

GEOTHERMAL ENERGY RESOURCES FOR ELECTRICITY GENERATION IN SRI LANKA: A CRITICAL REVIEW OF CURRENT STATUS AND PROSPECTS

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ABSTRACT: Sustainable development faces critical challenges including rapid population growth, energy shortages, and rising environmental pollution. With global electricity generation anticipated to triple by 2035, geothermal energy emerges as a notable solution due to its abundance, low CO₂ emissions, and stability. Despite geothermal energy accounting for approximately 0.3% of global power generation and 1.5% of renewable power, it remains underutilized compared to other renewable sources. The United States and China are leaders in geothermal applications having made significant advancements in recent years. This review paper examines the potential of geothermal energy for Sri Lanka, a nation grappling with increasing energy demands and environmental concerns. Through an analysis of 25 research papers and technical reports, this study evaluates various geothermal power generation methodologies and assesses the suitability of Sri Lanka's geothermal resources. The findings highlight the feasibility of different geothermal technologies, taking into account local temperature profiles and geographical distribution. The review also addresses environmental impacts, challenges, and the potential benefits of geothermal energy for Sri Lanka, advocating for its development as a viable, low-carbon alternative to fossil fuels.

Keywords: geothermal energy, geothermal resources, Sri Lanka, hot springs, renewable energy

1. INTRODUCTION

To mitigate the severe consequences of climate change, it is essential to limit global temperature rise to 1.5°C above pre-industrial levels. Currently, the Earth's temperature has risen by approximately 1.1°C compared to the late 19th century, with emissions still increasing. National strategies predict a 9% rise in global greenhouse gas emissions by 2030 compared to 2010 levels. Achieving the Paris Agreement's goal requires a 45% reduction in emissions by 2030 and net-zero emissions by 2050 (Arnórsson, 2004).

Geothermal energy has seen significant advancements, with an additional 1 GW of capacity projected annually over the next six to seven years. The World Bank's Energy Sector Management Assistance Program has allocated \$235 million through the Clean Technology Fund to expand geothermal energy under its Global Geothermal Development Plan (Zhu, 2020). Despite extensive research, reviews addressing geothermal energy's potential for electricity generation in developing countries like Sri Lanka remain scarce. This review evaluates Sri Lanka's geothermal resources and potential, addressing challenges and opportunities to support energy diversification and security.

Geothermal energy stands out among renewables for its stability, abundance, and carbon-neutral profile. It currently contributes 0.3% to global electricity and 1.5% to renewable energy production (Rybach, 2003; Arnórsson, 2004). Derived from the Earth's internal heat via hydrothermal reservoirs or enhanced geothermal systems, its technology is well-established (Arnórsson, 2004). Globally, renewable electricity is expected to triple from 2010 to 2035, reaching 31% of total production (Zhu, 2015). Currently, 82 countries use geothermal energy directly (Fig. 1), while 26 generate electricity, with a total installed capacity of 16,318 MW across 198 fields (Niknam, 2020). The U.S. leads in geothermal power production, contributing 28.8% of global capacity, while China leads in direct utilization, holding 25.2% of the global share (Montenegro, 2016; Zhu, 2020).

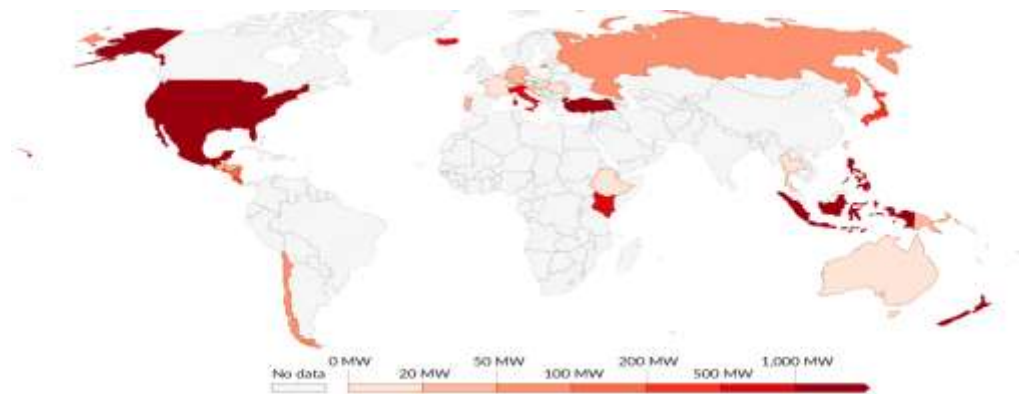


Fig. 1. Installed Capacity of Geothermal Power Generation in the World

2. METHODOLOGY

This review is based on an extensive literature survey of approximately 25 research papers and technical reports on geothermal energy. The search for relevant literature was conducted using databases such as Google Scholar, IEEE Xplore, and ScienceDirect. The primary keywords used in the search included: geothermal energy, geothermal power generation, geothermal resources in Sri Lanka, renewable energy technologies, geothermal plant efficiency, and sustainable energy systems. The reviewed papers span a publication range from 1995 to 2023, with the majority of them published in prominent journals focused on renewable energy, geothermal research, and power systems. The analysis considered both established global methodologies and emerging technologies for harnessing geothermal energy, particularly those applicable to regions with similar geological conditions to Sri Lanka.

The analysis also included Sri Lanka-specific studies, focusing on the temperature profiles and geographical distribution of potential geothermal resources. This allowed for an evaluation of the most suitable power generation methods for the country.

3. RESULTS

3.1 Methodologies Available Globally for Geothermal Power Generation

Geothermal energy is harnessed using various technologies, each suited to different geological conditions. Dry Steam Power Plants use steam from underground reservoirs to drive turbines, a simple and early technology limited to areas with high-temperature steam. Flash Steam Power Plants, the most common, release high-pressure hot water into low-pressure tanks, causing it to flash into steam that drives turbines. Binary Cycle Power Plants utilize lower temperature resources, where geothermal water heats a secondary fluid with a lower boiling point, making it viable in more diverse locations.

Enhanced Geothermal Systems (EGS) artificially increase rock permeability, allowing water to be heated in areas without natural hydrothermal resources. Hydrothermal Convection Systems use naturally occurring hot water or steam but are geographically limited. Lastly, Ground Source Heat Pumps (GSHPs), primarily used for heating and cooling rather than power generation, exploit the stable ground temperature for energy-efficient building systems. Each technology reflects the adaptability of geothermal energy, offering unique solutions based on resource availability and technological capability, with potential relevance to Sri Lanka's energy landscape.

3.2 Distribution of Geothermal Resources in Sri Lanka

Sri Lanka possesses considerable geothermal resources, though their distribution is uneven across the country. Geothermal resource assessments indicate significant potential, particularly in regions with high geothermal activity. Understanding this distribution requires examining Sri Lanka's geological framework, particularly its Proterozoic crustal units.

With reference to Fig. 2, the Proterozoic basement consists of three distinct crustal units: the Highland Complex (HC), with Neodymium (Nd) model ages ranging from 2.0 to 3.4 Ga, the Wannai Complex (WC), and the Vijayan Complex (VC), both dated between 1.1 and 1.8 Ga (Mathvan and Fernando, 2001). The 350 km thermal spring line at the tectonic contact between the HC and the eastern VC marks a significant area of high heat, with tectonic movements along deep-seated lineaments likely causing heat generation through exothermic reactions during serpentinization (Dissanayake and Jayasena, 1998).

The upward movement of magmatic fluids and mixing of crustal and mantle materials along the tectonic boundary has also contributed to the formation of heat-producing granites, which are associated with high concentrations of uranium, further adding to the geothermal system's heat balance. Despite this potential, Sri Lanka's geothermal resources remain largely underutilized, with most thermal springs used primarily for recreation. These geothermal manifestations, identified through ten low-enthalpy thermal springs with temperatures ranging from 35°C to 61°C, are located along a narrow belt parallel to the lithological boundary between the Highland Complex (HC) and the Vijayan Complex (VC) (Kumara, 2014).


A preliminary survey identified several significant hot spring sites, such as Kapurulla, which records the highest temperature, and others including Mahapelessa in Hambantota, Kanniya in Trincomalee, and Rangiriulpotha in Gomarankadawala. Some springs, like Mahapelessa and Rangiriulpotha, feature single wells in marshy environments with unique vegetation, while others, such as Kapurulla, display significant temperature variations over short distances (Samaranayake, 2021). The temperature variations of these springs, summarized in Table 1, highlight the diverse thermal characteristics of Sri Lanka's geothermal resources. The presence of medium- to low-temperature resources suggests that binary cycle power plants could be particularly suitable for the country. Binary cycle plants operate efficiently at lower temperatures (85°C–180°C), making them ideal for Sri Lanka's geothermal profile. In contrast, dry steam plants require resources over 235°C, and flash steam plants are effective at temperatures between 180°C and 235°C (Zarrouk & Moon, 2014).

Sri Lanka's geothermal resources fall within the medium to low-temperature range, making binary cycle technology the most suitable option for efficient power generation. Binary cycle plants operate at temperatures between 85°C and 180°C, achieving efficiencies of 10% to 13%. In contrast, dry steam plants, requiring temperatures over 235°C, can reach efficiencies of up to 20%, while flash steam plants, effective at 180°C to 235°C, offer efficiencies of 10% to 17% (Zarrouk & Moon, 2014). Considering the country's geothermal profile, the binary cycle method provides the best balance of efficiency and operational feasibility.



Fig. 2. Simplified Geological Map of Sri Lanka Showing the Proterozoic Crustal Units (Mathvan and Fernando, 2001)

Table 1. Average Temperature of Thermal Springs in Sri Lanka. (Samaranayake, 2021)

|  | Hot Spring | Average Temperature (°C) |
|---|-------------------|---------------------------------|
| | Rangiriulpotha | 39 |
| Kanniya | 42-44 | |
| Nelumwewa | 55-62 | |
| Kapurella | 73.5 | |
| Mahaoya | 47-54 | |
| Wahawa | 44-48 | |
| Mahapeless | 46 | |

4. DISCUSSION

Challenges and Barriers to Geothermal Development in Sri Lanka

Globally, geothermal prospects are typically associated with magmatic geological settings, where substantial development knowledge exists. In contrast, geothermal prospects in metamorphic terrains, such as those in Sri Lanka, remain largely experimental. The country's geology, dominated by ancient Proterozoic metamorphic rocks, shows minimal thermal signatures apart from sporadic hot spring occurrences, complicating the identification of heat sources for these springs (Samaranayake, 2021). Assessing geothermal prospects requires characterizing the heat source, geothermal gradients, and temperature levels; however, Sri Lanka lacks the expertise and equipment necessary for such integrated surveys, necessitating external support (Samaranayake, 2021). While solar and wind energy development progresses, geothermal energy remains underexplored due to limited initiatives from the government and private sectors. Unlocking geothermal potential could attract investments, but identifying and characterizing viable sources remains a primary challenge. Despite its technical potential, several barriers hinder large-scale geothermal development in Sri Lanka. The absence of comprehensive data on the location and characteristics of deep geothermal resources poses a critical challenge (Abewickrama, 2022). Additionally, accessing promising sites, often in remote or difficult-to-reach regions, complicates exploration efforts. Existing geothermal reservoirs that might support electricity generation are deemed economically unviable due to high upfront costs and uncertainties regarding resource depth and quality deterring investors (Abewickrama, 2022).

5. CONCLUSION

This review paper provides a comprehensive analysis of geothermal energy, its potential applications, and its suitability for Sri Lanka. By examining 25 research papers, we evaluated various geothermal methods and their applicability to the local context, including temperature profiles and geographic locations conducive to power generation. The findings underscore geothermal energy's potential as a sustainable solution to the country's energy needs, emphasizing the importance of addressing environmental impacts and operational challenges. With best practices and innovative solutions, geothermal energy can significantly contribute to Sri Lanka's energy security and environmental goals.

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