations, providing a structured approach to selecting the correct type of pump and AL system. By using this framework, geothermal operators can more easily identify and contact the right pump manufacturers or service providers, ensuring they choose the most suitable equipment based on the specific needs of their geothermal wells. This guidance can help bridge the knowledge gap, streamline decision-making processes, and ultimately enhance the efficiency and profitability of geothermal projects.

In Figure 2, the number of geothermal wells utilizing AL methods in geothermal power plants in Turkiye as of 2025 is presented. As shown in this figure, AL methods play a crucial role in meeting the capacity demands of geothermal power plants in Turkiye. The case well in this study was selected from a geothermal field in Turkiye.

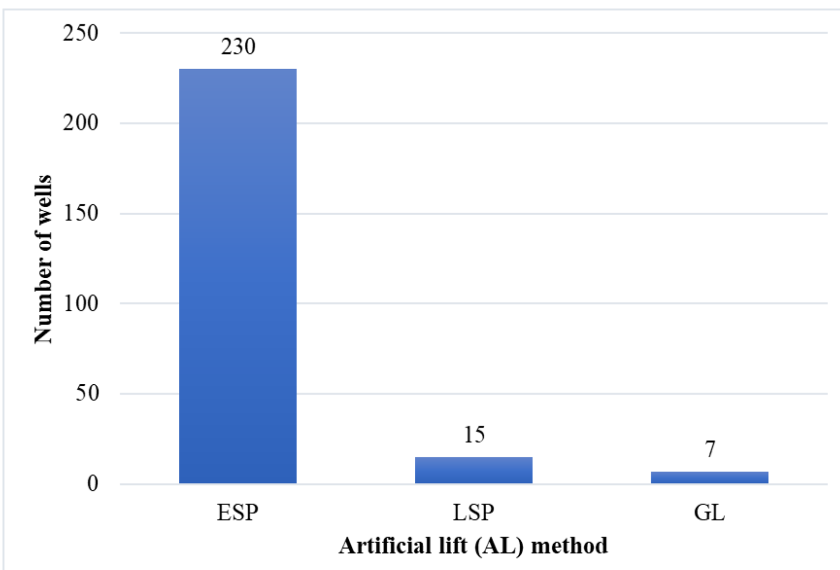


**Figure 2: The number of geothermal wells operating with AL methods in geothermal power plants in Turkiye as of 2025**

## 2. METHODOLOGY

The workflow of this study is illustrated in Figure 3. A Python script was developed to automate the selection of an optimal AL method using a structured decision-making approach. The process begins with user-defined input data to screen potential AL methods, namely ESP, LSP, and GL. Once the input parameters such as installation depth, maximum temperature, flow rate, and well deviation are specified, a Boolean logic approach is applied for the initial screening of AL methods for the candidate well. During the Boolean logic analysis, the characteristic properties of each AL method, as presented in Table 3, were considered. AL methods that pass the Boolean logic screening process are then considered for further technical and economic evaluation. Based on the required flow rate, the technical feasibility and cost of each method are assessed using benchmark systems commonly applied in Western Anatolia, Turkiye. In the final phase, a SWOT analysis is conducted by assigning quantitative values (ranging from 1 to 10) to strengths, weaknesses, opportunities, and threats. In the SWOT analysis, weaknesses and threats are treated as negative factors that reduce the overall SWOT score. The SWOT score is then incorporated into the MCDA framework, which also considers CapEx and OpEx. The final MCDA score is calculated using a weighting system, assigning 0.5 to the SWOT score and -0.3 and -0.2 to CapEx and OpEx, respectively.

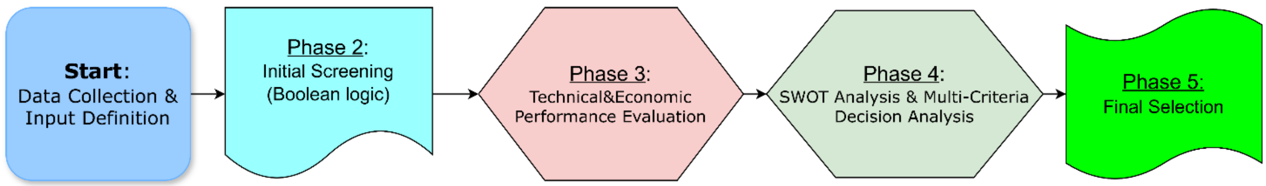


**Figure 3: Workflow of the proposed screening methodology**

**Table 3: Main properties of AL methods (Revised from Malatinszky and Marcu, 2022)**

| | ESP | LSP | GL |
|---|---|---|---|
| **Maximum Depth (m)** | 3000 | 600 | 3000 |
| **Maximum Flow Rate (ton/hr)** | 500 | 800 | 500 |
| **Maximum Temperature (°C)** | 230 | 180 | No limitation |
| **Dogleg (°/30m)** | <2 | <1 | <3 |
| **Efficiency (%)** | 35-60 | 60-80 | 10-30 |
| **Gas Handling** | Fair | Fair | Excellent |
| **Corrosion Handling** | Good | Good | Good |
| **Source of Energy** | Electric | Electric | Gas |
| **Solid handling** | Fair | Fair | Good |

## 3. RESULTS AND DISCUSSIONS

The proposed methodology has been applied to a candidate geothermal well for AL application in Western Anatolia, Turkiye. The candidate well was completed with a 9-5/8 in casing as a liner, hung within a 13 3/8-inch casing as seen in Figure 4. The top of the liner hanger is 375 meters. This configuration allows for the installation of a pump (ESP or LSP) with a large diameter. However, the flashing depth of the well is deeper than 375 meters at a flow rate exceeding 200 tons/hour. Therefore, the flashing depth poses a limitation for large-diameter pumps.

The well is almost vertical, with a dogleg of less than 2 degrees. Its productivity index is very high at 100 tons/hour per bar, and the reservoir pressure gradient is also considerably good at 0.095 bar per meter. The reservoir temperature is 195°C, and the NCG content is 0.35% by weight under reservoir conditions.

The well can produce 250 tons/hour through artesian flow and is planned to increase its flow rate to 350 tons/hour using an AL method. A reservoir temperature of 190°C is a limitation for the LSP in this well, preventing it from passing the Boolean logic test in the first screening analysis.

In the technical and economic analysis of ESP and gas lift, wellbore flow simulation was employed to identify constraints at a flow rate of 350 tons/hour. At the designed flow rate, the flashing depth is approximately 450 meters. A large-size ESP capable of delivering this rate would operate in a two-phase region, which negatively impacts its SWOT score due to the threats and weaknesses associated with ESP deployment in the two-phase depth of the well.

On the other hand, a gas lift does not pose risks related to flashing depth, as it can be easily installed below the flashing depth given the well's casing scheme. Additionally, the CAPEX for ESP in this case is twice as high as that of gas lift.

For the studied well, given its high productivity index, only 400 $m^3$ per hour of nitrogen would be sufficient to achieve the target flow rate of 350 tons/hour. Running the constructed Python code produced Figure 5 and Table 4, which demonstrates that gas lift provides superior results in terms of MCDA scores.

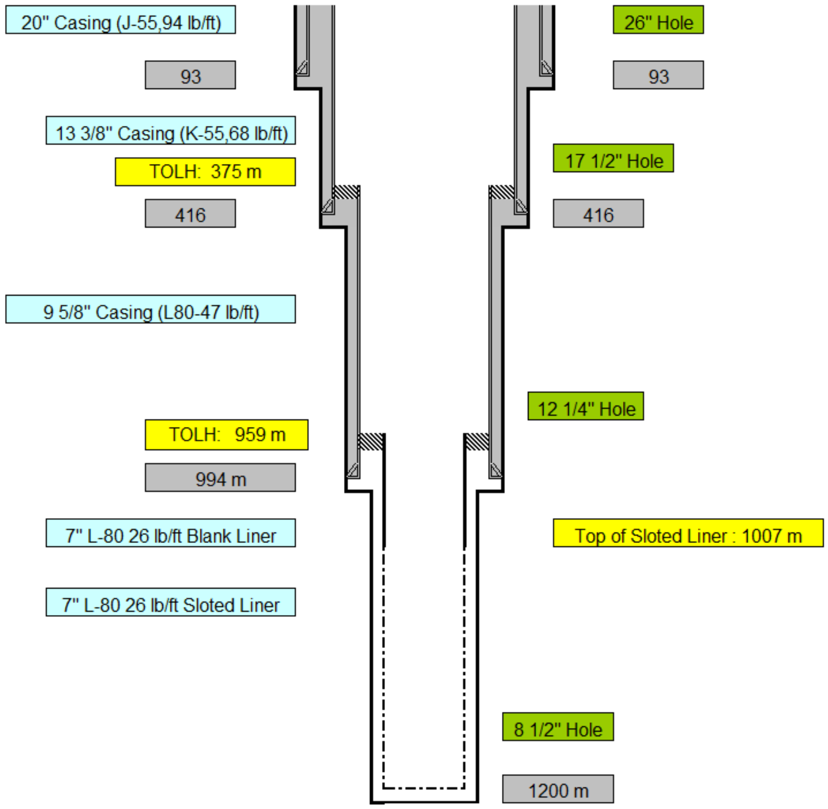


**Figure 4: Casing scheme of the geothermal well for AL screening**

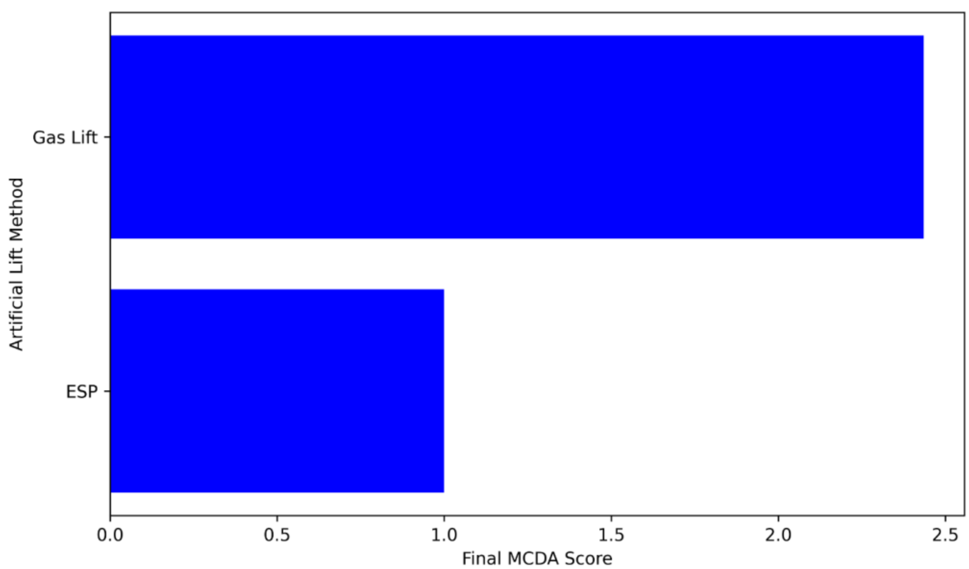


**Figure 5: Final selection of the artificial lift method**

**Table 4: Results of the case study well**

| | ESP | Gas Lift |
|---|---|---|
| **CapEx (M USD)** | 0.75 | 0.4 |
| **OpEx (M USD)** | 0.25 | 0.1 |
| **SWOT Score** | 2.55 | 5.15 |
| **Final MCDA Score** | 1.0 | 2.435 |

The weight of SWOT was 0.5, while the weights for CapEx and OpEx were -0.3 and -0.2, respectively, in the working methodology. Therefore, operating at flashing depth reduced the SWOT score and negatively impacted the overall MCDA score of the ESP option.

## 4. CONCLUSION

This study employed Boolean analysis, SWOT analysis, and MCDA for screening and decision-making in the selection of an artificial lift (AL) method for geothermal wells. The study considers both technical and economic parameters in the screening methodology. Therefore, risks and opportunities are evaluated within a structured decision-making approach. A case study of a geothermal well from western Anatolia, Turkiye, was presented to test the proposed method. Gas lift (GL) was found to be more applicable from both an economic and technical perspective for the selected case well.

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