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Study on Geothermal Energy Resources, Technologies and Future Directions in Bangladesh

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ABSTRACT

Geothermal energy in the country has been assessed using secondary data as well as hydrothermal exploration of potential areas. Notably, the Barapukuria and Madhyapara regions exhibit moderate-to-high geothermal gradients (20-30 °C km^{-1}), indicating promising prospects. A reviewed study highlights possible pathways for geothermal development, including regional resource mapping, pilot-scale demonstrations, and policy integration. Similar to solar and wind, geothermal energy represents a sustainable option for enhancing energy security and advancing decarbonization efforts.

Keywords: Renewable energy, Binary cycle, Geothermal, Sustainable energy.

1. Introduction

Geothermal energy is a clean, sustainable energy source that consumes less land, produces dependable baseload electricity,[1] and emits fewer greenhouse emissions than fossil fuels[2]. It is obtained from the Earth's internal heat through radioactive decay, primordial heat, and residual conduction. It provides more than 16 GW of electricity and 100 GWth of direct-use energy worldwide[3].The Bengal Basin in Bangladesh, particularly the Northwest Stable Platform (Bogra, Thakurgaon, Dinajpur) and Southeast Foredeep (Chattogram Hill Tracts, Cox's Bazar), has thermal gradients of 26-48 °C/km, with Barapukuria having a potential of 55-60 MW[4]. Geothermal energy is still mostly unexplored in spite of this. Low- to medium-temperature resources are now possible because to developments like enhanced geothermal systems, binary-cycle plants, and ground-source heat pumps[5]. This study assesses Bangladesh's geothermal potential, finds appropriate technologies, looks at obstacles, and suggests ways to incorporate geothermal energy into the country's renewable energy framework.

2. Geothermal Energy History

Using heat from the Earth's interior, geothermal energy is derived from the Greek words "geo" (Earth) and "therme" (heat)[6]. The temperature climbs 25-30 °C/km in most plate-boundary zones, and energy can be produced by pressurized hot water or steam that is 1-10 km deep[7]. While hot springs are created when groundwater seeps through rock cracks and allows for direct consumption or the production of power (as shown in **Fig.1**), heat comes from primordial sources and radioactive decay[8].
Three main geothermal domains of Bangladesh are the Sylhet Basin (deep sedimentary trough), the northwest Bogra-Rajshahi Shelf (stable continental edge), and the Chattogram Hill Tracts-Cox's Bazar foredeep (tectonically active)[10].

Bangladesh is located in the Bengal Basin and is bounded by the Indo-Burma and Himalayan Foredeep mountains. Hotspots exhibit 19.8-48.7 °C/km gradients, with Madhyapara and Bogra Ridge having temperatures above 150 °C and 70-120 °C at depths of 2-3 km[11].These locations are appropriate for hybrid and low- to medium-enthalpy direct-use geothermal systems due to their average heat flow of 60 to 80 mW/m²[12]. The geothermal gradients, geological environments, and possible uses in the major locations are compiled in **Table 1**.

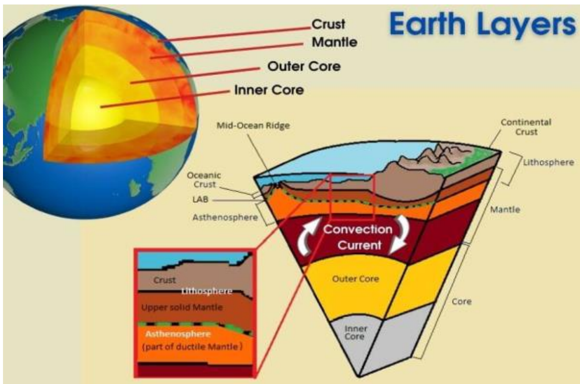

Fig. 1: Earth’s layers and heat distribution[9]

Way forward: The Southeast of Bangladesh is most suited for hybrid systems and geothermal tourism[14], the Northwest for direct-use heating and binary-cycle electricity, and Sylhet for low-temperature uses. Reusing decommissioned oil and gas wells and combining geothermal energy with solar or biomass can increase efficiency and achieve Net-Zero 2050 targets while supplying consistent, dependable renewable energy[15]. Subsurface temperatures at a depth of 3 km are displayed in **Fig.2**.

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Table 1: Geothermal Gradients and Application Potential in Bangladesh[13]

Region	Gradient (°C/km)	Geological Setting	Feasible Applications
Bogra and Rajshahi	20.8-48.7	Basement high	Binary-cycle power, industrial drying, greenhouse & space heating, GSHPs
Sylhet Basin	~30	Sedimentary basin	Direct heating, aquaculture, building HVAC
Chattogram and Cox's Bazar	19.8-29.5	Folded belt	Low-temp direct uses, tourism, hybrid solar-geothermal

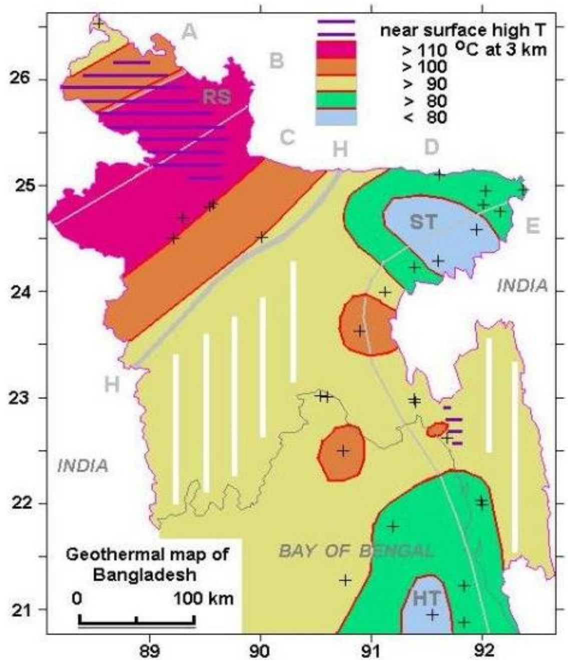

Fig.2: Geothermal Map of Bangladesh showing temperatures at 3 km [16]

3. Methods Of Geothermal Energy Extraction

3.1 Utilization of Geothermal Energy

Geothermal power involves either direct-use heating or electricity generation by utilizing heat from the Earth's crust. Geothermal power plants are selected based on reservoir characteristics and temperature, with three predominant types: dry steam, flash steam, and binary cycle systems. Hybrid configurations have also been developed to optimize efficiency according to site-specific conditions[17].**Table 2** summarizes reservoir temperature, pressure, and fluid composition, which are the main factors that influence the choice of a suitable technology[18].

3.2 Technologies for Power Generation

Dry Steam Plants: Steam is extracted directly from underground reservoirs and sent to turbines. Despite using naturally occurring steam (>180 °C), this method is unsuitable for Bangladesh due to the absence of high-enthalpy steam reservoirs [19].

Flash Steam Plants: High-temperature fluids (>182 °C) are depressurized in separators, producing steam that drives turbines. This method is suitable for regions with high-temperature liquid-dominated geothermal resources, but in Bangladesh, where such high-temperature resources are scarce, its direct application is limited [20].

Binary Cycle Plants: These plants are suitable for geothermal resources with temperatures between 80 and 150 °C. Heat from the geothermal fluid vaporizes a secondary low-boiling fluid, such as isobutane, which drives the turbines. After heat exchange, the geothermal fluid is reinjected into the reservoir (as shown in **Fig. 3**). They are the most potential technology for Bangladesh's geothermal profile because of their small size, minimal environmental impact, and ability to be hybridized with solar systems [21].

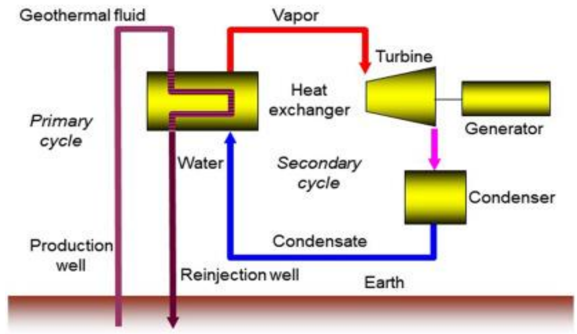

Fig.3: Plant System with Binary Cycle[22]

Table 2: Geothermal Technologies Applicable for Various Reservoir Temperatures[23]

Reservoir Temperature	Available Fluid	Technologies Used
High Temperature (>220 °C)	Steam, Water	Dry Steam, Flash Steam, Combined Cycle (Flash + Binary)
Intermediate Temperature (100-220 °C)	Water	Flash Steam, Binary Cycle
Low Temperature (30-150 °C)	Water	Binary Cycle, Direct-Use Systems

3.3 Applications for Direct Use

Direct-use geothermal systems work very well in Bangladesh's low- to moderate-temperature zones because they use geothermal fluids directly for heating or cooling instead of producing power. Important uses consist of:

- District heating and cooling: institutional or urban networks, especially in the north.
- Heating for greenhouses and aquaculture: Provides constant temperatures throughout the year to increase agricultural output.
- The food, textile, and agro-processing industries are supported by industrial pasteurization and drying.
- Utilizing the geothermal springs in Sitakund and Cox's Bazar, hot spring tourism and spas promote relaxation and well-being.

These direct-use systems are feasible for Bangladesh's near-term geothermal development since they demand less capital than power plants and provide instant social advantages.

3.4 Heat Pumps using Ground Sources (GSHP)

For effective room heating and cooling, ground source heat pumps (GSHPs) use shallow geothermal gradients (20-100 m)[24]. Benefits include easy integration into campuses and Net-Zero Energy Buildings, flexibility for home and commercial HVAC, and a 30-50% reduction in cooling energy. In Bangladesh, GSHPs provide scalable, reasonably priced geothermal use with instant socioeconomic benefits.

3.5 Hybrid Geothermal Technology

Efficiency and dependability are increased when geothermal energy is combined with other renewable sources [25]. Setups that show promise for Bangladesh include:

Solar-Geothermal: Combines GSHPs and solar thermal panels to balance daily and seasonal variations.

Geothermal-Biomass: Helps rural agro-industries by increasing thermal efficiency through the use of biomass or waste heat.

4. ENVIRONMENTAL AND ECONOMIC ASPECTS

4.1 Benefits to the Environment

Compared to coal or gas, geothermal energy produces fewer than 5% of emissions, making it one of the cleanest and most sustainable energy sources [26]. It is perfect for improving grid stability in Bangladesh since it takes little land, provides steady baseload electricity, and uses reservoir management and reinjection to guarantee long-term resource sustainability[27].

4.2 Financial Sustainability

Low operating costs and lengthy plant lifespans (30-50 years) make geothermal energy economically viable even with significant upfront exploration and drilling expenses (up to 50% of total capital). With a worldwide LCOE of 5-8 ¢/kWh[28], it is competitive with imported fuels, promotes job development and energy security, and meets Bangladesh's Vision 2041 and Net-Zero 2050 objectives.

5. Geothermal Potential, Renewble Energy Policy And Current Energy Scenario

Since natural gas has historically provided about 63% of power, Bangladesh's electricity industry is still largely dependent on it[29]. Peak demand is expected to surpass 33,700 MW by 2030, while installed capacity is expected to surpass 25,000 MW by 2024 [30]. Concerns about sustainability and energy security have been raised by the rapid growth that has increased dependency on coal and foreign fuels. Low-cost coal production has been promoted by government policies; however, projects like the Rampal 1320 MW plant near the Sundarbans and coal plants in Chattogram have been put on hold due to public opposition and environmental activism[31]. These difficulties show how urgently a greener, more equitable energy transition is needed.

Additionally, geothermal development supports regional job creation, skill enhancement, and industry diversification, all of which are consistent with the country's Vision 2041. Small-scale hydropower, solar, biomass, and biogas were all encouraged by the 2008 Renewable Energy Policy[32]. Geothermal energy is still underutilized, nevertheless, and is just mentioned as a possible resource without any specific goals or research initiatives[33]. Although there is a lack of systematic mapping and test drilling, preliminary surveys conducted by Petrobangla and the Geological Survey of Bangladesh (GSB) show promise[34]. The failure of the planned 200 MW Thakurgaon Geothermal Power Project (2011) [35] demonstrates the discrepancy between the adoption and application of policies. Bangladesh may exploit its geothermal resources, decrease imports of fossil fuels, improve energy resilience, and become a regional leader in low-enthalpy geothermal utilization with the help of certain regulations, financial incentives, and private sector involvement.

6. Observation, Barriers And Strategic Recommendations

6.1 Possible Geothermal Locations

With slopes >30°C/km and bottom-hole temperatures >100°C, northwest Bangladesh which includes Madhyapara, Barapukuria, and the Singra-Kuchma-Bogra zone shows strong geothermal potential and is appropriate for binary-cycle power plants[36]. Southeast areas with mild gradients (19.8-29.5°C/km), such as Sitakund and Cox's Bazar, are perfect for direct-use uses including aquaculture, greenhouse heating, and hybrid solarge-othermal systems [37].

6.2 Obstacles and Difficulties

Lack of exploration and policy emphasis, a lack of technical know-how, high upfront costs and drilling hazards, a lack of financial incentives, a lack of stakeholder awareness, and a small number of pilot projects are some of the obstacles to geothermal development in Bangladesh.

6.3 The Strategic Way Ahead

To unleash the potential of geothermal energy, Bangladesh might use a staged approach:

1. Utilizing existing oil and gas wells, evaluate geothermal resources.
2. Set up pilot binary-cycle plants in regions with strong gradients, such as Sitakund, Rajshahi, and Bogra.
3. To develop local knowledge, create a National Geothermal Research and Training Center.
4. Encourage public-private collaborations and financial incentives through the Renewable Energy Master Plan 2041.
5. Install hybrid geothermal-solar GSHP systems in institutions, hospitals, and government buildings to demonstrate low-carbon HVAC options.

6.4 Gaining Knowledge from Local Experiences

- **India:** The 2016 draft policy's geothermal framework set a goal of 1,000 MW by 2022 and 10,000 MW by 2030[38].A similar cooperative, policy-driven strategy might assist Bangladesh in reducing hazards in their early stages.
- **China:** Geothermal resources with high and low temperatures are effectively used to generate power and heat districts. Over 120 million m² of space are heated by Tibet's Yangbajain plant (26 MW), which generates over 100 GWh yearly[39]. Resilient reservoir management, financing, and policies provide an example for Bangladesh.

Bangladesh may convert undeveloped geothermal resources into dependable, renewable energy by taking inspiration from these models, promoting energy independence, climate resilience, and sustainable growth.

7. Conclusion

In addition to solar, wind, and hydropower, geothermal energy provides a sustainable answer to Bangladesh's energy problems and growing fuel prices. With present utilization significantly below national need, the nation possesses a large amount of unrealized geothermal potential. Iceland and other small countries show that geothermal energy may be used effectively[40]. A sustainable and resilient energy future can be fostered by making strategic investments in geothermal energy, which can also improve energy security, lessen reliance on fossil fuels, and promote global climate goals[41].

8. Future Direction

With the use of incentives, regulations, and public-private partnerships, Bangladesh should concentrate on mapping, pilot projects, EGS, and binary systems.

9. Acknowledgement

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