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Harnessing Bangladesh's Undeveloped Geothermal Potential: A Case Study of the Barapukuria Coal Basin

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Abstract

Despite its vast potential, geothermal energy still needs to be tapped in Bangladesh. This study addresses this gap by employing a data-driven, systematic approach to evaluate the Barapukuria Coal Basin as a candidate reservoir for the nation's first geothermal power plant. While existing research mainly focuses on resource identification, this work utilizes geotechnical data from the well-studied Barapukuria region to conduct a comprehensive and thorough analysis. The aim is to quantify the available geothermal power and assess the project's lifetime, energy output, and capacity. The methodology leverages the high geothermal gradient (>48°C/km) observed in the area and existing information on reservoir and fluid properties. This enables the estimation of the recoverable thermal energy and subsequent validation of geothermal system models with empirical data. With no operational or planned geothermal plants in Bangladesh, this study represents a crucial step toward unlocking the resource's potential. The initial results are promising, suggesting the Barapukuria basin is a viable location for transitioning toward cleaner baseload power generation.

Keywords: Renewable energy, Geothermal energy, Geothermal reservoir, Bangladesh energy sector.

Introduction

With its heaving population of 173 million within a compact 130,170 square kilometers, Bangladesh faces a constant challenge: ensuring sufficient energy for its ever-growing needs. As (Sajid, 2022) pointed out, an uninterrupted energy supply is crucial for the country's socio-economic development, yet securing it remains a struggle.

Despite global commitments to achieving SDG 7 - affordable and sustainable energy for all - Bangladesh is still searching for the ideal energy mix. While phasing out coal through the cancellation of ten mega projects, the government aims for a solar future, projecting 40% of electricity from this source by 2041. However, if no other alternatives are secured by then, natural gas, solar, nuclear, hydropower, wind, geothermal, and other fossil fuels will likely fill the gap. The grid relies solely on the Karnafuli hydropower and Feni wind power stations. While promising projects like Kutubdia and Patuakhli wind farms are in the pipeline, their slow progress must catch up to the 1370-megawatt wind energy target missed in 2021 (Chowdhury, Imran, 2016). Similarly, the Rooppur nuclear plant delays push its online inauguration beyond 2025 (Shetol, et al., 2019). The consequences of insufficient energy are stark – hindering socio-economic development, impacting industries, and limiting individual opportunities. While conventional sources like natural gas and coal have fueled the country's progress, their limitations are becoming increasingly apparent. The looming energy crisis calls for a paradigm shift, and a promising solution lies beneath Bangladesh's soil – geothermal energy. Geothermal energy harnesses the tremendous heat generated within the Earth, a renewable and sustainable resource generated by radioactive decay deep within the planet's core. This heat manifests as hot water and steam trapped in underground reservoirs, waiting to be harnessed. Unlike solar and wind, geothermal energy is independent of weather conditions, providing a reliable baseload power source that can operate continuously (Energy.gov, n.d.). While Bangladesh hasn't yet tapped into its geothermal potential, initial explorations paint a promising picture. The Barapukuria coal basin area, in particular, exhibits a high geothermal gradient (50°C within 500 meters), meaning the temperature increases significantly with depth. Studies indicate temperatures exceeding 100°C at depths of just 2-3 kilometers, making it a viable candidate for geothermal power generation (Hasanuzzaman, Shahriar, & Faisal, 2014). The Barapukuria coal basin, with its existing geological data and high geothermal potential, presents a strategic starting point for Bangladesh's geothermal journey. In-depth analysis of the reservoir characteristics, fluid properties, and temperature gradients is crucial to assess the feasibility of a geothermal power plant. This paper will determine the project's potential power output and gross thermal energy through a comprehensive evaluation.

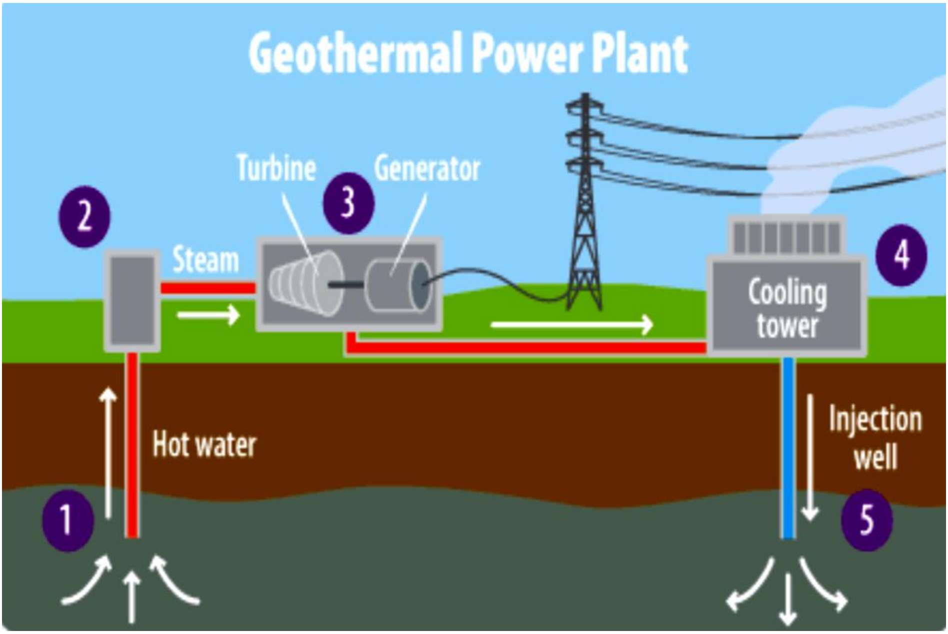
An overview of geothermal energy

What is geothermal energy?

Geothermal energy refers to the heat content of the Earth’s interior. Heat has been emanating from the Earth's core for over 4 billion years, maintaining temperatures akin to those found on the surface of the sun (5,500°C). The estimated power flow from the Earth's interior, primarily by conduction, is around 42 million megawatts (Barbier, 2002). Geothermal energy generally uses the high enthalpy or high temperature in the subsurface of a favorable geological site through extraction or conversion of the heat from the geothermal fluids into different forms of energy.

The sustainable process involves a pair of deep wells in the reservoir. A production well to pump the hot fluids to the surface of the Earth, and an injection well, to inject the cooled fluids back into the underground reservoir, Figure 1 (Barbier, 2002). If the temperature of the geothermal fluid is sufficiently high to offset entropy losses during the conversion of heat into electricity, the processes have the potential to produce electrical energy. The geothermal plant uses a secondary working fluid in a closed cycle to operate the turbine for resources with lower temperatures. This process is recognised as a binary plant and is shown in Figure 1. Alternatively, flash steam geothermal plants directly employ the produced steam from the wells to run the turbines. Bangladesh is mostly considered to have low to medium-enthalpy resources. With binary geothermal plants, the resources can still be attractive economically despite their diminished thermal efficiency (Frick, et al., 2011) (Banks, Rabbani, Nadkarni, & Renaud, 2020).

Figure 1: Schematic of geothermal energy production. A binary geothermal plant contains at least three major components: pumps for circulating the brine, cooling fans and pumps used for re-cooling the hot fluid, and the feed pump for circulating working fluid (photo source: (United States Environmental Protection Agency, n.d.)



Worldwide overview of geothermal energy

The flourishing of geothermal heat pumps, which are also well known as ground-source heat pumps, has driven the surge in direct geothermal energy use across 58 countries, a significant jump from 48 in 2015. This technology's global appeal stems from its ability to tap into underground or groundwater heat anywhere, regardless of location. Compared to 2015 data, the installed capacity of these pumps almost doubled (calculated increase is approximately 1.54 times) at a remarkable annual rate of 9.06%. Their yearly energy usage skyrocketed nearly 1.85 times (12.92% yearly growth) since 2015. China, the USA, Sweden, Germany, and Finland are leading the charge, both in terms of total installed capacity (megawatts thermal) and annual energy consumption (terajoules per year). China, followed by the USA, Sweden, Germany, and Finland, dominate yearly energy use. Global estimates show that 6.46 million geothermal heat pumps are installed, with the leaders above reporting a staggering 77.4% of them (Lund & Toth, 2021). The total installed thermal capacity (MWt), the annual energy use (TJ/year and GWh/year), and the capacity factors throughout 2019 around the world are summarized in Table 1.

Table 1: The installed thermal capacity (MWt), the annual energy use (TJ/year and GWh/year), and the capacity factors through 2019 listed by continents. Among 88 total geothermal power stations Africa, America, Asia, Europe, and Oceania have 11, 17, 18, 34, and 3 stations respectively (Lund & Toth, 2021)

List of continents and regions	**Installed thermal capacity, MWt**	**Annual energy use, TJ/year**	**Annual energy use, GWh/year**	**Capacity Factor for each**
Africa	198	3,730	1,036	0.597
Americas	23,330	180,414	50,115	0.245
- Central America and the Caribbean	9	195	54	0.687
- North America	22,700	171,510	47,642	0.24
- South America	621	8,709	2,419	0.445
Asia (18)	49,079	545,019	151,394	0.352
Commonwealth of Independent States	2,121	15,907	4,419	0.238
Europe (34)	32,386	264,843	73,568	0.259
- Central and Eastern Europe	3,439	28,098	7,805	0.259
- Western and Northern Europe	28,947	236,745	65,762	0.259
Oceania	613	10,974	3,048	0.568
Total	**107,727**	**1,020,887**	**283,580**	**0.300**

Important factors related to geothermal energy development

The risks of a geothermal project are associated with its early stages, as seen in Figure 3. The survey, exploration, and test drilling are more important than the planning, field development, or construction. Any geologically unfamiliar zone possesses higher risks for exploring its potential for geothermal energy development. Therefore, most of the geothermal locations are selected based on their known geotechnical knowledge and behaviors. Some examples are abandoned gas fields, current hydrocarbon fields that co-produce hot water, or a basin with a proven high heat flow with a nearby active tectonic zone. The objective of this research is to assess a geothermal reservoir in Bangladesh, utilizing existing geotechnical data sourced from a region exhibiting a notably high geothermal gradient. The Barapukuria Coal Mine site is selected for its comprehensive prior investigations and well-documented findings, offering a solid foundation for this study (Gehringer & Loksha, 2012).

Why Barapukuria?

The Gondwana Sandstone Sequence underneath the coal layers in the Barapukuria coal mine shows a temperature of 50°C within the depth of 400 m. According to (Guha, Henkel, & Imam, 2010) the coal seams may have an insulating effect that results from elevated temperature in the basement below (figure 2, 3). As there is no deep well in the Barapukuria area, the temperature of the crystalline basement rocks is still unknown. It requires an exploration well to establish a representative temperature profile. This study will provide the scientific base and economic feasibility of the exploration work for the development of geothermal resources in that region.

The Barapukuria coal mine already has an established underground mine facility, which could reduce the exploration cost for geothermal energy to a greater extent. It could also save a substantial amount of time needed for the exploration. Some subsurface data (gravity, temperature, and water samples) can be accessed for preliminary survey design and implementation. Geothermal energy can produce electricity for the off-grid marginal areas in North-western Bangladesh and share the load of the existing grids.

Figure 2: Geothermal map of Bangladesh, modified after (Guha, Henkel, & Imam, 2010)

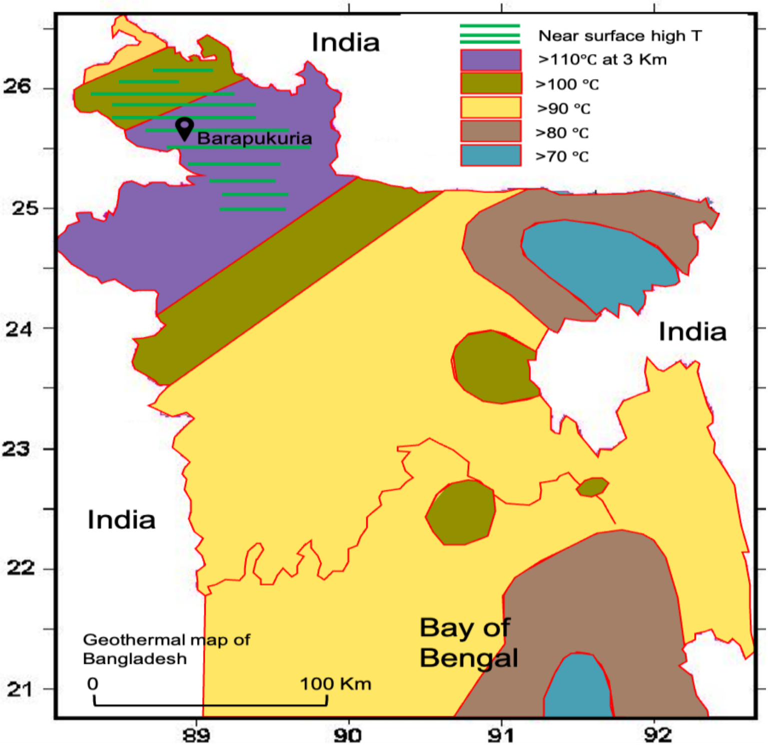
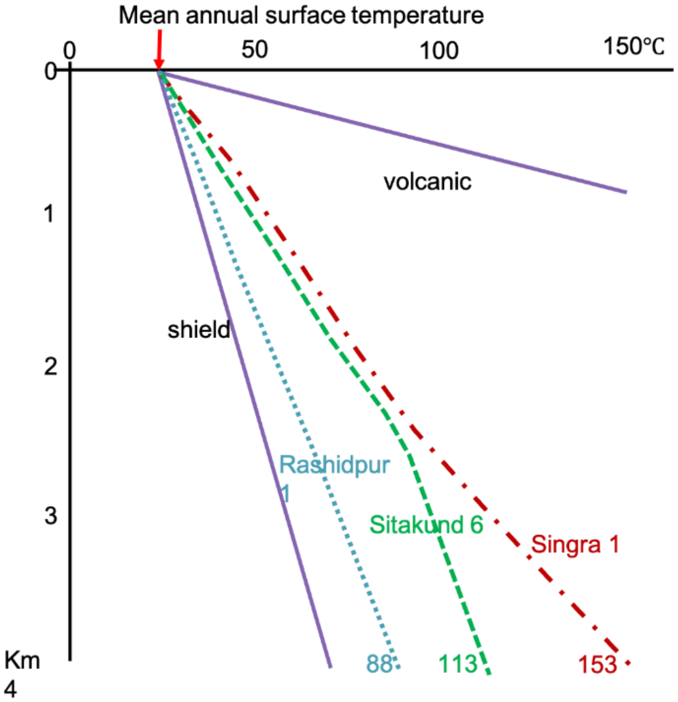


Figure 3: geothermal gradients obtained from measurements in deep abandoned wells. From left: The deep basin well Rashidpur-1, Siltakund-5 at the margin of the Fold Belt, and Singra-1 at the Bogra Shelf, modified after (Guha, Henkel, & Imam, 2010)

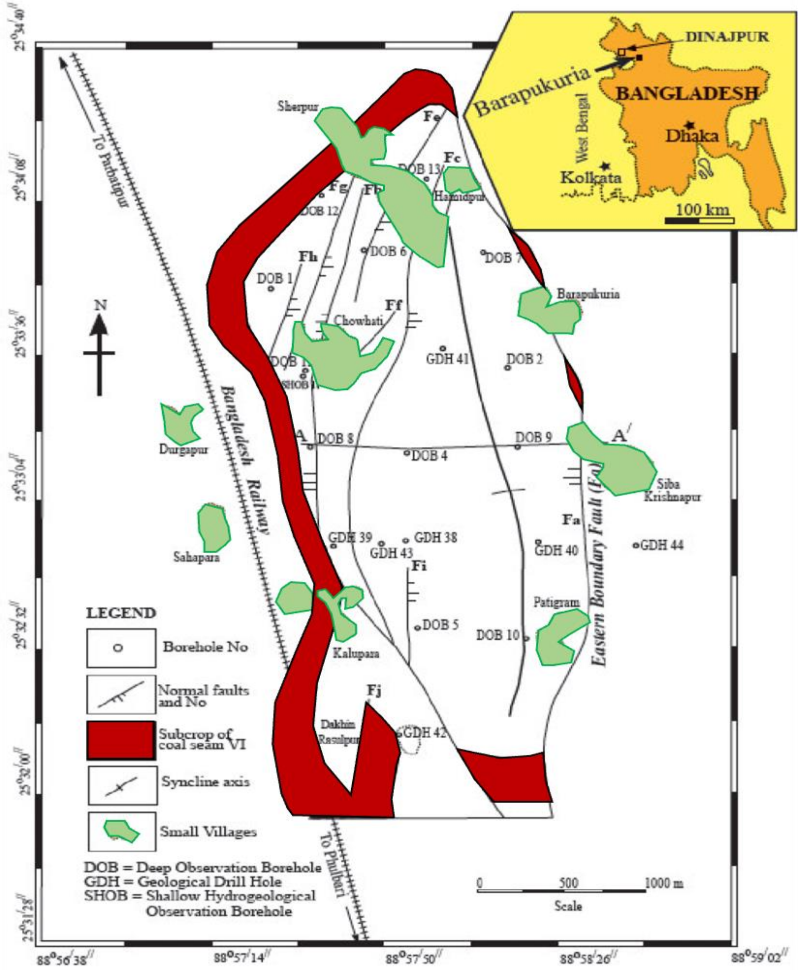


Geology of Barapukuria Area

Barapukuria is located in the Northern part of Bangladesh, which tectonically falls in the Rangpur saddle of the stable platform. The Rangpur saddle is delimited by the Indian Shield in the west and the Shillong Plateau in the east. A gravity survey over the region has revealed the presence of several grabens and half grabens on the Precambrian basement of the Rangpur saddle and Bogra shelf, which may have formed during the post-Gondwana rifting. To the west of the Rangpur saddle, the Gondwana sediments are deposited within several graben and half-graben structures

(Figure 4). Some of these grabens and half grabens also contain coal seams (Guha, Henkel, & Imam, 2010).

Figure 4: Detailed structure of Barapukuria coalfield, modified after (Islam M. R., 2009)



The Barapukuria Basin area is mostly plain land which is covered with the Recent Alluvium and Barind Clay/Madhupur Clay Residuum of Pleistocene time. Based on the observations from borehole datasets, the stratigraphic succession of this Basin has been founded (Bakr, et al., 1996) (Islam, et al., 1987). The sedimentary rocks of the Gondwana Group which dates back to the Permian age, lie on the Precambrian crystalline basement complex, followed unconformably above by Dupi Tila Formation (Pliocene), Madhupur Clay Residium (Pleistocene), and Alluvium (Recent). The rock units are established based on gross lithology, grain size variation, sedimentary structures, etc. Each lithofacies indicates an individual sub-environment of deposition within a fluvial regime (Bakr, et al., 1996).

Methodology

A technique involving two sequential steps has been applied to quantify the potential for geothermal power generation in the Barapukuria Coal Field area. First, borehole data, including borehole logs, porosity, permeability, and lithology data, have been collected from drill-stem tests (DST) and bottom-hole temperature measurements (BHT) taken from the Barapukuria Coal Mines Limited. Datasets are filtered for the upper sedimentary layers of the Madhupur clay Formation, Dupi Tila Formation, and the Gondwana group of sediments. The temperature input incorporates data from both DST (Downhole Shut-in Test) and BHT (Bottom Hole Temperature) measurements, while the evaluation of geothermal reservoirs' power generation potential utilizes the Volume method.

The following datasets have been collected from several sources for gross thermal capacity and gross power capacity:

Geothermal rock density, Pr
Reservoir rock sp. heat capacity Cr
Density of brine ṗf
Geothermal brine specific heat capacity Cf
Reservoir area Ar
Reservoir thickness Dr
Reservoir temperature Tr
Rejection temperature To
Utilization Efficiency
Project Lifetime
Reservoir Recovery Factor
Geothermal Brine Entropy Sr at Tr
Geothermal Brine Entropy So at To
Geothermal Brine Enthalpy Hr at Tr
Geothermal Brine Entropy Ho at To

Processing of the available data has been done to filter out erroneous data. Data could be incorrect for various reasons, for instance, wrong entry or faulty instruments for well-logs and extreme noise in geophysical surveys. Temperature and rock properties have been corrected to establish accuracy and confidence in the total power estimations. The total thermal energy Q_R of the reservoir is determined by factors including its volume, temperature, and heat capacities, as outlined below:

$$CapQ_R = [(1-\emptyset)(\rho_R C_R) + \emptyset(\rho_F C_F)]A_R D_R(T_R - T_0)$$

Where $\emptyset$ is the reservoir porosity, ρ_R is the reservoir rock density, C_R is the reservoir rock specific heat capacity, ρ_F is the geothermal fluid density, C_F is the geothermal fluid specific heat capacity, A_R is the reservoir area, D_R is the reservoir thickness, T_R is the reservoir temperature, and T_0 is the rejection temperature. The calculation of gross power capacity (P) involves dividing the total electric energy available by the project lifetime. Gross power capacity (P) is calculated as follows:

$$P = \frac{\eta(u)}{l}[Q(R)r(g) - \frac{Q(R)r(g)T(0)\{S(R) - S(0)}{h(R) - h(0)}$$

Where, η_u is the power plant utilization efficiency, l is the power plant lifetime, r_g is the recovery factor, T_0 is the rejection temperature, S_R is the specific entropy of geothermal fluid at T_R, S_0 is the specific enthalpy of geothermal fluid at T_0, h_R is the specific enthalpy of geothermal fluid at T_R, h_0 is the specific enthalpy of geothermal fluid at T_0.

Results

Imagine unlocking a clean, sustainable energy source capable of not only powering a specific region but also alleviating nationwide energy shortages. This is the exciting prospect presented by the geothermal potential of the Barapukuria coal basin in Bangladesh. Our analysis, based on a 60°C reservoir temperature, reveals a significant gross thermal energy potential of 6.17286 x 10^17 Joules. This translates to a gross power capacity of 56.388 MW, a substantial addition to Bangladesh's current energy landscape.

The impact of this geothermal energy extends beyond just numbers. It represents a beacon of hope in a country grappling with energy scarcity. In 2023, a stark reality emerged: of Bangladesh's 170 power units, only 57 operated at full capacity, 62 managed half their potential, and a worrying 51 remained idle. This paints a picture of underutilized resources and unmet energy demands. The Barapukuria geothermal project holds the potential to be a game-changer. Its estimated power output could illuminate countless homes, and fuel industries, and drive economic growth in the surrounding regions. Moreover, reducing dependence on conventional energy sources can pave the way toward a cleaner and more supportable future for Bangladesh. The success of this project can pave the way for further exploration of Bangladesh's geothermal potential. Studies suggest promising geothermal gradients in other regions, hinting at the possibility of a nationwide geothermal energy network. This network could provide a reliable, baseload power source, crucial for grid stability and industrial development.

Challenges and opportunities

While the potential is immense, realizing it requires careful consideration of challenges. Initial investments, technical expertise, and addressing environmental concerns are hurdles that need to be overcome. However, the potential rewards - clean energy, economic growth, and energy security - make this pursuit worthwhile. International partnerships and knowledge sharing can play a vital role in overcoming technical challenges and accelerating the development of geothermal projects. By working together, Bangladesh can unlock its vast geothermal potential and step towards a brighter, more sustainable future. The Barapukuria project is not just about harnessing the Earth's heat; it's about igniting a new era of clean energy for Bangladesh. Its success can be a step in paving the way for a sustainable and secure energy future.

Conclusion

The findings from this study provide Bangladesh with a chance to experience geothermal energy's transformational potential. The expected outcomes of this research encompass the identification of geothermal reservoirs in Barapukuria and, the quantification of geothermal energy potential. The next step in the research would be to assess the economic feasibility, environmental impact assessment, and findings with significant implications for policymakers, energy companies, and researchers.

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