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Original paper

Investigating the geothermal energy potential of Absheron region for electricity generation using binary cycle technology

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Abstract: Relevance. Geothermal energy offers a clean and sustainable alternative to fossil fuels for electricity and heat generation. This study explores the potential for utilizing geothermal energy alongside existing oil production in the Bibiheybat field, Azerbaijan. **The aim of this work** is to assess the geothermal energy potential of the Bibiheybat field and evaluate its feasibility for electricity generation. **Methods.** The study analyzes well flow rates, temperatures, and pressure distributions within the X stratum of the field. Temperature and pressure distribution models are developed using Surfer software. Geothermal energy potential is calculated based on well data and formula application. Binary cycle technology is proposed for electricity conversion. **Results.** The X stratum exhibits an anticlinal fold structure with varying well depths and temperatures (46-24°C). The geothermal energy potential of the field is estimated at 307,578.56 kWh, with 25,090.15 kWh carried by oil and 282,488.41 kWh by water. Utilizing a binary cycle power plant, approximately 107,652.49 kWh of electrical energy could be generated.

Keywords: geothermal energy, temperature distribution, pressure distribution, geothermal energy potential, binary cycle power plant, electricity generation.

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Оригинальная статья

Исследование геотермального энергетического потенциала Апшеронского района для производства электроэнергии с использованием технологии бинарного цикла

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Резюме: Актуальность работы. Геотермальная энергия представляет собой экологически чистую и устойчивую альтернативу ископаемому топливу для производства электричества и тепла. В данном исследовании рассматривается потенциал использования геотермальной энергии наряду с существующей добычей нефти на месторождении Бибихейбат, Азербайджан. **Целью данной работы** является оценка геотермального энергетического потенциала месторождения Бибихейбат и его целесообразности для производства электроэнергии. **Методы.** В исследовании анализируются дебиты скважин, температура и распределение давления в пласте X месторождения. Модели распределения температуры и давления разработаны с помощью программы Surfer. Потенциал геотермальной энергии рассчитан с применением формул на основе данных скважин. Для преобразования электроэнергии предложена технология бинарного цикла. **Результаты.** Пласт X демонстрирует антиклинальную складчатую структуру с различной глубиной скважин и температурой (24–46°C). Геотермальный энергетический потенциал месторождения оценивается в 307578,56 кВт ч, из которых 25090,15 кВт ч приходится на нефть, а 282488,41 кВт ч – на воду. При использовании электростанции бинарного цикла может быть выработано около 107652,49 кВт ч электроэнергии.

Ключевые слова: геотермальная энергия, распределение температуры, распределение давления, потенциал геотермальной энергии, электростанция бинарного цикла, производство электроэнергии.

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Introduction

Geothermal power plants. Geothermal energy is a renewable source of electricity and heat that can meet base load demand. As a result, they can help reduce greenhouse gas emissions by replacing fossil fuel energy sources in heat and electricity generation [Ugochukwu, 2013; European Commission, 2012; Quick et al., 2010; Lundin et al., 2014]. The potential for geothermal energy is enormous, as 99% of the Earth's surface is hotter than 1,000°C and 99% of the remaining 1% has temperatures above 100 ◦C [Quick et al., 2010]. Thermal energy stored beneath the Earth's crust has the potential to supply all of humanity's energy needs today [Koroneos et al., 2013]. The most appealing aspect of geothermal power plants is their high dependability and ability to run at high load and capacity factors, with system reliability averaging 95% and an average load factor of more than 95% [Kabeyi et al., 2021a; Kabeyi, 2019]. However, geothermal power plants account for less than 1% of worldwide electrical capacity and have a much slower rate of capacity expansion than other renewable energy sources [Kabeyi et al., 2020a; Kabeyi et al., 2020c]. For example, between 2005 and 2020, average annual capacity growth was only 4.01% [Kabeyi et al., 2021a; Kabeyi, 2019]. High temperature and enthalpy geothermal resources can be utilized to generate energy, but they require the extraction of geothermal fluid from depths typically greater than 3 kilometers beneath the Earth's crust. The conversion technology varies from steam field to steam field, and in the case of wellhead power generation, it may differ from well to well, depending on well characteristics and use.

Following the successful drilling and testing of an exploratory well, a decision must be taken regarding the number of production wells to be dug in a specific geothermal steam field to completely exploit the available resource. In a vapor-dominated geothermal system, producing wells are drilled, tested, and connected to a common power plant via a network of insulated steam pipes to supply steam to the power plant. According to output well capacity, tens of geothermal wells may be linked to a line for a 50-55 MW unit, with one or two more wells kept on standby [Windrem et al., 1982]. Drilling wells is costly and time-consuming because wells are frequently drilled one or more at a time, depending on the number of drilling rigs [Ahmadi et al., 2020]. This frequently results in successfully dug and tested geothermal wells sitting idle while other wells required to maintain central power plant operations are completed [Kabeyi et al., 2020a; Kabeyi et al., 2020b]. This provides an opportunity to establish a temporary wellhead power plant.

Material and methods

Geothermal conversion technologies. There are three types of geothermal power plants based on thermodynamic cycles and conversion technology. These include dry steam power plants, flash power plants, and binary, hybrid, or combination cycle power plants. The geothermal fluid parameters dictate the conversion method used [Cao et al., 2021]. The conversion technologies used are common to both central and wellhead power plants [Kabeyi et al., 2020a; Kabeyi, 2019; Cao et al., 2021]. Geothermal resources are classified into three categories: high temperature (>150°C), medium temperature (90°C to 150°C), and low temperature (<90°C) [Cao et al., 2021]. Over 70% of global geothermal resources are in the form of low-enthalpy geothermal fluid. Organic Rankine cycles (ORC) technologies are widely used to convert low-temperature geothermal energy to electricity [Bruhn et al., 1999; Liu et al., 2016; Islamzade, Mammadov, 2023].

The thermodynamic parameters of the steam or geothermal fluid are used to determine technology selection [DiPippo et al., 2007]. The thermodynamic parameters of the resource, particularly temperature, determine its application and energy conversion technique. Non-electrical applications can employ geothermal resources at temperatures ranging from 40°C to 180°C (100-350°F) depending on the application [Windrem et al., 1982; Kabeyi et al., 2021b]. Conventional Rankine cycle steam turbines typically operate above 180°C (350°F). The operational design of geothermal power plants is similar to that of fossil fuel and nuclear power plants, both of which use the Rankine cycle, with the exception of the heat source, which is geothermal fluid from the earth transported by production wells and a system of pipes [Dincer et al., 2020].

Binary power plants. Binary and Kalina cycles are mostly employed to convert medium-low temperature geothermal resources to electricity [Meng et al., 2020]. In a closed loop cycle, binary cycles use two fluids: geothermal resource fluid and organic fluid [Kabeyi, 2019]. The geothermal fluid passes via a heat exchanger, which transfers heat to a low-temperature boiling fluid that serves as a working fluid [Kabeyi et al., 2020a]. The working fluid vaporizes and expands through a turbine, which rotates and turns a generator to produce electricity. The working fluid is then condensed and circulated through the heat exchanger multiple times. The geothermal fluid that exits the heat exchanger in a single pass is frequently reinjected back into the reservoir [Windrem et al., 1982]. The organic Rankine cycle has been recognized as the optimal cycle for low-temperature thermal energy sources [Herath et al., 2020; Kabeyi, 2020].

Geothermal power plants use various binary cycles depending on the working fluid. They are divided into Organic Rankine cycles, which employ refrigerants or organic fluids, and Kalina and Goswami cycles, which use ammonia mixes [DiPippo et al., 2007]. In organic Rankine power plants, the geothermal fluid heats and pressurizes a secondary fluid with a low boiling temperature and pressure, such as penta-fluoropropane and isobutane, which is typically in a closed cycle with no mixing.

Binary plants are designed to run on two thermodynamic cycles, a geothermal fluid loop and a power cycle loop, and are categorized as organic Rankine Cycle plants or Kalina plants depending on the working fluid [Bonalumi et al., 2017]. Kalina cycles, which use a working fluid of 70% ammonia and 30% water, have a better efficiency and exergy potential than Organic Rankine cycles [Koroneos et al., 2013]. The Kalina cycle is a modified Rankine cycle that incorporates a distillation separator and an absorption recuperator. Alex Kalina invented the cycle back in the 1980s. These power plants are more secure, have fewer capital costs, and are simpler, with applications ranging from 50 to 100 megawatts [Marugun et al., 2008; Shehata, 2019].

Advanced types of organic Rankine cycles include the organic flash, regenerative, and supercritical cycles.

Geothermal energy potential of Absheron oil and gas region

Geothermal energy utilization is critical, as is the exploitation of oil resources near the border. To evaluate geothermal energy potential, it's important to measure the flow rate and temperature of fluids (oil, water, gas) exiting wells in the area.

Determining the distribution of pressure and temperature relative to the X stratum is also a critical challenge in the field. To accomplish this, it would be appropriate to first investigate the depth structure of the Bibiheybat deposit in relation to the X stratum.

A two-dimensional and three-dimensional model of the area was created to visually observe the depth structure of the Bibiheybat field X layer and obtain more detailed information about it. These models were created using the Surfer application after examining the wells' coordinates and depth (in m).

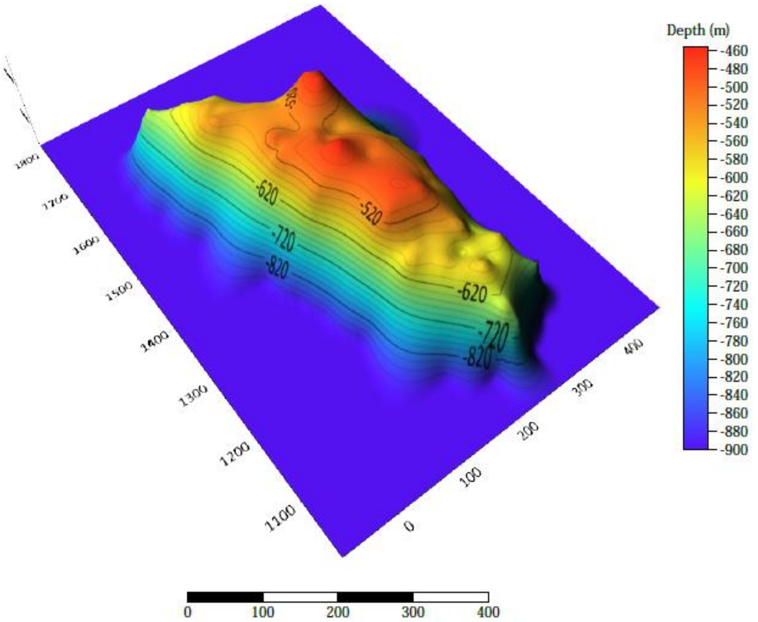


Fig. 1. Three-dimensional model of the depth structure of the Bibiheybat deposit

If we examine the three-dimensional model, we can see that the X layer is geologically an anticlinal fold. Wells here range in depth from 450 to 670 meters.

Looking at the two-dimensional model, we recognize that the X strata is an anticlinal fold.

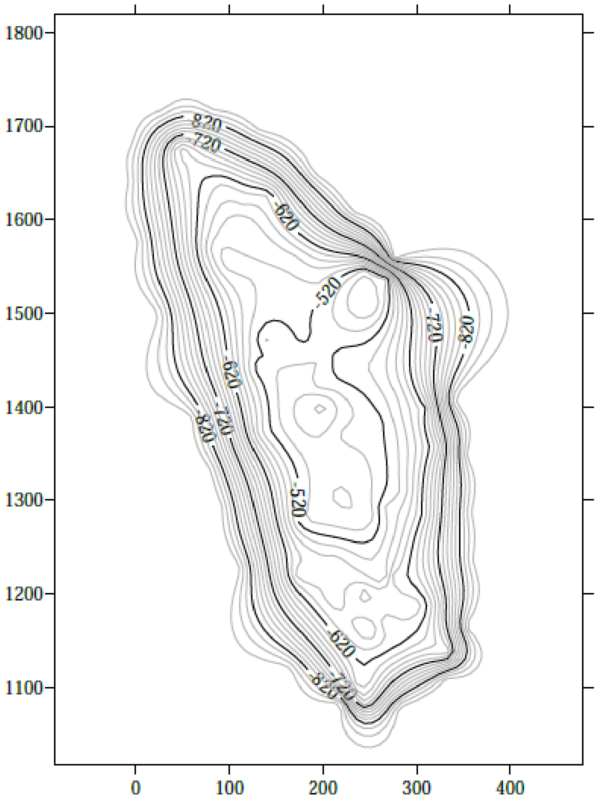


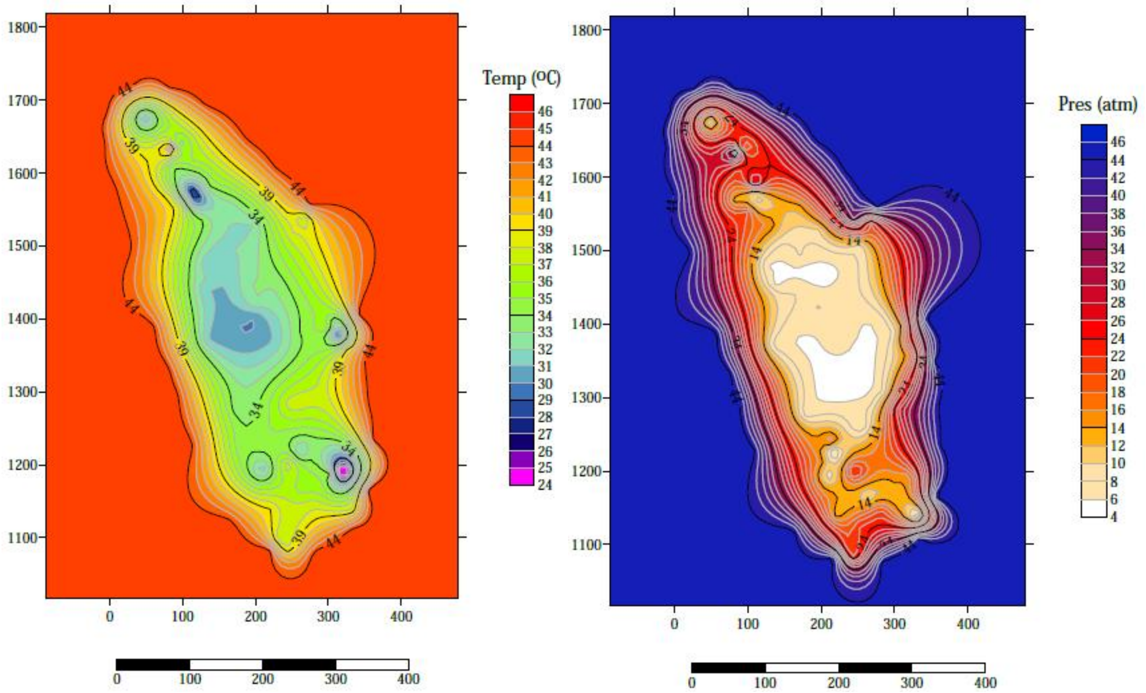
Fig. 2. Two-dimensional model of the depth structure of the Bibiheybat deposit

In general, in order to evaluate the potential of geothermal energy available throughout the field, the flow rate and temperature of the fluid (oil, water, gas) retrieved from the wells must be determined.

In this process, we will need to determine the temperature and pressure measurements for each well, which are calculated and recorded in the Bibiheybat Scientific-Research and Production Department's monthly reports. The production department conducts field measurements using a device known as a manometer, which also includes a thermometer. This enables us to measure both pressure and temperature in the borehole simultaneously.

In addition to the previously described measurements, we used specific devices to determine the temperature of the fluid that enters and departs the wells and pipes. It is known that as the fluid passes along the wellbore and is impacted by the surroundings, it loses some of its temperature. The goal of taking these measurements was to determine the temperature differential between various points.

Special algorithms are utilized to generate a temperature and pressure distribution model for the Bibiheybat field's X layer based on the measurement results. This model enables us to visually monitor the temperature distribution over the area.



a) b)

Fig. 3. Temperature and pressure distribution models of the Bibiheybat field

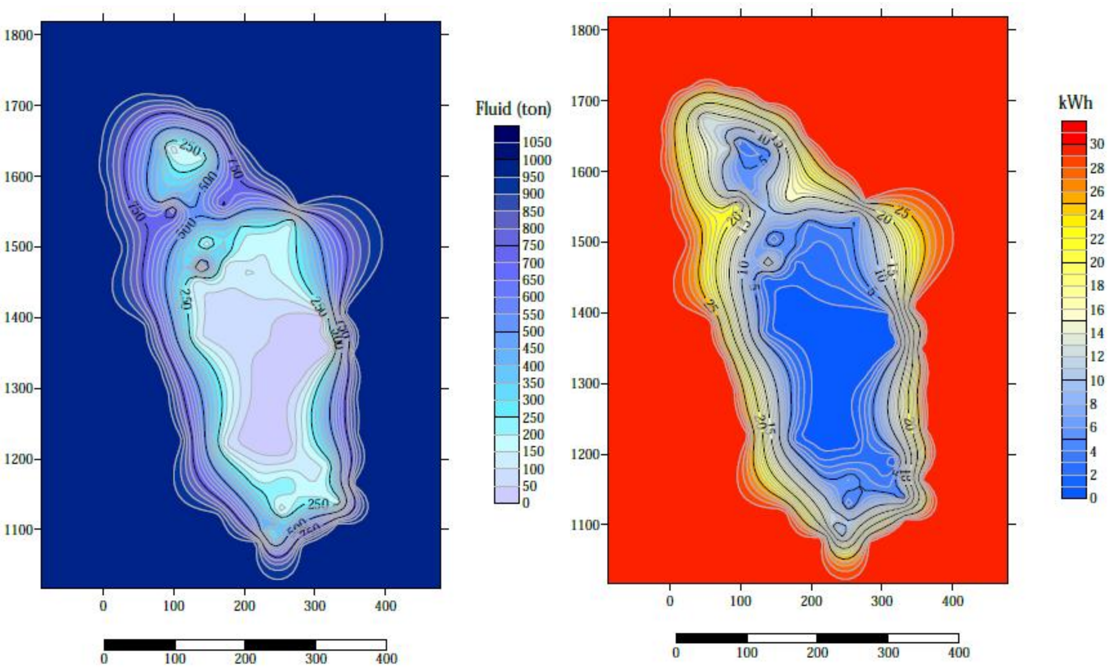
In the first model (a), the temperature distribution map in the X stratum is shown. The temperature in the producing wells across the field ranges from 46 to 24 degrees Celsius. If we look attentively at the image, we can notice that the temperature falls in the center and increases in the wings. Observing at the subsequent model (b), we are able to see that both pressure and temperature decrease as we move from the wings to the center. The pressure across the X layer fluctuates between 46 and 4 atm.

The Bibiheybat deposit has geothermal energy potential that is worth exploring. The goal is to evaluate the geothermal energy potential of the Bibiheybat deposit and identify the energy distribution law across the field.

To accomplish this, we must first determine the flow rate and temperature of the wells in that area. The heat energy delivered from the subsurface to the surface by the wells is calculated using their production flow rate. If we describe the flow rate as $q = m^3/day$, the mass of the fluid, m, provides energy up to q times. The heat quantity, $Q = mc\Delta T$, can also be represented as $Q = qtc\Delta T$. From here, we may calculate the amount of heat (heat power) produced by the oil wells over a given time period.

$$W=Q/t=qc\Delta T \tag{1}$$

After determining the flow rate and temperature of each well, the geothermal energy (for oil and water) is estimated in a laboratory setting using the formula 1. After the calculations were finished, models were created with the Surfer application to visualize the distribution of geothermal energy across the field.



a) b)

Fig. 4. Distribution model of flow (a) and geothermal energy potential (b) of Bibiheybat field

Figure 4 shows the flow rate of oil wells drilled in the Bibiheybat field and distribution models of geothermal energy potential on the field. If we look at the first model (a), we can see that the discharge of the wells located in the north and south wings is higher than the wells located in the center. Flow rate of fluid varies from 5 to 862 tons/month. In the second model (b), mainly the regularity of distribution of geothermal energy is visually described. This model is based on the results obtained during laboratory calculations. The geothermal energy potential of the deposit varies from 0.129 to 24.789 kWh.

In conclusion, the total geothermal energy capacity of the 70 wells was calculated as 307,578.5578 kWh. Of this energy, 25,090.14518 kWh is the geothermal energy carried by oil, and 282,488.4126 kWh is the geothermal energy carried by water.

Following evaluating the geothermal energy for the X stratum of the Bibiheybat deposit, one of the most significant aspects to address is the computation of the electrical energy that can be extracted from it.

Results

As we know, in order to convert geothermal energy into electricity, it is necessary to build circuits consisting of special devices. It is advisable to use the binary cycle geothermal power plant technology to convert the calculated geothermal energy into electricity. The recommended scheme is as follows:

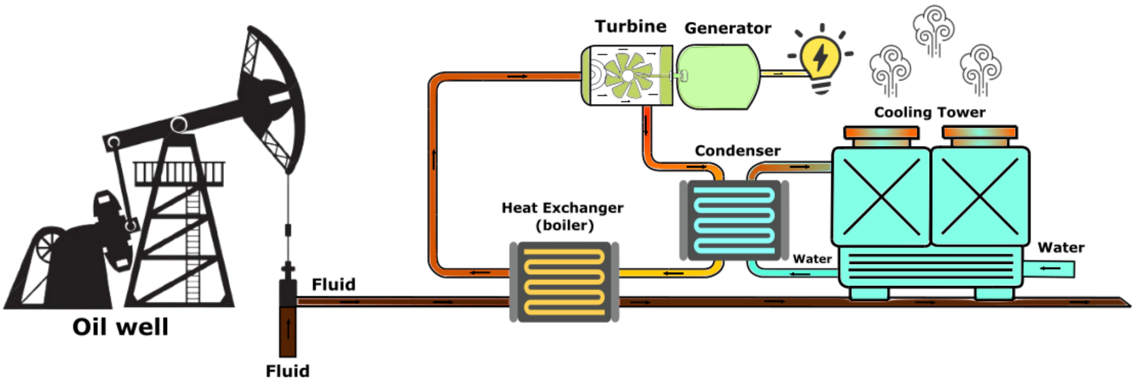


Fig. 5. Scheme of binary cycle geothermal power plant technology for converting geothermal energy into electrical energy

As seen in this diagram, there are two circuits. The first circuit is the fluid transport circuit, and the second is the working fluid circuit. The first circuit cannot be considered a circuit in the traditional sense. This is because the fluid extracted from the oil well will be used for oil production.

The fluid from the oil wells enters the heat exchanger and transfers its heat to the working fluid. This causes the working fluid to vaporize, resulting in high pressure and temperature steam. The hot steam transports through pipes at high pressure and enters the gas turbine. As the steam turns the turbine's rotor, a generator connected to the turbine converts the mechanical energy into electrical energy. Afterward, the working fluid enters the condenser, where it condenses back into a liquid. The liquefied working fluid then re-enters the heat exchanger, completing its cycle.

In general, the overall efficiency of this scheme can be up to 35%. In other words, it is possible to convert 35% of the calculated geothermal energy into electrical energy. For the calculated geothermal energy of 307,578.5578 kWh (~308 kWh) for the 70 wells, we can obtain approximately 107,6524952 kWh (~108 kWh) of electrical energy using this scheme.

With the proposed scheme, it has the potential to supply 2 operating wells (power 40-50 kWh), all offices and equipment in the production area, as well as 388 residential apartments with a consumption of 200 kWh/month located near the Bibiheybat field, with full uninterrupted electricity.

Conclusion

This study investigated the potential of utilizing geothermal energy alongside existing oil production in the Bibiheybat field, Azerbaijan. The X stratum was identified as a promising target and its temperature, pressure, and flow rate distribution were analyzed. Key findings include:

1. The X stratum exhibits an anticlinal fold structure with well depths ranging from 450 to 670 meters.
2. Temperature within the producing wells varies from 46 to 24°C, decreasing towards the center and increasing in the wings.
3. Pressure also decreases from the wings towards the center, ranging from 46 to 4 atm.
4. The total geothermal energy potential of the 70 studied wells was estimated at 307,578.5578 kWh, with 25,090.14518 kWh attributed to oil and 282,488.4126 kWh to water.
5. Utilizing a binary cycle geothermal power plant, approximately 107,652.4952 kWh of electrical energy could be generated from this potential.
6. This generated electricity could power two operating wells, all field offices and equipment, and even supply nearby residential areas.

In conclusion, the Bibiheybat field possesses significant geothermal energy potential that can be harnessed for electricity generation alongside oil production. Implementing the proposed binary cycle power plant scheme would contribute to a more sustainable and diversified energy mix for the region. Further studies are recommended to refine the estimations and assess the economic and technical feasibility of large-scale geothermal development in the field.

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