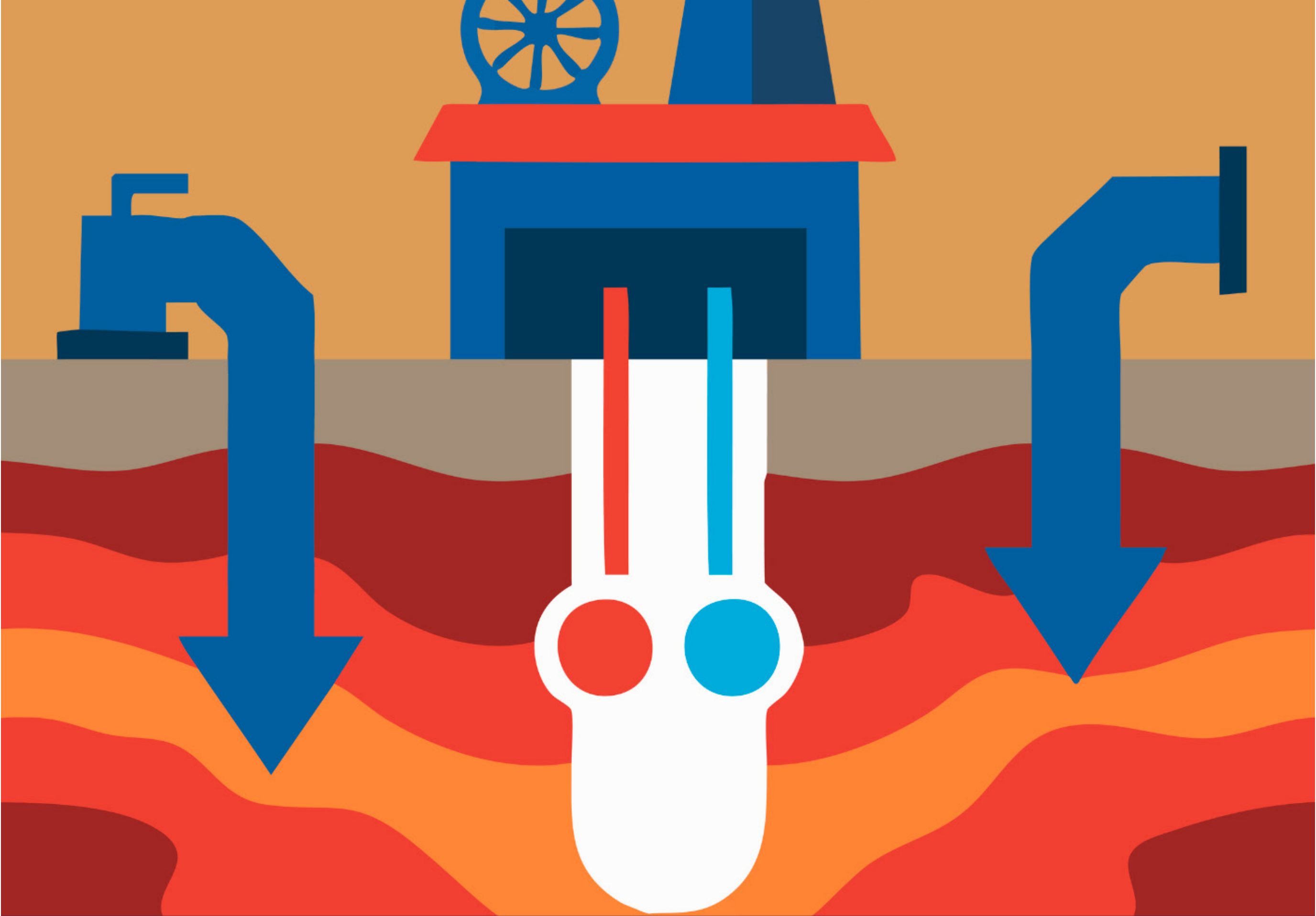
Geothermal Energy Systems: Applications, Opportunities, and Challenges for Sustainable Development



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Vol. 7-2

Asian Productivity Organization

The Asian Productivity Organization (APO) is an intergovernmental organization that promotes productivity as a key enabler for socioeconomic development and organizational and enterprise growth. It promotes productivity improvement tools, techniques, and methodologies; supports the national productivity organizations of its members; conducts research on productivity trends; and disseminates productivity information, analyses, and data. The APO was established in 1961 and comprises 21 members.

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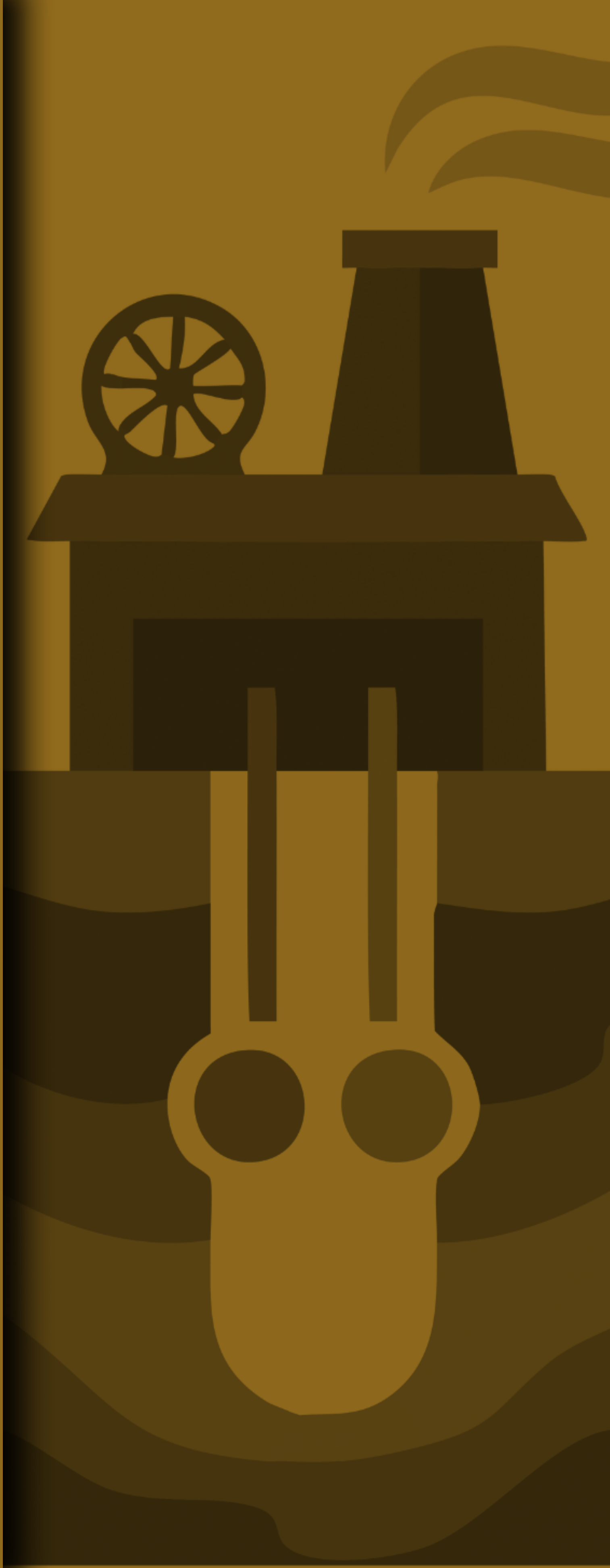

GEOTHERMAL ENERGY SYSTEMS

APPLICATIONS, OPPORTUNITIES, AND CHALLENGES FOR SUSTAINABLE DEVELOPMENT

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Geothermal Energy Systems: Applications, Opportunities, and Challenges for Sustainable Development

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PREFACE

The Productivity Insights (P-Insights) series is an extension of the Productivity Talk (P-Talk) series, which is a flagship program under the APO Secretariat's digital information initiative. Originally designed to maximize the full potential of the APO's digital outreach, the interactive, livestreamed P-Talks bring together practitioners, experts, policymakers, and ordinary citizens from all walks of life with a passion for productivity to share their experiences, views, and practical tips on productivity improvement.

With speakers from every corner of the world, the P-Talks effectively convey productivity information to APO members and beyond. However, it was recognized that many of the P-Talk speakers had much more to offer beyond the 60-minute presentations and Q&A sessions that are the hallmarks of the series. To take full advantage of their broad knowledge and expertise, the APO invites some to elaborate on their P-Talks, resulting in this publication. It is hoped that the P-Insights series will give readers a deeper understanding of the practices and applications of productivity.

INTRODUCTION

Geothermal energy represents one of the most promising renewable energy sources for sustainable development, especially in the context of heating and cooling applications. For Asia-Pacific nations that are members of the Asian Productivity Organization (APO), geothermal systems provide opportunities to reduce carbon emissions, enhance energy security, and align with the UN Sustainable Development Goals (SDGs). This publication focuses on the applications, opportunities, and challenges of geothermal energy systems in Asia, with a particular emphasis on direct approaches to heating and cooling.

Overview of Geothermal Energy Systems

Geothermal energy is derived from the natural heat of the earth. Systems that harness this energy can be broadly categorized into two types: direct-use systems for heating and cooling; and indirect-use systems for electricity generation. In the Asian context, direct-use geothermal applications present the highest potential for integration in urban and rural development. In Asia, direct-use heating and cooling represent a significant opportunity to reduce energy consumption (Table 1 and Figures 1 and 2). Ground-source heat pumps (GSHPs) are gaining traction, offering 30–70% higher efficiency than conventional heating, ventilation, and air-conditioning (HVAC) systems.

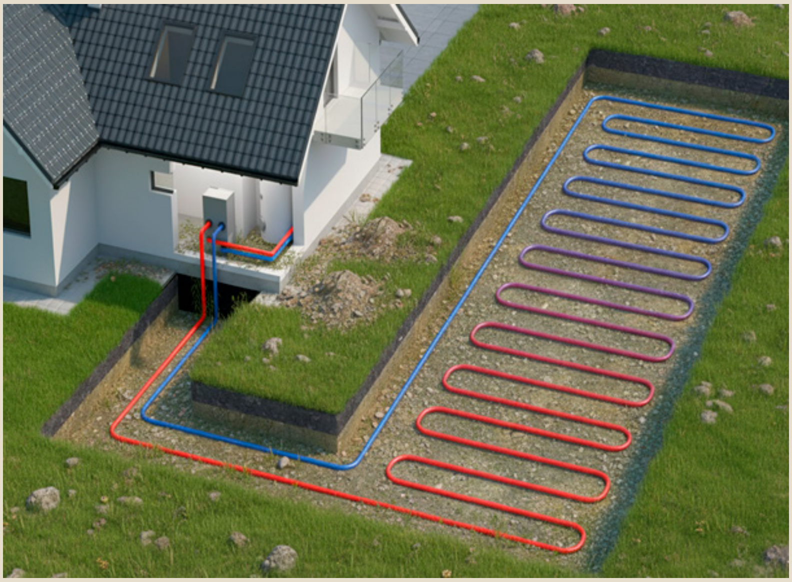
TABLE 1

CLASSIFICATION OF GEOTHERMAL ENERGY SYSTEMS.

Type	Application	Examples
Direct use	Heating and cooling	Commercial, industrial, and residential air-conditioning, district heating and cooling plants
Indirect use	Power generation	Geothermal power plants for electricity generation

FIGURE 1

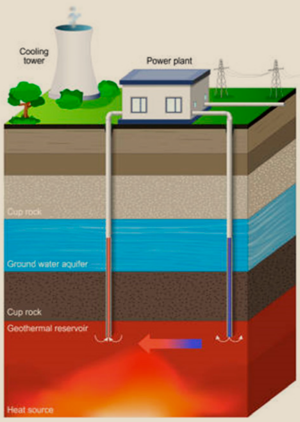
DIRECT USE.



Source: https://www.ny-engineers.com/blog/what-is-a-geothermal-hvac-system-and-how-it-works

FIGURE 2

INDIRECT USE.



Source: https://www.alamy.com/stock-photo/geothermal-plant-diagram.html?sortBy=relevant

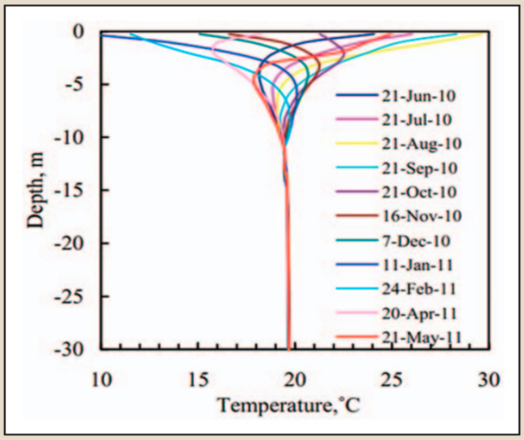
Applications of Geothermal Energy in Heating and Cooling

Geothermal energy has emerged as a highly versatile, sustainable resource for direct applications in heating and cooling, particularly in the context of rapidly urbanizing and energy-intensive economies across Asia (International Ground Source Heat Pump Association, n.d.). Unlike conventional geothermal power generation, which requires high-temperature reservoirs, direct use for heating and cooling relies on shallow geothermal resources that are available almost everywhere, making it a widely replicable technology. GSHPs utilize relatively stable underground temperature to provide efficient space conditioning for residential, commercial, and industrial buildings. Figure 3 shows the ground temperature with depth for typical days in Malaysia (Alam et al., 2015).

By circulating a fluid through vertical or horizontal ground heat exchangers, GSHPs can extract heat from the ground during winter to warm buildings and reject excess heat into the ground during summer to provide cooling. This dual functionality is particularly relevant for APO member economies, many of which experience significant cooling loads in hot and humid climates as well as heating demands in colder regions such as Mongolia, Japan, the ROK, and northern India.

FIGURE 3

MALAYSIAN GROUND TEMPERATURE WITH DEPTH.



Source: https://www.researchgate.net/figure/Temperature-variation-of-underground-soil-with-depth-for-typical-days-in-Malaysia-15_fig3_256838899

Overall, the direct application of geothermal energy for heating and cooling addresses multiple priorities like reducing greenhouse gas (GHG) emissions, lowering energy costs, and strengthening energy security. Given the diversity of climates across Asia, geothermal systems provide a flexible solution adaptable to both tropical and temperate regions. With proper policy support and investment in local expertise and demonstration projects, geothermal applications in heating and cooling have the potential to scale significantly, contributing to sustainable development across the region.

GLOBAL AND ASIAN MARKET TRENDS

Globally, geothermal installed capacity for direct use exceeds 100 GWth. Asia leads in electricity from geothermal sources (Indonesia, Philippines), but heating and cooling applications lag. The US and European markets have been installing geothermal systems for decades, and the market is established with the tools and manpower.

The global geothermal heat pump market size accounted for USD11.21 billion in 2024 and is anticipated to reach around USD27.79 billion by 2034, growing at a compound annual growth rate (CAGR) of 9.50% from 2024 to 2034 (Precedence Research, 2025). Technological advances, especially in heat pump design and smart system controls, are increasing efficiency while lowering costs. Integration of the IoT and smart sensors is becoming a leading trend in system controls for monitoring and optimizing energy use.

PR China, India, Indonesia, and Japan are rapidly expanding geothermal heating and cooling deployments, with India especially leading growth due to intensive energy demand from urbanization and rising middle-class households. From USD4.37 billion in 2024, the Asia-Pacific's geothermal heat pump market is projected to reach USD10.98 billion by 2034, growing at a CAGR of 9.64% (Precedence Research, n.d.). Strong government support, including investments and policy mandates for energy-efficient buildings and carbon emission reductions, are driving market expansion. India, PR China, and other Asian countries have prioritized geothermal and hybrid HVAC solutions as part of broader clean energy initiatives with integration of other renewables like solar collectors and solar photovoltaic systems.

OPPORTUNITIES FOR GEOTHERMAL SHALLOW ENERGY USE IN THE ASIA-PACIFIC

Shallow geothermal options, principally GSHPs with energy piles, vertical boreholes, horizontal loops, water body loops, and open loops, represent one of the most deployable low-carbon heating and cooling options across the Asia-Pacific. Hybrid systems of geothermal, aerothermal (air to water heat pumps), solar collectors, and solar PV further optimize complete systems for energy efficiency.

Why Opportunities Are Widely Available in the Asia-Pacific

Massive cooling (and growing heating) demand: Rapid urbanization and rising incomes are driving explosive growth in building cooling demand across tropical and subtropical Asian economies, while temperate/high-latitude areas face substantial winter heating loads. Shallow geothermal options provide efficient heating in cold seasons and a stable heat sink for cooling in hot seasons, improving seasonal performance compared with air source-only solutions. Conventional systems like split units, VRF, chillers, etc. have limitations because energy efficiency drops with increases in the ambient temperature.

Scalability from building to district: GSHPs can be applied to single homes, commercial buildings, campus/institutional projects, and large shared borefields that serve multiple buildings, unlocking economies of scale. District/shared borefields reduce per-unit capital costs and are especially promising for new urban developments. PR China is one of the biggest players to install geothermal district heating plants.

Integration with storage and flexible grids: Hybrid systems enable shifting thermal loads to off-peak electricity periods and increase the value of variable renewable electricity. Thermal storage of energy during nonpeak hours makes such systems more viable solutions.

Widespread resource availability: Shallow ground temperatures are relatively uniform and predictable over large regions, so technical potential exists in most countries even where deep geothermal resources are absent. These attributes create a broad market opportunity if financing, regulation, and local capacity are addressed. Geothermal energy is always available 24/7 compared with other renewable sources that are dependent on the availability of solar intensity for particular hours or the wind velocity to rotate blades.

Countries Already Deploying Shallow Geothermal Systems at Scale

PR China: The single largest contributor to direct-use geothermal capacity worldwide, PR China has deployed GSHPs for residential, commercial, and district heating/cooling and is piloting integrated district concepts and deep/shallow hybrids. Large industrial and municipal projects and wide GSHP adoption give PR China an outsized share in Asia's installed base.

Japan: With a long history of GSHP use in residential and public buildings, plus advanced pilot projects such as fifth-generation district heating pilots and energy-pile R&D, Japan's technical standards and demonstration projects make it a mature shallow-geothermal adopter (Furubayashi & Kudo, 2025).

ROK: Rapid GSHP growth in the public and private sectors has allowed the ROK to publish status studies showing widespread GSHP deployment driven by policy support and energy-efficiency programs (Aikins & Choi, 2012).

Mongolia: Active donor-supported pilot and ADB projects targeting replacement of coal-based heating with GSHP systems for district heating and public buildings as medium-depth GSHP pilots are underway to address extreme winter heating needs. These projects show that shallow/medium-depth GSHPs can substantially cut coal consumption.

India: Demonstration, residential, and commercial projects already showcase the efficiency of geothermal adoption with net-zero integration.

Countries with High Potential for Geothermal Adoption

Indonesia and the Philippines: Large geothermal industries for power suggest latent capacity and skills for direct shallow/deep applications. Cooling demand growth and growing commercial/industrial loads (data centers, hotels) offer strong market pull, although financing and the granting of permits have constrained rapid scale-up.

Vietnam, Thailand, Malaysia, and Singapore: With strong demand centers (commercial buildings, hotels, data centers), Singapore has limited land but interest in energy piles and building-integrated GSHP systems. Southeast Asian tropical regions may favor hybrid GSHP plus storage solutions to cope with long cooling seasons.

Nepal, Pakistan, Sri Lanka, and Bhutan: In cold-region pockets or higher-altitude zones where heating demand makes shallow geothermal options attractive for public buildings and district retrofits, pilot testing and capacity building are needed.

ROC and Mongolia: The ROC's industrial and urban centers and Mongolia's cold-climate districts both offer contexts where GSHPs or medium-depth geothermal systems can cut heating fuel use.

Priority Opportunities and Enabling Actions

Pilot Projects: Asian countries should explore geothermal systems for small pilot projects to showcase their efficiency. This will enable subsequent larger-volume projects with more confidence and resources.

De-risk Financing for drilling and thermal response testing (TRT): Blended finance, grants for TRT, and ESCO models can accelerate early adoption.

Invest in Installer/Driller Training and Standards: Quality installation prevents thermal short-circuiting and ensures performance.

Promote Hybrid Systems: GSHP plus borehole thermal energy storage (BTES)/aquifer thermal energy storage (ATES) + solar PV/electric heat pumps smooths seasonal performance and reduces peak electricity demand.

Shallow geothermal systems for heating and cooling are commercially proven in several countries and technically feasible across nearly all APO members. The main barriers are capital cost, regulatory/permitting friction, and local capacity, which are all solvable with targeted demonstration projects, blended financing, and regional capacity building. If APO members prioritize district pilots, data-driven monitoring, and installer certification, the region can rapidly expand direct shallow geothermal deployment and unlock substantial emission and fuel-cost reductions.

GEOTHERMAL ENERGY AND THE SDGs

Geothermal heating and cooling, especially through shallow geothermal systems such as GSHPs, borehole thermal energy storage (BTES), and aquifer thermal energy storage (ATES), offer a powerful pathway for Asia-Pacific countries to advance the UN SDGs (Figure 4). While geothermal power generation has traditionally received more attention in volcanic regions, direct applications for heating and cooling align more closely with urbanization trends, rising energy demand, and climate goals across APO member economies. By displacing fossil fuel-based systems and inefficient air-conditioning, shallow geothermal systems can accelerate sustainable development in a way that is highly relevant to the region's socioeconomic and environmental contexts.

FIGURE 4

UN SDGs.

Source: https://www.un.org/en/teach/SDGs

SDG 7: Affordable and Clean Energy

Geothermal direct use provides reliable, indigenous, renewable heating and cooling energy. Unlike solar and wind power, shallow geothermal delivers a stable resource throughout the year, reducing dependence on imported fossil fuels such as LPG, coal, or oil for space heating and cooling.

In countries like India, PR China, Japan, and the ROK where GSHP installations have grown steadily, geothermal has demonstrated cost competitiveness over the life cycle. Scaling similar models across other Asian countries could lower long-term energy bills and reduce exposure to fossil fuel price volatility.

SDG 11: Sustainable Cities and Communities

Asia-Pacific cities face surging cooling demand due to rising urbanization and temperature extremes. Shallow geothermal systems integrated into urban master plans, smart city initiatives, and district energy networks reduce peak electricity demand from air-conditioning.

Examples include Beijing's district GSHP systems and Tokyo's pilot fifth-generation district energy grids, which demonstrate how cities can deploy geothermal cooling and heating at scale. Such models can be adapted for new urban developments in Southeast Asia, where cooling demand is the fastest growing.

SDG 12: Responsible Consumption and Production

Shallow geothermal systems are highly efficient, often achieving COP values between 3.5 and 5.0, which means that they consume less electricity compared with conventional chillers or resistance heating. This translates into more responsible energy consumption patterns and reduces strain on national grids. Additionally, when paired with thermal energy storage (TES), geothermal systems enable demand-side management, allowing for more balanced consumption across peak and off-peak hours.

SDG 13: Climate Action

Heating and cooling account for over 40% of building energy use in the Asia-Pacific. Transitioning to geothermal systems can dramatically cut emissions by replacing coal-fired boilers, diesel gensets, and inefficient split AC units. For example, Mongolia's geothermal pilots for district heating in soums are directly reducing coal dependency, improving local air quality, and contributing to nationally determined contributions (NDCs) under the Paris Agreement (International Renewable Energy Agency, 2023). Widespread adoption of geothermal heating and cooling could save millions of tons of CO_2 annually in large economies like PR China, India, and Indonesia, aligning with SDG 13 targets.

SDG 3: Good Health and Well-being

Geothermal heating and cooling improve indoor environmental quality by providing stable, quiet, clean temperature control without direct combustion. This reduces exposure to indoor air pollutants associated with kerosene, biomass, or coal heating, still prevalent in parts of Asia. In urban areas suffering from severe smog (e.g., Delhi, Ulaanbaatar, Beijing), replacing traditional heating fuels with geothermal systems helps lower particulate matter (PM2.5), yielding immediate health benefits.

SDG 9: Industry, Innovation, and Infrastructure

The geothermal heating and cooling sector fosters local industries in drilling, pipe manufacturing, system integration, and smart control technologies. This creates new green jobs and stimulates R&D in areas like energy piles, hybrid PV-GSHP systems, and seasonal storage. For example, the ROK and Japan have strong domestic industries around heat pump technology, while India and Indonesia have untapped potential to build similar industrial ecosystems, leveraging their large construction and engineering sectors.

SDG 17: Partnerships for the Goals

Regional collaboration under organizations such as the APO and through development banks (ADB, World Bank) can accelerate technology transfer, financing, and demonstration projects. Shared learning across Asia, e.g., Mongolia's heating pilots, PR China's urban-scale GSHP networks, and Japan's energy-pile research, can enable replication and scale-up across diverse climates. Strategic policies, financing mechanisms, and capacity building can turn geothermal heating and cooling into a cornerstone of the Asia-Pacific's clean energy and climate strategies, directly aligning with the SDGs and the urgent need for sustainable urbanization.

CHALLENGES AND BARRIERS IN GEOTHERMAL ADOPTION

Despite the strong potential of geothermal energy for heating and cooling in Asia, its deployment remains uneven and often limited to pilot projects or specific countries such as PR China, Japan, and the ROK. For most Asian countries, geothermal energy remains an underutilized resource due to a mix of technical, economic, institutional, and social barriers. Understanding these challenges is essential for formulating strategies that can accelerate uptake and ensure long-term success.

High Upfront Capital Costs

Drilling and installation expenses for GSHPs and BTES systems are significantly higher than those for conventional air-conditioning or boiler systems. The payback period can often exceed 7–12 years, which discourages adoption in cost-sensitive markets such as India, Southeast Asia, and parts of South Asia. Unlike deep geothermal power, shallow geothermal lacks large-scale subsidy frameworks in many Asian countries, making it harder to justify investments without dedicated financial incentives.

Lack of Awareness and Market Education

Many building developers, architects, and policymakers remain unaware of geothermal direct-use applications, confusing them with deep geothermal electricity projects that require volcanic geology. In emerging economies, renewable energy discussions are often dominated by solar PV and wind, leaving geothermal heating and cooling overlooked despite its stability and efficiency. Misconceptions about land or geological constraints further reduce market uptake.

Technical and Infrastructure Barriers

Limited availability of trained drillers, designers, and system integrators in many Asian countries affects quality and confidence in system performance.

In tropical and subtropical climates (e.g., India, Thailand, Malaysia, Indonesia), where cooling dominates year-round, shallow geothermal systems face challenges of thermal imbalance, such as excessive heat rejection into the ground without adequate seasonal recovery. This requires hybrid designs (e.g., aerothermal heat pumps), which add cost and complexity. Dense urban areas often face land constraints, making borefield installation difficult.

Policy and Regulatory Gaps

Few Asian countries have dedicated regulations, standards, or incentives for shallow geothermal applications. For example, while PR China and the ROK have developed frameworks for GSHP adoption, countries like India, Vietnam, or Indonesia lack building codes or policy mandates that promote ground-source systems. India has recently launched its Geothermal Policy of India that promotes the tapping of geothermal direct and indirect energy (Ministry of New and Renewable Energy, 2025). The absence of standardized design, awareness programs, certification, and quality control undermines investor and user confidence.

Financing and Business Model Limitations

Banks and financial institutions often lack familiarity with geothermal heating and cooling, leading to reluctance in offering loans or green finance packages. Few energy service company or third-party ownership models exist in Asia, meaning that clients must shoulder high upfront costs. This contrasts with solar PV, where leasing and power purchase agreements have driven rapid adoption.

Competing Technologies and Market Priorities

ASHPs and VRF/VRV air-conditioning systems are rapidly gaining ground in Asia due to lower capital costs and wide availability. Developers often choose cheaper systems with shorter payback, even if life cycle costs and carbon emissions are higher. National policies tend to prioritize renewable electricity (solar, wind, hydro) over thermal energy efficiency, leaving geothermal heating and cooling in a policy vacuum.

Social and Perceptual Barriers

Public perception sometimes associates geothermal with volcanic regions only, limiting its acceptance in countries without obvious geothermal activity. In rural areas, households may prefer traditional fuels (coal, biomass, LPG) due to familiarity and cultural preferences, even when geothermal could provide cleaner alternatives.

Climate and Geological Diversity

The Asia-Pacific's diversity means that geothermal solutions must be tailored to local conditions. For example:

1) In cold-climate Mongolia or northern PR China, heating dominates, making GSHPs attractive.

2) In tropical Southeast Asia, cooling is dominant, but thermal imbalance is a barrier.

3) In earthquake-prone zones (Japan, Indonesia), engineering costs and risk management concerns are higher.

4) This diversity complicates the development of standardized, scalable solutions.

The challenges facing geothermal heating and cooling adoption in Asia are not primarily about resource availability, but rather about finance, policy frameworks, technical expertise, and market awareness. Overcoming these barriers requires:

1) Incentive mechanisms (subsidies, low-interest loans, carbon credits) to reduce upfront costs;

2) Capacity building through training programs for drillers, engineers, and policymakers;

3) Demonstration projects in high-demand cities to showcase cost savings and emission reductions; and

4) Hybrid system designs to manage Asia's diverse climates and cooling-dominated loads.

By addressing these hurdles, Asia-Pacific economies can unlock geothermal's full potential and position it as a cornerstone for sustainable, low-carbon heating and cooling.

POLICY AND INVESTMENT FRAMEWORKS FOR ASIA

Why Does a Dedicated Policy and Investment Framework Matter?

Shallow geothermal systems for heating and cooling are capital intensive up front but deliver low operating costs and deep carbon reductions over the life cycle. Without targeted policy and financing, adoption remains limited to pilot projects and subsidy-driven pockets, even where resources and demand are favorable. Well-designed frameworks shorten paybacks, mobilize private capital, build installer capacity, and standardize quality, which are all essential to scale direct use across diverse Asian economies.

Core Policy Instruments to Enable Scaling Up

Practical, proven measures that governments can adopt or adapt to enable the scaling up of geothermal energy projects include the following.

Capital Subsidies and Tax Incentives: Partial grants, tax credits, or accelerated depreciation for borehole drilling, heat pumps, and thermal storage reduce high upfront hurdles and are widely used in mature markets.

Soft Loans and Blended Finance: Concessional financing (from development banks, green windows, or public investment funds) lowers the effective cost of capital for long-payback thermal infrastructure, blending public grants with commercial debt de-risk in early projects. Options include:

1) Result-based financing and performance contracts: Energy performance contracting, where third parties finance and operate systems with repayment from energy savings, addresses split-incentive problems in commercial and public buildings.

2) Targeted demonstration and anchor projects: Public-sector or donor-funded district pilots (campuses, government estates, new townships) create market reference cases and train local contractors.

3) Permitting and planning reforms: Streamlined, time-bound permitting for borehole drilling and subsurface work reduces administrative cost and uncertainty.

4) Standards, certification, and quality assurance: Mandatory thermal response testing (TRT) protocols, installer certification, and commissioning checks protect performance and customer confidence. Examples in PR China and Japan show how standards complement subsidies to improve outcomes.

5) Grid and tariff alignment: Time-of-use electricity tariffs, demand charges, and distributed energy resource integration rules can be designed to favor high-efficiency heat pumps and reward load-shifting with seasonal thermal storage. Guidance from the IEA on aligning heat electrification with grids is useful.

Investment and De-risking Tools

Policymakers must make drilling and resource uncertainty bankable. Some methods utilized are:

1) Exploration grants/co-funded TRT programs: Public support for initial site investigations and TRTs reduces discovery risk for developers and financiers.

2) Drilling risk guarantees or first-loss funds: Public or MDB guarantee facilities absorb early drilling failures, enabling private lenders to underwrite projects.

3) Standardized contracting templates and procurement frameworks: Such templates and frameworks reduce transaction costs and speed public-sector rollouts.

4) ESCO and third-party ownership models: Distributing capital costs to specialized providers increases adoption in cash-constrained public

buildings and commercial portfolios. The ADB and MDBs can anchor first ESCO deals to build market confidence.

Institutional Roles and Governance

Scaling direct geothermal projects requires cross-sector coordination, for example:

1) National energy/climate ministries set targets and incentives for renewable heat.

2) Local governments/municipalities enable permitting, host pilots, and aggregate demand for district borefields.

3) Standard and certification bodies create installer, driller, and equipment certification regimes.

4) Development banks and climate funds provide concessional capital, guarantees, and technical assistance. The ADB's activity in Mongolia demonstrates this multiple-actor approach.

Market Models that Work in the Asian Context

1) Public-led district pilots: Municipality-owned borefields serving public buildings and low-income housing demonstrate value and lower per-unit capital cost.

2) Private ESCOs for commercial portfolios: ESCOs install and operate GSHPs for hotels, malls, and data centers with payments tied to energy savings.

3) Developer-led integration in new towns: Includes GSHP borefields and energy piles in zoning/land-sale conditions to avoid retrofit barriers.

4) Rural and hybrid models: Models combine solar thermal and shallow geothermal for agriculture applications (greenhouses, drying) where capital is constrained.

Monitoring, Measurement, Reporting, and Verification (MRV) and Co-benefit Measurement

Mandate monitoring of energy savings, CO_2 reductions, and air-quality impacts for public pilots to build the economic case and attract climate finance. Standard MRV templates (kWh saved, tCO_2e avoided, fuel displaced, local air pollutant reductions) make projects bankable and eligible for carbon or resilience financing.

CONCLUSION

Geothermal energy, particularly its direct-use applications in heating and cooling, represents one of the most practical, scalable, sustainable energy solutions for Asia-Pacific economies. Unlike other renewables that are intermittent, shallow geothermal systems provide a stable, year-round resource, well suited to both the cold winters of Mongolia and northern PR China and the cooling-dominated climates of Southeast Asia and South Asia.

Across the region, successful examples already exist: PR China's large-scale GSHP networks; Japan's energy-pile innovations; the ROK's steady market expansion; and Mongolia's donor-backed coal-replacement pilots. These demonstrate that geothermal energy applications are not limited to volcanic regions but can be effectively deployed wherever demand for space heating or cooling exists. At the same time, the diversity of climates, building practices, and policy frameworks across APO members highlights the need for tailored solutions, from district-scale borefields in new urban developments to hybrid GSHP + solar systems in tropical markets.

The opportunities are clear. Geothermal energy use can advance multiple SDGs, reduce reliance on imported fossil fuels, improve air quality, enhance urban resilience, and create local green jobs. Yet barriers remain, including high upfront costs, lack of awareness, weak policy support, and limited financing models. These challenges are surmountable with the right combination of policy instruments (incentives, standards, permitting reform), investment frameworks (soft loans, ESCO models, donor support), and capacity-building measures.

For APO member economies, the path forward is to mainstream geothermal into national energy and urban planning strategies, scale up demonstration projects, and encourage regional knowledge sharing. If supported by coherent policies and innovative financing, geothermal heating and cooling can move from being a niche solution to a cornerstone of the Asia-Pacific's sustainable energy transition.

CONCLUSION

In conclusion, geothermal direct use is not just a technical option. It is a strategic enabler for sustainable development, helping APO member countries meet climate commitments, improve energy security, and build healthier, more resilient cities for the future.

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