The Future of Geothermal in Indonesia

AN ABUNDANT NEW ERA OF COOLING, CLEAN INDUSTRY, AND POWER

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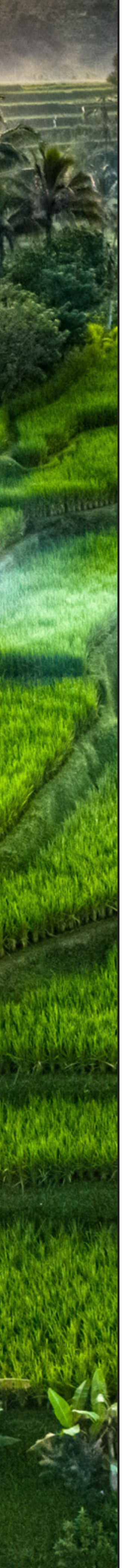
Edited by:

Jackson Grimes

Drew Nelson



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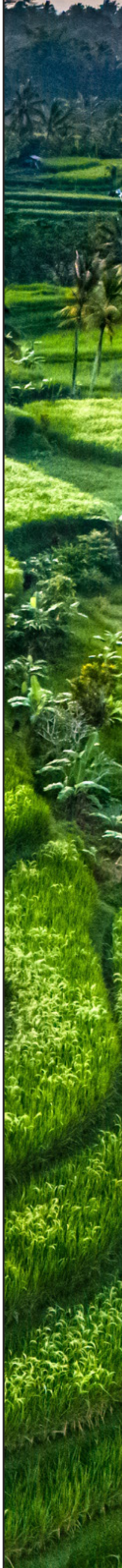

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His Muhammad Bintang is a researcher at the Institute for Essential Services Reform (IESR). He has worked on energy transition policy, power systems, and clean technology economics. Bintang's work at IESR aims to bridge technical analysis with policy recommendations and to support the integration of emerging clean technologies into national energy strategies. Bintang holds a master's degree in energy and environmental engineering from the Korea University of Science and Technology. He previously worked as a battery researcher at the Korea Institute of Science and Technology.

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Michael Suryaprawira is a researcher at the Purnomo Yusgiantoro Center (PYC). He graduated with a master's degree from the Institut Teknologi Bandung ocean engineering program and now works on multi-stakeholder projects related to Indonesia's energy transition, including currently leading the collaboration between PYC and Climateworks Centre on the Indonesian low-carbon battery supply chain program. His previous work included initiatives related to grid decarbonization, energy policy strengthening, and geothermal governance. He collaborates and networks with stakeholders from ministries and agencies, PLN, and international nonprofit organizations. He has also led the development and writing of energy sector grant proposals, with partners including Innovate UK (United Kingdom) and the Department of Foreign Affairs and Trade in Australia, as well as organizations such as the Ford Foundation (United States) and AVPN (Asian Venture Philanthropy Network).

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Jackson Grimes is the director of global engagement at Project InnerSpace, where he focuses on introducing geothermal technologies to developing economies and broadening the global influence of the sector. Since beginning his career at the Iceland School of Energy at Reykjavik University, Grimes has focused his research on the social development opportunities that geothermal presents to marginalized communities. Upon returning to Texas, Grimes joined the Bureau of Economic Geology at the University of Texas at Austin, where he investigated workforce opportunities for the state's oil and gas sector; he spent the 2023 Legislative Session with the Texas Geothermal Energy Alliance, helping advance landmark legislation that has positioned the state to be a leader in next-generation geothermal systems.

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Figures

Definitions

Advanced geothermal system (AGS): Occasionally referred to as closed-loop geothermal systems, a geothermal technology (with many configurations) that allows the circulation of fluid in the subsurface without fluid leaving the wellbore. Fluid is pumped from the surface, picks up heat from the surrounding formation (primarily through conduction), and flows back to the surface, where the heat is harvested for direct-use or power applications. AGS can be deployed in various rock types, can use engineered fluids such as supercritical carbon dioxide (sCO_2) to improve efficiency, and is considered scalable.

Brittle-ductile transition zone: The zone of the Earth's crust that marks the transition from the upper, more brittle (fractured) crust to the lower, more ductile (plastically flowing) crust.

Caldera: A large volcanic depression, generally circular in form, with a diameter many times greater than that of a crater. A caldera forms when a volcano's magma chamber empties during an eruption, causing the ground above to collapse.

Conventional geothermal: A geothermal extraction method that requires a hydrothermal system and does not use hydraulic fracturing to artificially engineer a subsurface reservoir. Horizontal drilling may be used, but only to improve access to otherwise naturally occurring reservoirs and naturally occurring fluid.

Conventional hydrothermal system (CHS): Also known as a traditional geothermal system or hydrothermal geothermal system, a geothermal resource that is often accessible close to the surface and at times has surface manifestations, such as hot springs, volcanic rock formations, geysers, or steam vents, among others. A CHS has a combination of sufficient permeability in the subsurface, sufficient heat transfer into the system, and the natural presence of circulating water, which produces an exploitable geothermal resource. Heat flow is convection dominant (i.e., conduction and advection contribute to the movement of heat). Most of the world's developed geothermal capacity is currently produced from CHS resources.

Direct-use geothermal system: Instead of using geothermal heat to generate electricity, uses the heat contained in geothermal fluids to enable various heating and cooling applications. This system can be shallow or deep.

- Shallow direct-use applications typically use a ground source heat pump to harvest the constant temperature of the shallow subsurface for a variety of low-temperature applications, including heating and cooling buildings.
- With deep direct-use, wells are drilled to reach higher subsurface temperatures that can be used for various applications, including industrial and commercial direct heating or numerous industrial and manufacturing processes. Deep direct-use applications may still use heat pumps but do so at much higher temperatures. Wells can target deep aquifers or human-made places filled with water, like mines.

Engineered/enhanced geothermal system (EGS): A geothermal technology that uses hydraulic fracturing to engineer a subsurface reservoir by creating or enhancing existing fractures in rock. Fluids are then circulated through the fracture network, where they heat up and are then brought to the surface for generating electricity or for direct use. This system can be deployed in various rock types and is considered scalable.

- **Traditional engineered geothermal system:** A system that uses hydraulic fracturing to engineer or enhance a subsurface reservoir to produce geothermal heat or electricity but does not use advanced directional drilling or multi-stage fracturing techniques. This system is typically developed by drilling vertical or deviated wells and can be deployed in various rock types, but the development of the system has historically focused on basement rock formations.
- **Next-generation engineered geothermal system:** Not to be confused with the umbrella "next-generation geothermal" concept, a subtype of EGS that still uses hydraulic fracturing to engineer or enhance a subsurface reservoir while also incorporating advanced drilling and/or fracking techniques, including but not limited to horizontal drilling and multi-stage fracturing. This system can be deployed in a variety of rock types.

Geophysics: The study of the Earth's physical properties and processes, combining knowledge from geology, physics, mathematics, and other sciences. In geothermal exploration, geophysical methods are used to map the Earth's subsurface, including the distribution of rock types, geological structures, temperatures, magnetic and gravity fields, occurrence of groundwater, and other features.

Geothermal gradient: The rate at which temperature increases with depth in the Earth.

Geothermal system: A system involving the transfer of heat from the Earth's interior to the surface.

Granite: A coarse-grained, light-colored intrusive igneous rock composed mainly of quartz, feldspar, and mica minerals. It often contains relatively high concentrations of radioactive elements such as uranium, thorium, and potassium, which release radiogenic heat as they decay, contributing to the Earth's internal heat.

Ground source (Geothermal) heat pump (GSHP): Pump that harvests the ambient temperature in the top 1 meters to 2 meters of the subsurface, where the ground remains at a relatively constant temperature of 13°C. GSHPs have traditionally been used to heat and cool buildings, but these pumps are increasingly used in higher-temperature industrial and commercial applications.

Hydrothermal: Relating to hot water, especially in processes involving heated fluids within a geothermal system.

Magma: Molten or semi-molten natural material located beneath or within the Earth's crust that forms igneous rocks as it cools and solidifies. Magma temperatures generally range from 700°C to 1,300°C but can exceed 1,800°C.

Manifestation: Surface features where geothermal fluids are discharged (e.g., hot springs, hot lakes/pools, fumaroles) and those formed by hot fluid-rock interactions and hydrothermal mineral deposition at the ground surface.

Mohorovičić (Moho) discontinuity: The boundary between Earth's crust and the underlying mantle. It is typically found at depths of between 5 kilometers and 10 kilometers beneath the ocean floor and between 30 kilometers and 40 kilometers beneath the continents.

Next-generation geothermal: An umbrella term for any geothermal extraction technology that harvests subsurface energy outside the geography of a conventional hydrothermal system. In most cases, next-generation geothermal technologies rely on advances from the oil and gas industry and expand the geographic potential of geothermal.

Pluton: A massive body of igneous rock that forms below the Earth's surface by the slow cooling and solidification of magma.

Radiogenic: Related to radioactivity. Radiogenic heat is thermal energy released by the radioactive decay of elements in the Earth's crust and mantle, contributing to geothermal heat.

Rock types

- **Igneous rock:** A rock formed by the solidification of molten rock material (magma) generated deep within the Earth.
- **Sedimentary rock:** A rock formed from the accumulation and cementation of sediments, which may include fragments of other rocks, minerals, or biological materials. These rocks typically form in sedimentary basins and are heated by conductive heat from the Earth's interior and by radiogenic heat from decaying elements.
- **Metamorphic rock:** A rock created when existing rocks (igneous, sedimentary, or metamorphic) are gradually transformed by heat and pressure without melting. This transformation alters the rock's mineralogy and texture and can generate residual heat that may be extracted.

Sedimentary geothermal system: A type of conduction-dominated geothermal resource found in sedimentary rock formations (with some convection cells in complex settings). These sedimentary rocks—including sandstone, shale, and limestone—often contain water within their pores that can be harvested for geothermal energy production. Most sedimentary basins are closed systems, unless they have experienced uplift, in which case surface springs may highlight geothermal potential.

Supercritical: Refers to a state above the critical temperature and pressure at which a substance becomes a supercritical fluid. Such fluids exhibit properties of both gases and liquids, making them highly efficient for heat extraction in geothermal systems.

Superhot rock (SHR): A term given to geothermal technologies that aim to exploit hot-rock resources above approximately 373°C, the supercritical point of water. In volcanic regions of the world, SHR may be encountered relatively close to the surface; in other regions, SHR may require drilling to as deep as 10 kilometers or more, so SHR is sometimes referred to as *deep geothermal*.

Tectonic plates: Massive slabs of the Earth's lithosphere (crust and upper mantle) that move slowly across the planet's surface. There are two main types: oceanic and continental plates. Their movement drives many geological processes, including earthquakes, volcanism, and mountain formation.

Abbreviations

This list defines the report's frequently used abbreviations. Many of the abbreviations are based on the Bahasa Indonesian wording, though we provide the English definitions only for clarity.

AGS: advanced geothermal system

AHP: analytical hierarchy process

AI: artificial intelligence

ASHP: air source heat pump

Bappenas: Ministry of National Development Planning

BOO: Build-Own-Operate

BOOT: Build-Own-Operate-Transfer

BPPB: geothermal production bonus

BRIN: National Research and Innovation Agency

CAPEX: capital expenditure

CMEA: Coordinating Ministry for Economic Affairs

CO_2: carbon dioxide

COD: Commercial Operation Date

COP: coefficient of performance

CR: consistency ratio

CSR: corporate social responsibility

°C: Celsius

dBA: A-weighted decibels

DBH: Revenue Sharing Funds

EEZ: exclusive economic zone

EGS: engineered geothermal system

EIA: Environmental Impact Assessment

EWTTF: Energy Workforce Transition Task Force

FORGE: Frontier Observatory for Research in Geothermal Exploration

FPIC: free, prior, and informed consent

GES: geothermal energy storage

GHG: greenhouse gas

GREM: Geothermal Resource Risk Mitigation Project

GSHP: ground source heat pump

GW: gigawatts

GWh: gigawatt-hours

HDR: hot dry rock

HiP: heat-in-place

HSA: hot sedimentary aquifer

HSAs and CSAs: heat and cooling supply agreements

HVAC: heating, ventilation, and air-conditioning

IBSAP: Indonesian Biodiversity Strategy and Action Plan

IEA: International Energy Agency

IESR: Institute for Essential Services Reform

INWCS: Indonesian National Work Competency Standards

IPB: Geothermal Permit

ITB: Bandung Institute of Technology

I-NCAP: Indonesia National Cooling Action Plan

KBLI: Indonesia Standard Industrial Classification

LCOE: levelized cost of electricity

LPG: liquid petroleum gas

MEMR: Ministry of Energy and Mineral Resources

MHGR: metamorphic-hosted geothermal resource

MHGS: metamorphic-hosted geothermal systems

MoE: Ministry of Environment

MoF: Ministry of Forestry

MoI: Ministry of Investment

MoM: Ministry of Manpower

$MtCO_2e$: million tons of carbon dioxide equivalent

MTOE: million tons of oil equivalent

MW: megawatts

MWh: megawatt-hours

NDC: Nationally Determined Contribution

NCG: non-condensable gas

O&G : oil and gas

O&M: operations and maintenance

OSS: Online Single Submission

PGE: PT Pertamina Geothermal Energy

PJ/km^2: petajoules per square kilometer

PLN: state electricity company

PNBP: non-tax geothermal revenues

PPA: Power Purchase Agreement

ppm: parts per million

PPP: public-private partnership

PT: limited liability company

PT SMI: Multi-Infrastructure Facility

PYV: Purnomo Yusgiantoro Center

RUKN: National Electricity General Plan

RUPTL: Electricity Supply Business Plan

SHGR: sedimentary rock-hosted geothermal

SHR: superhot rock

SKK Migas: Special Task Force for Upstream Oil and Gas Business Activities

SLO: social license to operate

SWIFT: Specialized Workforce for Indonesia's Transition

TEN: Thermal Energy Networks

TJ: terajoules

TRL: Technology Readiness Level

TWh: terrawatt-hours

VAT: value-added tax

VOC: volatile organic compound

WKP: Geothermal Working Areas

Executive Summary

Unlocking Indonesia's Geothermal Potential

Project InnerSpace

By expanding beyond conventional geothermal power to next-generation systems, industrial heat, and district cooling, Indonesia can improve quality of life, add thousands of new jobs, promote a more equitable energy transition, reduce fuel imports, and decrease emissions.

Stretching from Sumatra to Papua, Indonesia spans thousands of islands, deep rainforests, high volcanoes, fertile valleys, and dense megacities. Its people and landscapes are as varied as its geology. Sitting along the Pacific Ring of Fire, the subsurface holds active volcanic arcs, young magmatic systems, and large sedimentary basins that concentrate the Earth's heat. All of these features mean that Indonesia has one of the world's richest endowments of geothermal resources. Heat rises beneath hydrothermal fields and across wide regions without natural fluids. That geological diversity underpins a broad menu of geothermal solutions.

Conventional hydrothermal projects remain an essential pillar for firm, clean electricity across Indonesia. (See Chapter 1, "Geothermal 101: Overview of Technologies and Applications.") Yet the nation's geothermal opportunity is larger—much larger. With advanced drilling and modern well construction, next-generation systems can access heat in low-permeability formations and deliver direct-use heat for industry. These systems can also deliver reliable cooling for campuses and buildings. Broadening the national focus beyond conventional reservoirs substantially increases Indonesia's geothermal potential.

Indonesia's energy and climate plans reflect the need for this expanded view. National targets call for renewables to make up between 19% and 23% of the energy mix by 2030 and around 70% by 2060, yet the National Electricity General Plan (RUKN) and PLN's Electricity Supply Business Plan (RUPTL) envision only between 21 gigawatts and 23 gigawatts of geothermal capacity by 2060—about 5% of the projected electricity capacity.[1,2] Fully tapping into Indonesia's resource base would strengthen the country's pathway to achieving net-zero status.

INDONESIA'S TOTAL GEOTHERMAL HEAT-IN-PLACE WITH PROTECTED AREAS

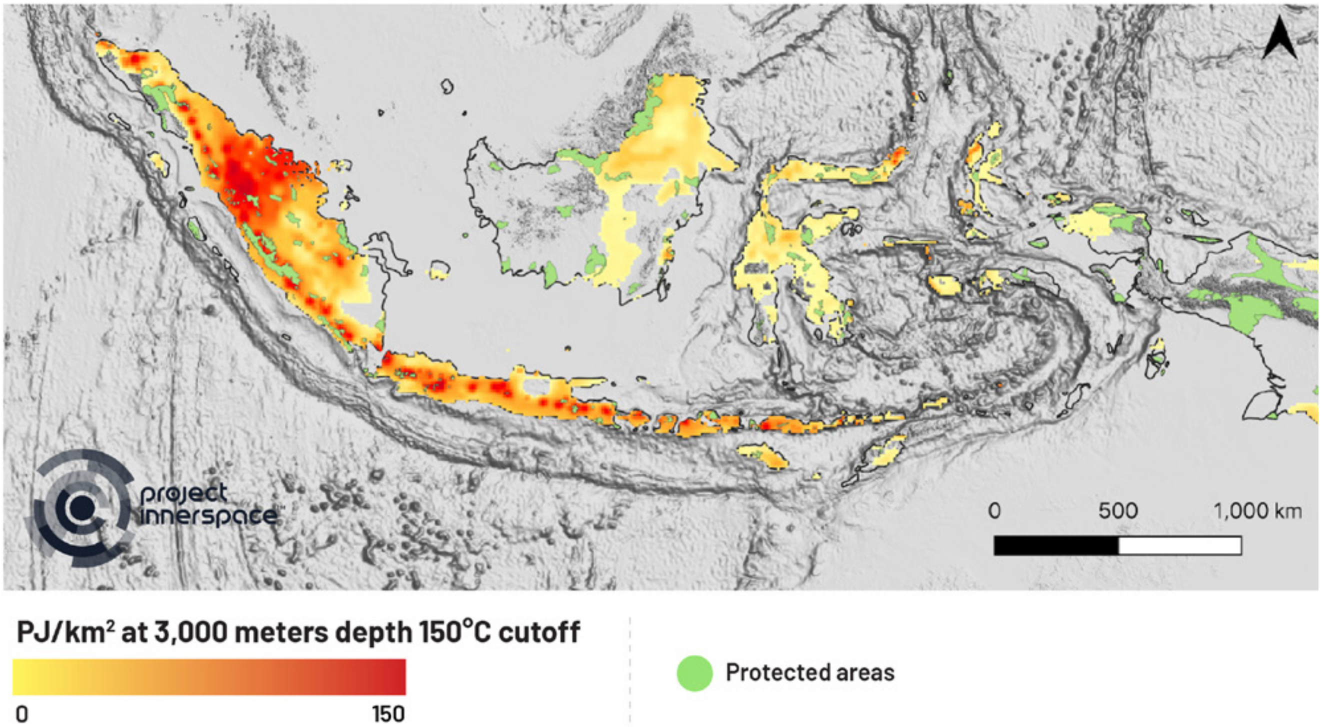

Figure ES.1: The map presents heat-in-place (HiP) estimates expressed in petajoules per square kilometer (PJ/km^2) for a 3,000 meter thick interval between 0 meters and 3,000 meters depth, applying a minimum subsurface temperature cutoff of 150°C. Source: Project InnerSpace. (2025); UNEP-WCMC and IUCN (2025), Protected Planet: [The World Database on Protected Areas (WDPA)][On-line], [October/2025], Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net

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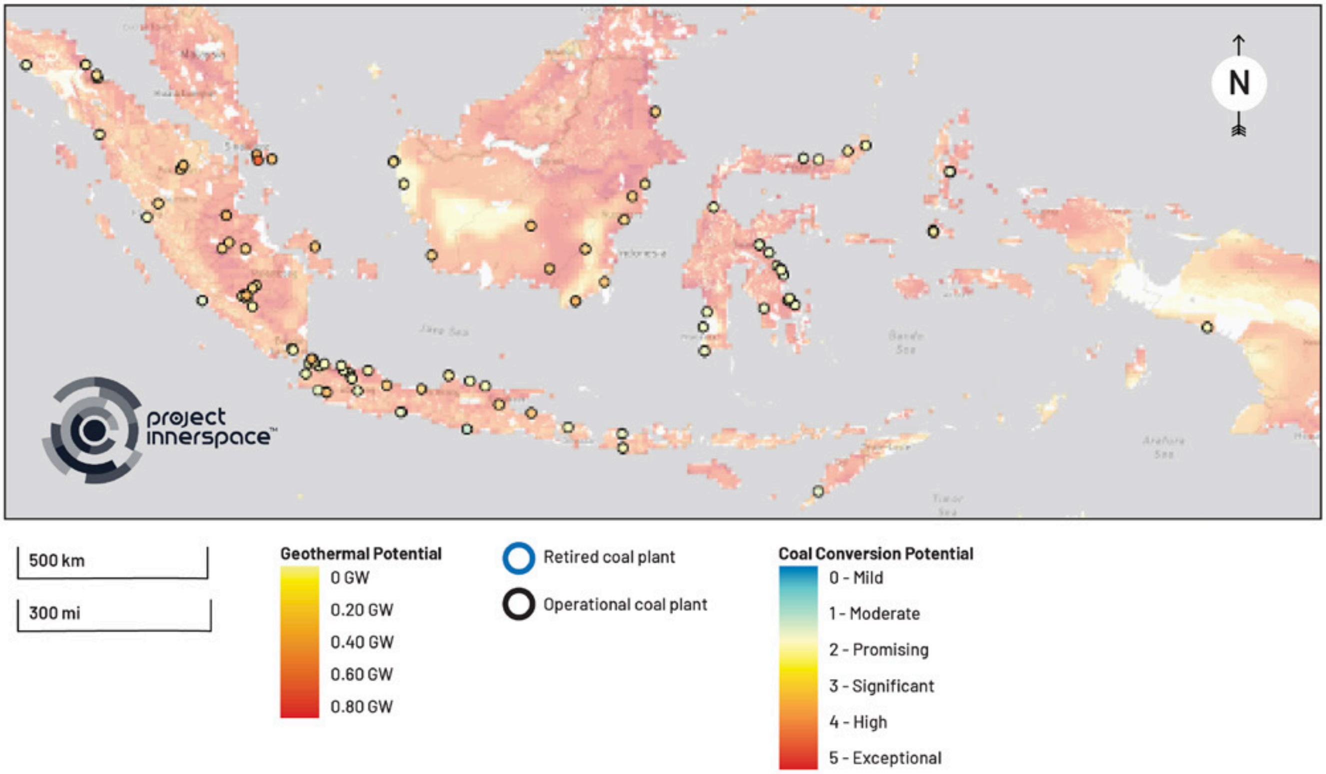
Given Indonesia's long history with geothermal, a strong regulatory foundation already guides geothermal electricity development, but it must evolve to reflect geothermal's multi-sector capabilities. Current instruments—such as the Energy Law, Electricity Law, National Energy Policy, RUKN, and RUPTL—still treat geothermal predominantly as an electricity resource. Recognizing geothermal as an asset for power, heat, and cooling can give investors and developers a clearer, more predictable basis for project development.

Analysis in Chapter 3 of this report estimates that Indonesia holds 2,160 gigawatts of geothermal technical potential—21 times the current installed capacity and much more than the current estimate of 27 gigawatts of hydrothermal resources (see **Figure ES.1**). The International Energy Agency (IEA) also estimates the nation has about 60 terawatts of thermal energy suitable for industrial heat and cooling.[3] By 2050, geothermal could meet nearly 90% of Indonesia's process-heat demand in key manufacturing sectors. (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential.") In its recent report *The Future of Geothermal Energy*, IEA noted that in Southeast Asia, "next-generation geothermal could be an affordable domestic option to reduce current coal-fired dependency while ensuring continued energy security."[4] In practical terms, this means Indonesia can combine proven hydrothermal development with modular next-generation systems, thermal networks, and district cooling to serve growing cities and industrial corridors.

This opportunity directly supports Indonesia's coal transition. Coal supplies about 40% of the nation's primary energy,[5] and many industries rely on coal boilers for heat. Deploying roughly 15 gigawatts electric and 15 gigawatts thermal within a decade—ramping up to 25 gigawatts electric and 35 gigawatts

COAL FACILITIES OVERLYING GEOTHERMAL RESOURCES



ES.2: Map showing the cumulative geothermal potential between 0 meters and 5,000 meters, with a 150°C temperature cutoff, representing the minimum threshold for power generation, overlaid with coal-fired power plants and their suitability for geothermal conversion based on Project InnerSpace's Weighted Overlay Analysis. GW = gigawatts. Source: Project InnerSpace. (2025). *Today's Power Potential GW 5000m* [Power Generation Module]. GeoMap; Project InnerSpace. (2025). *Coal Plant WOA* [Indonesia Module]. GeoMap

thermal by 2045—could replace a significant share of this coal use. In the power sector, these additions could raise renewable generation to roughly 67% by 2045,[6] enabling early retirement or repurposing of coal plants in Java and Sumatra, where geothermal prospects and demand align.

Recent regulations establish a pathway for retiring and replacing coal with renewable generation. Next-generation geothermal can accelerate these transitions by repurposing existing plant sites, leveraging nearby transmission nodes, and using plant wastewater to support engineered reservoirs (see **Figure ES.2**). Legacy plants such as Suralaya and Bukit Asam sit close to high-quality geothermal zones and could serve as early conversion sites.

Indonesia's workforce has decades of geothermal development experience, supported by a deep pool of geoscientists and drillers. The country also has an experienced oil and gas sector whose rigs, services, and safety practices transfer readily to geothermal. Universities, state-owned enterprises, and private developers have long collaborated across exploration, drilling, and field operations, creating an integrated supply chain that can be expanded and redirected to accelerate additional conventional geothermal development and next-generation demonstrations.

Increasing geothermal energy development also supports grid reliability. Indonesia's power system remains fragmented: Java-Madura-Bali and parts of Sumatra are interconnected, while many islands rely on smaller, isolated grids (see **Figure ES.3**). Nearly all renewable potential lies outside Java, even though Java consumes the bulk of the nation's electricity. RUKN anticipates major transmission expansion—48,000 kilometers of new lines and 108,000 substations—to close this gap. Strategically sited geothermal plants can ease pressure on new infrastructure by providing firm, dispatchable power near demand centers; stabilizing grids; and reducing the storage and long-distance transmission needed to integrate solar and wind.

Taken together, expanding geothermal across electricity, industrial heat, and cooling positions this resource as a central pillar of Indonesia's pathway to 70% renewables by 2060. This expansion can reduce energy costs, attract private investment, create more than 650,000 jobs, improve grid stability, and enhance regional development.

INDONESIA'S GRID TO DATE

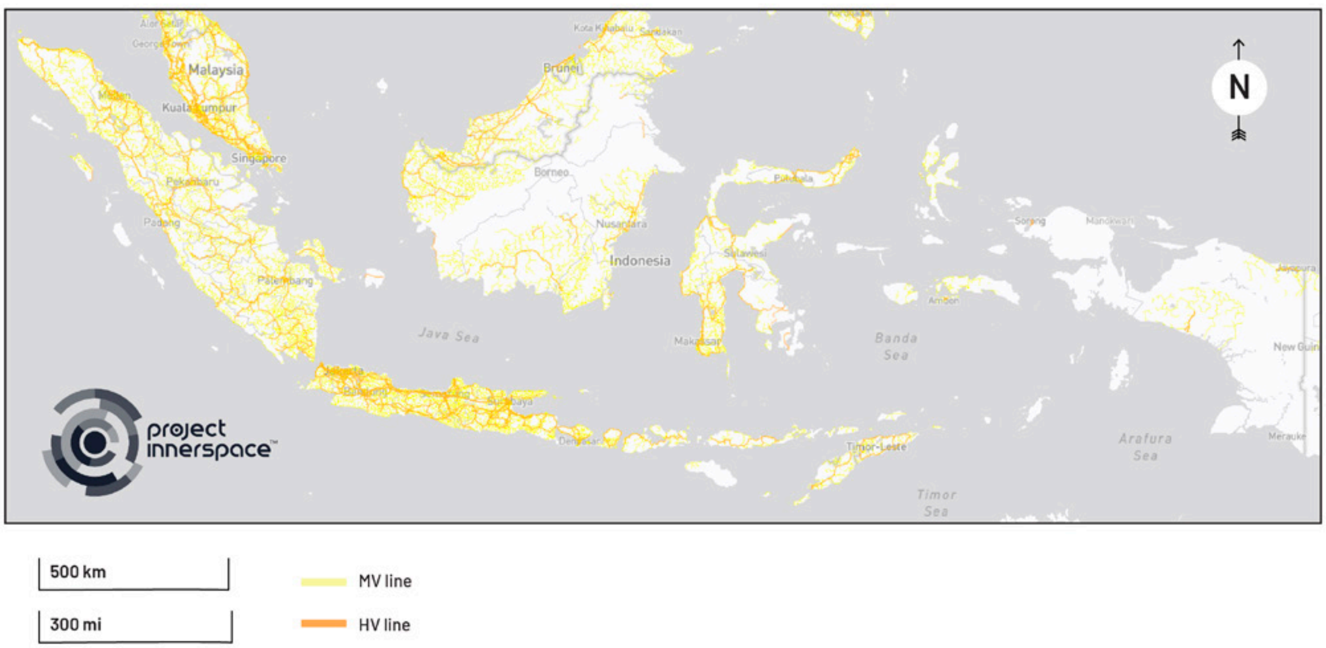


Figure ES.3: Indonesia's transmission network, highlighting Java's interconnection and the smaller, isolated grids of other islands. HV = high voltage; MV = medium voltage. Source: Arderne, C., Zorn, C., Nicolas, C., & Koks, E. E. (2020). [Predictive mapping of the global power system using open data](). *Scientific Data*, 7, 19; OpenStreetMap contributors. (2023). [Planet OSM](); OpenStreetMap. (n.d.). [OpenStreetMap]().

Expanding geothermal in Indonesia beyond its current hydrothermal resources brings many advantages:

- **Energy independence:** The country can benefit from tapping domestic heat to cut fuel imports, anchor critical loads like industrial parks and data centers, and keep value in local economies.
- **Always on, everywhere:** Geothermal provides round-the-clock electricity and thermal energy; stabilizes still-fragmented systems; eases peaks with cooling; and can be sited across Java, Sumatra, Sulawesi, Bali–Nusa Tenggara, Kalimantan, and Papua.
- **Jobs and investment:** An expansion of geothermal can mobilize private capital; broaden Indonesian supply chains; and support more than 650,000 skilled jobs across exploration, drilling, construction, operations, and services.
- **Increased competitiveness:** The country has 60 terawatts of thermal potential that direct-use heat and district cooling can tap into in order to lower fuel costs for industry and buildings. Next-generation electricity expands siting options, tapping a technical base of about 2,160 gigawatts.
- **Low-impact, reuse-ready deployment:** Next-generation geothermal can be sited in less environmentally sensitive areas, uses far less land and new transmission than most alternatives, and repurposes retired coal sites and existing corridors to cut costs and speed delivery.
- **Cleaner air, lower emissions:** By replacing coal, diesel, and furnace oil in power, heat, and cooling, geothermal cuts greenhouse gases and local pollutants, helping Indonesia meet its renewable energy milestones through 2030 and its long-term clean energy goals by 2060 while also delivering immediate public health benefits.

LEGISLATION, REGULATION, AND RECOMMENDED POLICIES TO EXPAND INDONESIA'S GEOTHERMAL INDUSTRY

Indonesia's geothermal framework is evolving, but the country must make legal updates to fully unlock the next generation of geothermal development identified in this report. Priority actions include updating definitions and licensing to explicitly allow next-generation geothermal, direct-use heat, and district-scale cooling, giving developers and financiers the clarity required to move forward with confidence. The 10 recommendations outlined in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," build on existing Indonesian instruments and global best practices to provide that roadmap. (See **Figure ES.4**).

To reach the proposed national goals of 15 gigawatts electric and 15 gigawatts thermal by 2035, scaling to 25 gigawatts electric and 35 gigawatts thermal by 2045, Indonesia needs a legal foundation that reflects how the sector is changing. Current statutes—particularly Geothermal Law No. 21/2014 and Government Regulation No. 7/2017, both written for conventional hydrothermal systems—do not yet recognize engineered reservoirs, closed-loop systems, or geothermal heat and cooling, despite their potential to meet nearly 90% of projected thermal demand by mid-century. Updating these instruments to clearly define next-generation geothermal and direct-use systems would be an important and immediate action that Indonesia could take to tap into its 2,160 gigawatts of technical potential.

Achieving these national deployment goals will also require more coherent and predictable permitting and stronger inter-ministerial coordination. Even with the Online Single Submission platform, geothermal projects still encounter fragmented authority, multi-step reviews, and slow approvals. A geothermal-specific fast lane anchored by the Ministry of

GEOTHERMAL POLICY RECOMMENDATIONS FOR INDONESIA

UNLEASH INDONESIA'S NEXT-GENERATION GEOTHERMAL POTENTIAL

- Update Geothermal Laws to Clearly Address Next-Generation and Direct-Use Geothermal
- Set National Targets for Geothermal Electricity and Industrial Heat and a Pathway to Get There
- Power Industry and Data Centers with Geothermal Heat and Cooling
- Make Geothermal Cooling Core to Urban Development

MOBILIZE INVESTMENT AND ACCELERATE SCALE

- Fast-Track Permitting, Administrative Coordination, and Other Procedures
- Reduce Financial Risk with Open Data and Expanded Exploration Programs
- Use Collective Procurement to Lower Project Costs
- Standardize Long-Term Geothermal Power Contracts

STRENGTHEN COMMUNITY TRUST AND BENEFITS

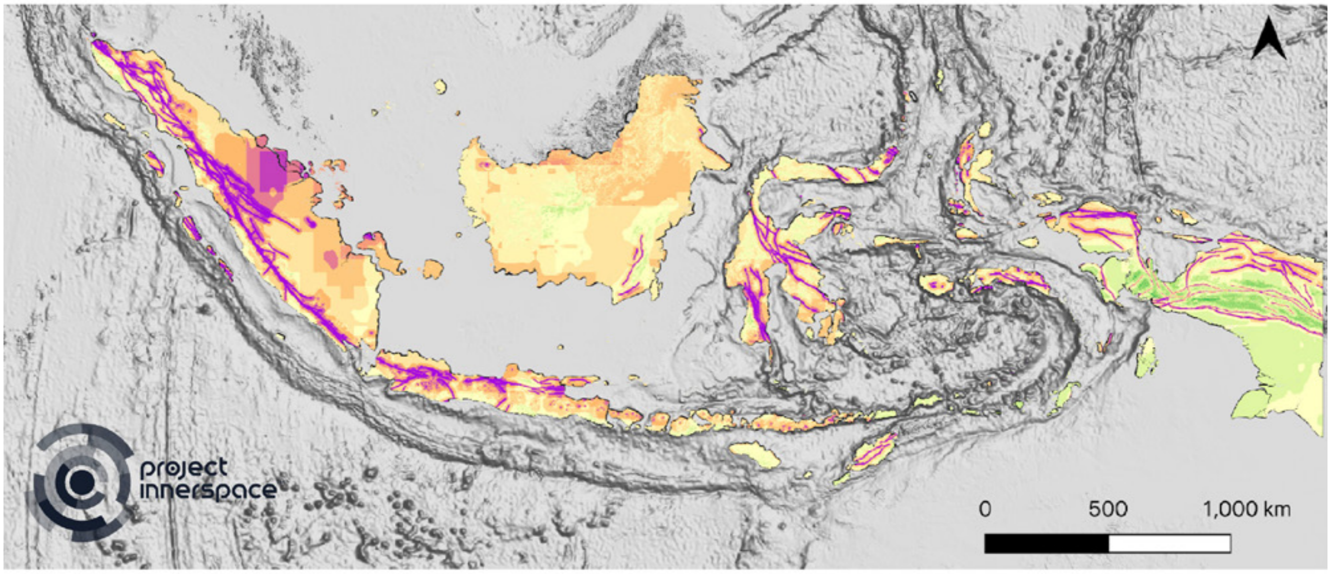
- Empower Community Participation and Guarantee Community Benefits by Reforming Geothermal Production Bonuses
- Expand the Geothermal Ecosystem to Unlock Local Jobs

ES.4: Overview of 10 policy recommendations to help unlock a new era of geothermal growth in Indonesia. Source: authors.

Energy and Mineral Resources (MEMR) as the single coordinating authority would streamline licensing, reduce duplicative procedures, and establish statutory timelines that match the urgency of Indonesia's 2035 and 2045 targets. Integrating updated Indonesia Standard Industrial Classifications (KBLIs) for direct-use heat and cooling—alongside expanded open-data requirements and accelerated implementation of early-stage risk-sharing mechanisms such as the Government Drilling Scheme[7] and the Geothermal Resource Risk Mitigation Project[8]—would give developers a clear, more dependable pathway from exploration to construction. Together, these reforms would help mobilize private and public capital at the scale required for Indonesia's next phase of geothermal growth.

Ultimately, long-term progress depends on community trust and clearly visible local benefits, especially as development expands into more regions. While

INDONESIA'S GEOTHERMAL RESOURCES MAP



Potential geothermal resources based on Weighted Overlay Analysis (WOA):

- Conventional (hydrothermal power)
- Next-generation (power)

Next-generation (direct use):

- Direct use and district cooling
- Low-temperature industrial heating and cooling
- Geothermal heating and cooling

Figure ES.5: Indonesia's geothermal resource map identifying regions best suited for geothermal technologies based on underlying thermal and subsurface characteristics, via the Project InnerSpace Weighted Overlay Analysis, designed to identify and prioritize areas with geothermal potential based on key geological and geophysical factors. Source: Project InnerSpace. (2025). *Indonesia Weighted Overlay Analysis Data Set*.

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geothermal revenue sharing through Revenue Sharing Funds (DBH) provides a financial channel for host regions, outcomes vary widely and often lack transparency, fueling hesitancy.

Harmonizing geothermal revenues within a unified geothermal production bonus by consolidating DBH, non-tax geothermal revenues, and developer contributions would create a transparent, accountable system for investing in schools, clinics, geothermal cooling networks, industrial-heat pilots, and workforce training in host communities. Linking fund access to compliance with free, prior, and informed consent; corporate social responsibility obligations; and Certificates of Operational Worthiness can ensure that communities participate directly in the rewards of development. A trusted, community-centered system will help sustain the pace of geothermal deployment required to meet Indonesia's 2035 and 2045 ambitions—and sets the stage for targeting development in the regions with the strongest resource potential.

EXPANDING THE SCOPE

Chapter 3, "Beneath the Archipelago: Indonesia's Geothermal Systems," and its supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities," identify geothermal opportunities across Java, Sumatra, Sulawesi, Bali–Nusa Tenggara, Kalimantan, and Papua. Conventional hydrothermal remains essential at proven fields, with step-outs, make-up wells, and capacity additions. In parallel, next-generation systems—which unlock heat in areas with limited permeability and fluids—expand the locations where geothermal projects can be located. This aspect includes the potential to repurpose energy and industrial installations such as retiring coal sites and brownfields, which reduces interconnection costs and takes advantage of existing roads, pads, and transmission.

Additionally, many next-generation designs have smaller surface footprints per unit of delivered energy, which simplifies environmental management and reduces potential community impacts. One result of this feature is that more communities and regions can take advantage of the technology. Next-generation systems can also pair with thermal storage to shift heat and cooling to daily peaks, offering operational flexibility across islands and grid types.

The combined portfolio—conventional where it is strongest and next-generation geothermal where it is most practical—can put Indonesia's vast geothermal potential to full use. (See **Figure ES.5**).

INDONESIA'S MOST PROMISING OPPORTUNITY: DIRECT-USE GEOTHERMAL

Direct-use geothermal is Indonesia's most promising and fastest-growing geothermal opportunity, with the potential to transform both industrial heat and urban cooling. Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," shows that geothermal could already meet 66.5% of national thermal demand, rising to nearly 90% by 2050 and displacing much of the coal and oil now used for process heat and cooling. Put another way: Today's thermal sector emits roughly 241 metric tons of carbon dioxide equivalent ($MtCO_2e$). The shift to direct-use geothermal could avoid about 160 $MtCO_2e$ annually and deliver 44% of Indonesia's 2030 energy sector climate goal. The opportunity is especially strong in industries with temperature needs below 200°C heat—textiles, agro-processing, dairy, pulp and paper, and food and beverage—where geothermal can directly replace fossil-fired boilers.

Geothermal could already meet 66.5% of national thermal demand, rising to nearly 90% by 2050 and displacing much of the coal and oil now used for process heat and cooling. Put another way: Today's thermal sector emits roughly 241 metric tons of carbon dioxide equivalent ($MtCO_2e$). The shift to direct-use geothermal could avoid about 160 $MtCO_2e$ annually and deliver 44% of Indonesia's 2030 energy sector climate goal.

Cooling is the fastest-growing driver of electricity demand in Indonesia, with air conditioner ownership expected to reach 85% by 2050, placing heavy pressure on grids in major urban population centers. Geothermal cooling—via ground-coupled systems, aquifer-source cooling, and district cooling networks—offers a scalable, land-efficient alternative. For example, Europe is widely deploying geothermal heating in urban areas, and Indonesia could do the same for geothermal cooling. Meeting even 10% of Indonesia's projected 2040 cooling demand with geothermal could avoid between 10 gigawatts and 15 gigawatts of peak power demand and prevent tens of millions of tons of carbon dioxide emissions each year.[9] Doing so would also ease strain on the grid during the hottest hours.

Direct-use opportunities are available across industrial corridors, campuses, hospitals, airports, and new districts such as Nusantara, all of which can anchor geothermal networks for heating and cooling. Coastal and delta cities—where large populations and concentrated demand align with favorable geology—are especially well suited for subsurface cooling.

Scaling systems will require not only investment and efficient permitting but also a skilled, multidisciplinary workforce capable of drilling, operating, and maintaining next-generation geothermal systems. As Indonesia expands industrial heat applications and district cooling networks, developing this specialized talent—engineers, drillers, technicians, and system operators—becomes essential. Launching geothermal cooling pilots is the fastest way to build the skills, standards, and supply chains needed for nationwide deployment.

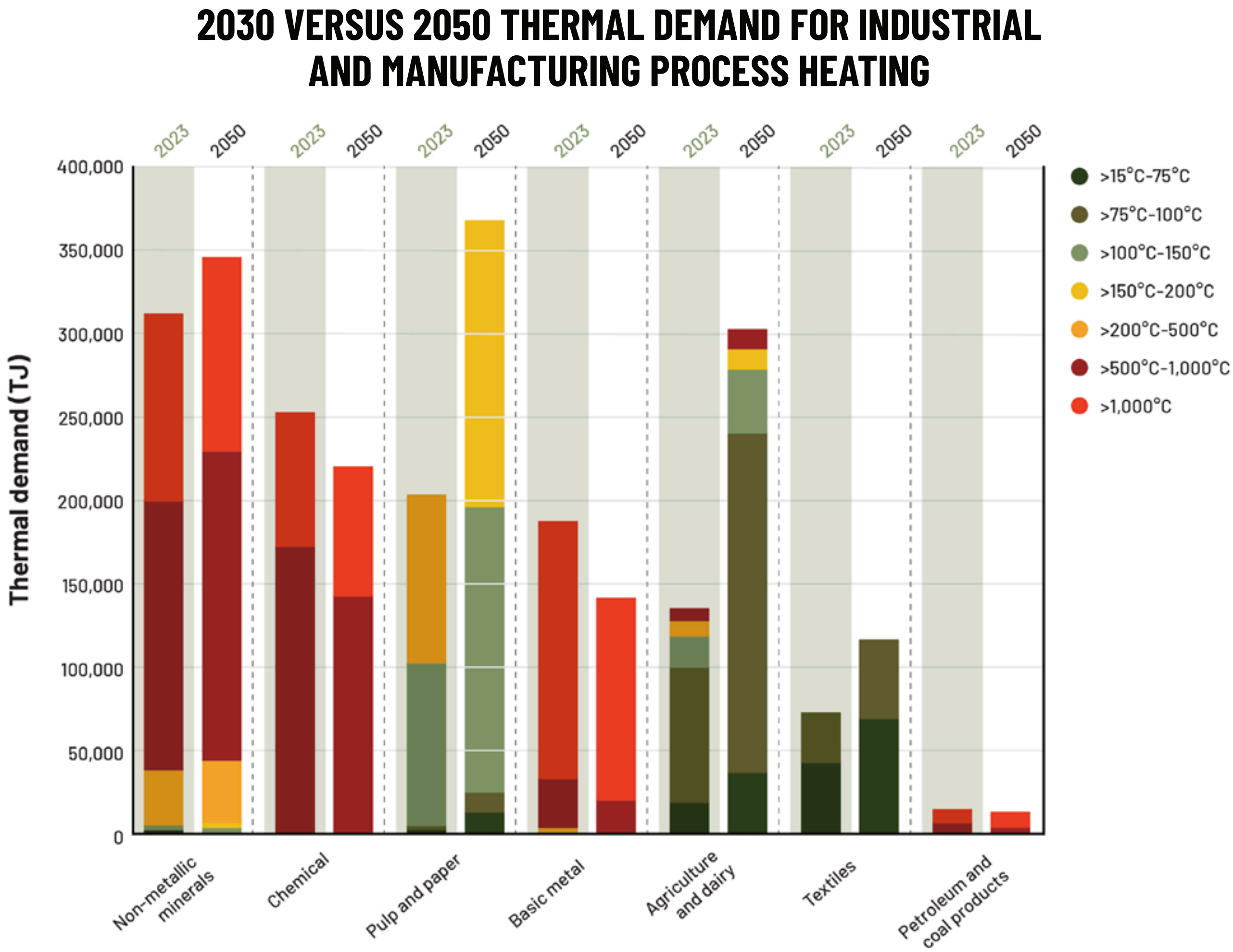

Figure ES.6: Indonesia's industrial and manufacturing total process heating thermal demand by temperature in the 2023 baseline year and the forecast for 2050. Full source list can be found at the end of Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential."

Data Centers

Indonesia's exceptional subsurface heat resources should not be overlooked as an energy source for data centers. Geothermal can deliver clean, always-on power at the source and cut the levelized cost of electricity by between one-third and one-half compared with grid-dependent models. PLN already serves about 1 gigawatt of data center load, but demand is projected to reach 4 gigawatts by 2033, with the processing requirements of artificial intelligence (AI) potentially doubling or tripling that trajectory. Next-generation geothermal can unlock prime digital corridors such as Jakarta–Purwakarta, Surabaya, Batam, and Medan by placing reliable, low-carbon baseload power directly beneath major fiber nodes and industrial clusters.

Batam is an especially strategic location because it can supply firm geothermal power with ultra-low latency across the strait to Singapore, a constrained data center hub. In other words, Batam can host green, high-density data processing centers that Singapore cannot site within its own borders, thereby functioning as an extension of Singapore's digital backbone. As global technology companies seek 24/7 low-carbon power for AI and cloud workloads, few countries combine geothermal capacity, fiber connectivity, and proximity to a world-class data hub as effectively as Indonesia.

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

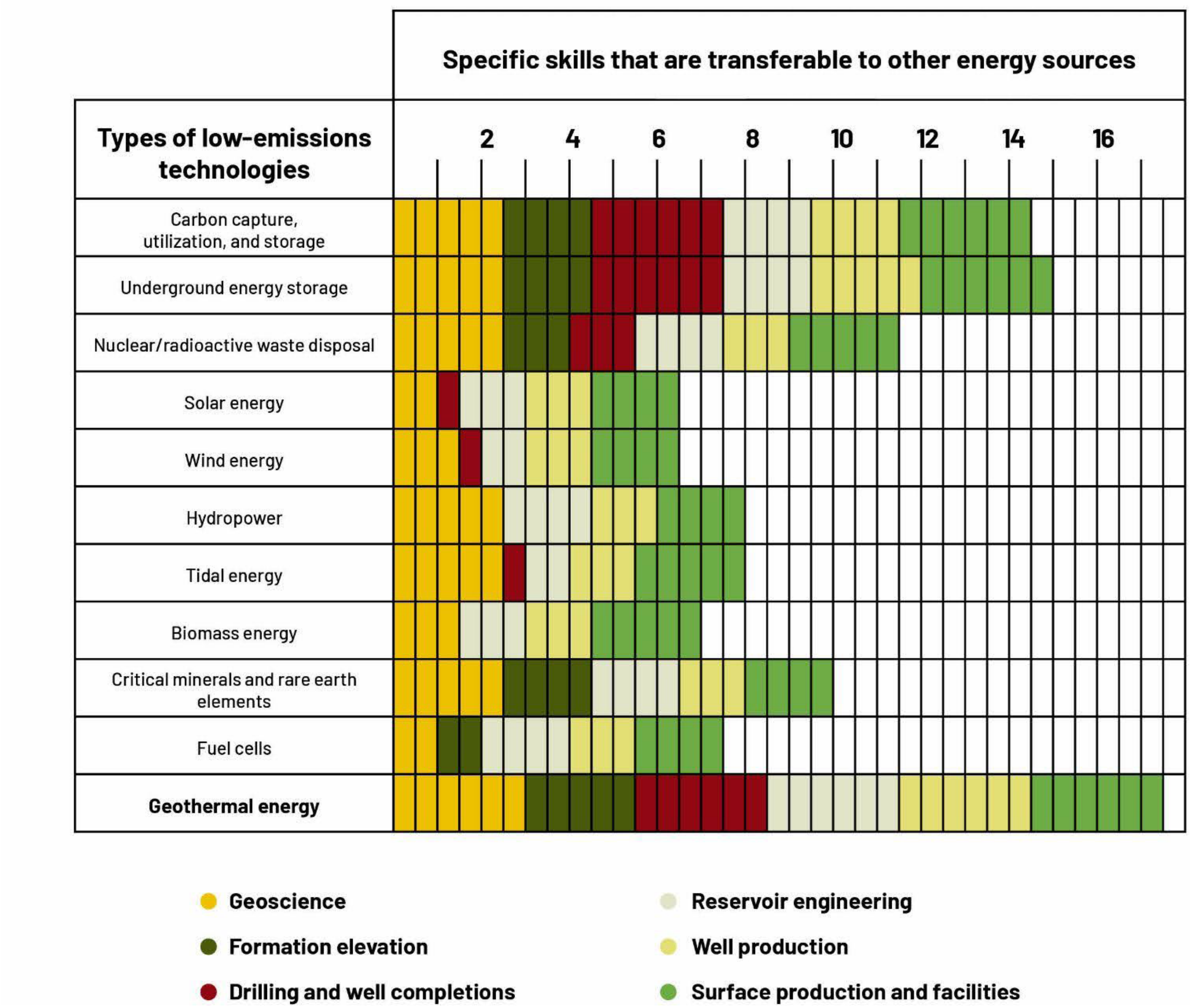

Figure ES.7: Geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). *Oil and gas skills for low-carbon energy technologies*. Society of Petroleum Engineers Annual Technical Conference and Exhibition.

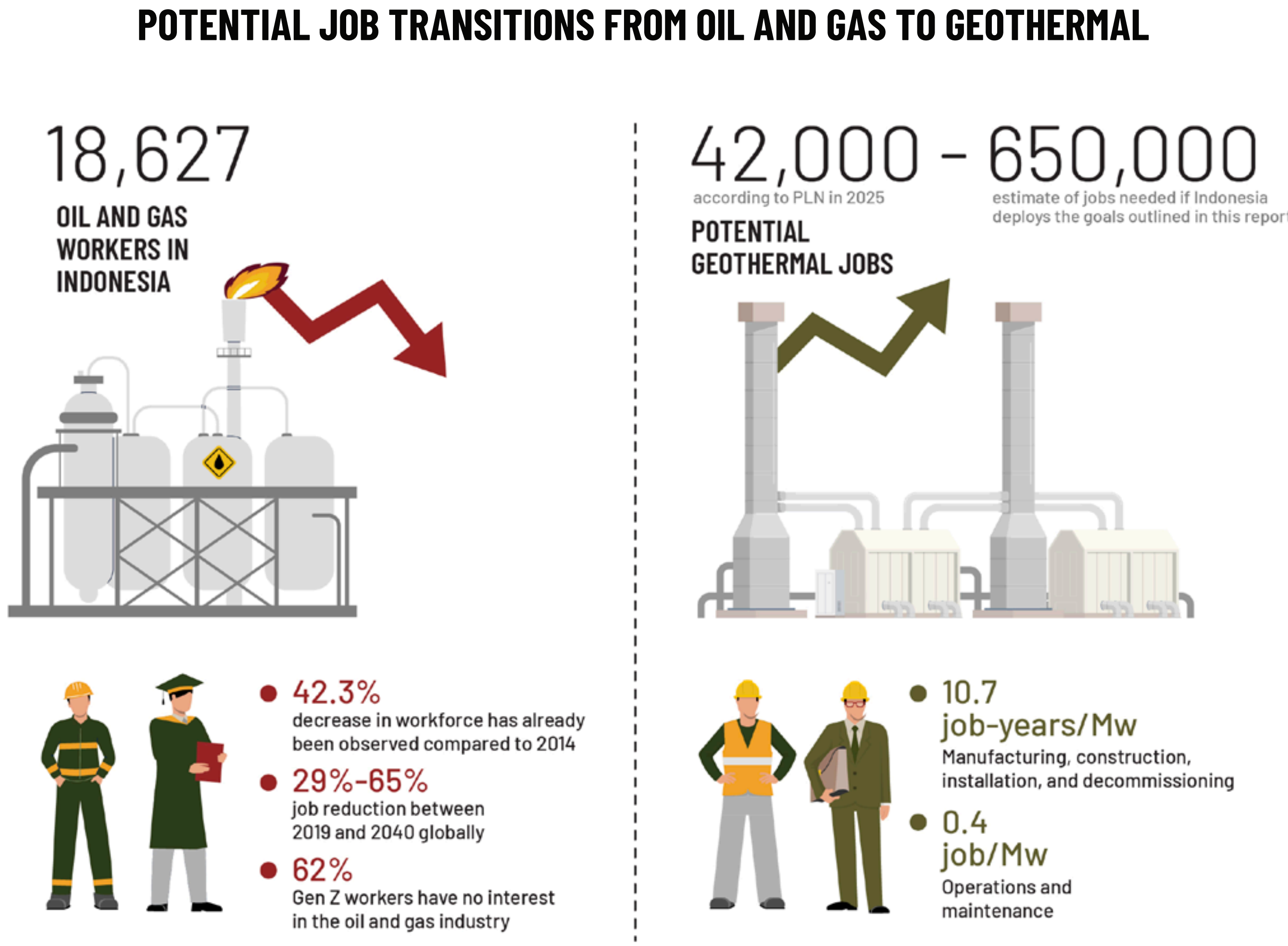

Figure ES.8: Estimated number of potential job transitions from oil and gas to geothermal. Source: Indonesian Petroleum Association. (2017). *Indonesia overview*; Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas). (2023). *Annual report 2023*; Ernst & Young. (2020). *Preparing for the future now: Rethinking the oil and gas workforce in 2040*. EY Global; Halimatussadiah, A., Irhamni, M., Riefky, T., Nur Ghiffari, M., & Razak Afifi, F. A. (2024). *Employment impacts of energy transition in Indonesia*. Institute for Economic and Social Research, University of Indonesia; PLN. (2025). *PLN electricity supply business plan (2025-2034): Enhancing national energy resilience and sustainability*. Government of Indonesia.

LEVERAGING EXISTING KNOW-HOW

Indonesia's oil and gas and conventional geothermal drilling ecosystem has rigs, drillers, cementing crews, logging specialists, stimulation teams, and project managers whose skills transfer directly to geothermal development (see **Figure ES.7**). Depending on how much geothermal is produced, estimates of new jobs created range from 42,000 to upwards of 650,000 if Indonesia meets the combined electricity and thermal targets outlined in this report (see **Figure ES.8**). However, universities are not producing graduates at anywhere near this scale. Indonesia currently generates fewer than 20 geothermal-focused graduates per year. Meeting even the low end of workforce demand would require between six and seven times more graduates; the high end of the range would require between 15 and 30 times more. Indonesia's long oil and gas heritage is one of its greatest assets for building a geothermal workforce and gives the country a ready-made talent pipeline that is well positioned to fill this gap.

This gap underscores the need for much stronger coordination among the Ministry of National Development Planning (Bappenas); MEMR; the Ministry of Manpower; and the Ministry of Education, Culture, Research, and Technology, whose mandates for planning, training, certification, and curriculum are currently fragmented and difficult for industry to navigate. Better institutional alignment—particularly through unified occupational mapping, standardized competency frameworks, and expanded certification pathways—will be essential to meet the pace and scale of geothermal development.

Highlighting this continuity through university outreach, vocational programs, and streamlined fast-track certifications can help the geothermal field attract students who might otherwise default to oil and gas, where career interest remains high. With the right investment in training and institutional coordination, Indonesia can grow a workforce that is not only capable of supporting gigawatt-scale geothermal expansion but also excited by the chance to help shape the country's clean energy future.

LOW-IMPACT GROWTH THAT SHARES BENEFITS LOCALLY

Geothermal's benefits extend beyond carbon and air quality gains; with the right governance, the sector can also strengthen social equity and shared prosperity. Indonesia already has the foundations for fair geothermal development through its revenue-sharing mechanisms and its emerging concept for a transparent geothermal fund, which can channel DBH allocations, royalties, and corporate commitments directly into *wilayah adat* (traditional territory) communities with clearer visibility and accountability. (See Chapter 6, "Common Ground: Building Trust and Transparency in Indonesia's Energy Transition.") Strengthening this approach will also support more effective administration across ministries, providing a clearer structure for how benefits are tracked, delivered, and reported at the national and regional levels. Improved coordination—particularly among MEMR, the Ministry of Environment, the Ministry of Forestry, the Ministry of Home Affairs, and local governments—can streamline community engagement processes, reduce duplication, and ensure that geothermal development reinforces local trust while supporting inclusive regional development.

Finally, and most important, geothermal stands out as one of Indonesia's lowest-impact energy options. Much of the country's 2,160 gigawatts of geothermal technical potential lies outside protected ecosystems, and next-generation systems can access this heat without entering steep volcanic terrain or high-biodiversity conservation areas. Modern practices—such as closed-loop designs, improved reinjection, microseismic monitoring, and noise control—further minimize disturbance and safeguard water resources, strengthening Indonesia's commitment to environmental stewardship. (See Chapter 8, "Keeping Geothermal Green: Safeguarding Nature and Communities in a New Era of Growth.") These approaches keep land footprints small and avoid the large-scale clearing required by many other renewable technologies. Next-generation projects also rely heavily on civil works, construction, monitoring, and operations roles that can be filled by non-skilled and semiskilled workers, widening the pool of Indonesians who benefit directly from geothermal development while keeping sensitive ecological zones intact.

CONCLUSION

With vast resources and deep domestic expertise, Indonesia can expand geothermal into a national platform for not only electricity but also industrial heat, cooling, and data center growth. The pathway is clear: Set ambitious targets; update legal frameworks; scale direct use; and deploy next-generation systems in industrial parks, cities, and brownfields. Acting now will deliver reliable power, competitive energy for industry and data centers, cleaner air for communities, and a world-class domestic supply chain and workforce. Broadening Indonesia's geothermal focus will bring immediate benefits with cleaner air, lower energy costs, and new jobs, and these benefits will endure for decades through resilient power, reduced fuel imports, and steady progress toward national climate goals.

CHAPTER REFERENCES

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2 PT Perusahaan Listrik Negara (Persero). (2025). *Dissemination of RUPTL PLN 2025-2034: Beyond the greenest RUPTL*. https://gatrik.esdm.go.id/assets/uploads/download_index/files/06524-bahan-dirut-pln.pdf

3 International Energy Agency (IEA). (2024). *The future of geothermal energy*. https://www.iea.org/reports/the-future-of-geothermal-energy. See p. 49.

4 IEA, 2024, p. 90.

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6 Several assumptions were made for the estimate: (i) Capacity factor was assumed at 80%, quoted from Ea Energy Analyses. (2024). *Technology data for the Indonesian power sector 2024: Catalogue for generation and storage of electricity*. https://gatrik.esdm.go.id/assets/uploads/download_index/files/c4d42-technology-data-for-the-indonesian-power-sector-2024-annoteret-af-kb-.pdf. (ii) Total generation for the higher geothermal capacity scenario was kept the same as in the total generation of MEMR, *National Electricity General Plan*, 2025. This was done by reducing the generation from coal.

7 Soerono, D. (2017, December 4). *Risk mitigation and the restructuring of geothermal funds in Indonesia*. ThinkGeoEnergy. https://www.thinkgeoenergy.com/risk-mitigation-and-the-restructuring-of-geothermal-funds-in-indonesia/

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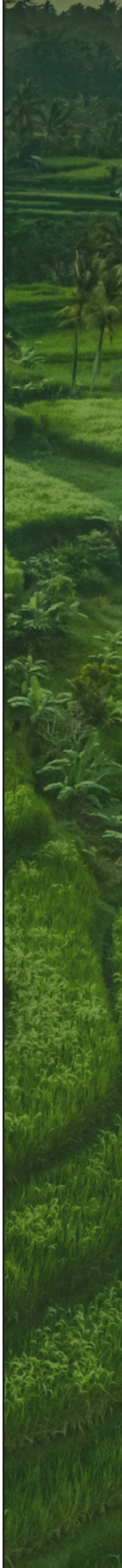
9 United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) & United Nations Environment Programme (UNEP). (2024, August 6). *Indonesia sets path for climate-friendly cooling with National Cooling Action Plan*. https://www.unescap.org/news/indonesia-sets-path-climate-friendly-cooling-national-cooling-action-plan

Part I

The Basics of Geothermal



Chapter 1

Geothermal 101: Overview of Technologies and Applications

Project InnerSpace

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas industry, we can access underground heat in significantly more locations than was historically possible. The potential for geothermal development across a variety of applications and use cases is now truly global.

Geothermal is a naturally occurring, ubiquitous, and clean energy source. About 6,400 kilometers from the planet's crust, the core of the Earth is roughly as hot as the surface of the sun—approximately 6,000°C (see **Figure 1.1**). Geothermal heat is present across the entire planet—on dry land and on the ocean floor—and offers enough potential energy to power the whole world thousands of times over.

These resources have been exploited for centuries: In the 19th century, people started using heat from the Earth for industrial processes like heating and cooling buildings and generating electricity. The first documented instance of geothermal electricity generation was in Larderello, Italy, in 1904.[1]

But throughout history, these conventional hydrothermal systems have been geographically limited. They require specific subsurface conditions—sufficient heat, water, and rock permeability—which are typically found in tectonically active regions such as Indonesia, Iceland, and the western United States.[2] Only when all three of these factors overlapped was there an exploitable geothermal resource. Even then, finding such a resource typically required a fourth natural phenomenon: an obvious surface manifestation, such as a geyser or hot spring.[3] The need for these specific conditions severely restricted geothermal's broader global use, as few locations met these natural requirements.

Today, geothermal energy provides only 0.5% of global electricity.[4] Adoption of this energy is much higher in (primarily) volcanic regions, where geothermal resources—those conventional hydrothermal systems—are uniquely

TEMPERATURE OF THE EARTH'S INTERIOR

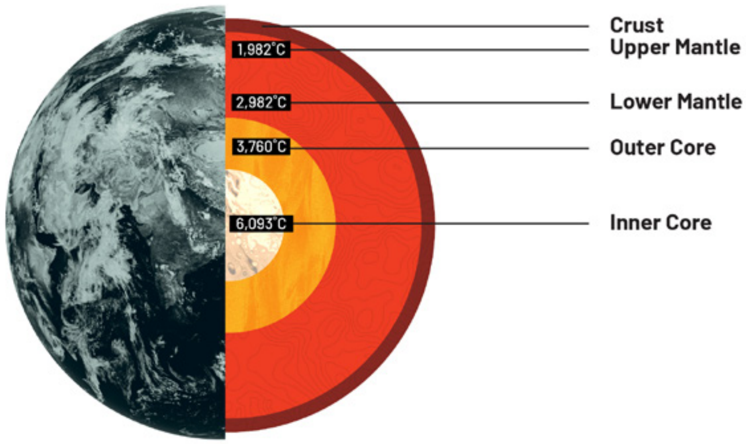


Figure 1.1: The temperature of the core of the Earth exceeds the temperature of the surface of the sun. Because the crust of Earth is an excellent insulator, enough heat is trapped beneath us to power the world thousands of times over. Source: Project InnerSpace.

COMPARING SURFACE FOOTPRINT

Geothermal has the smallest footprint of any renewable energy source

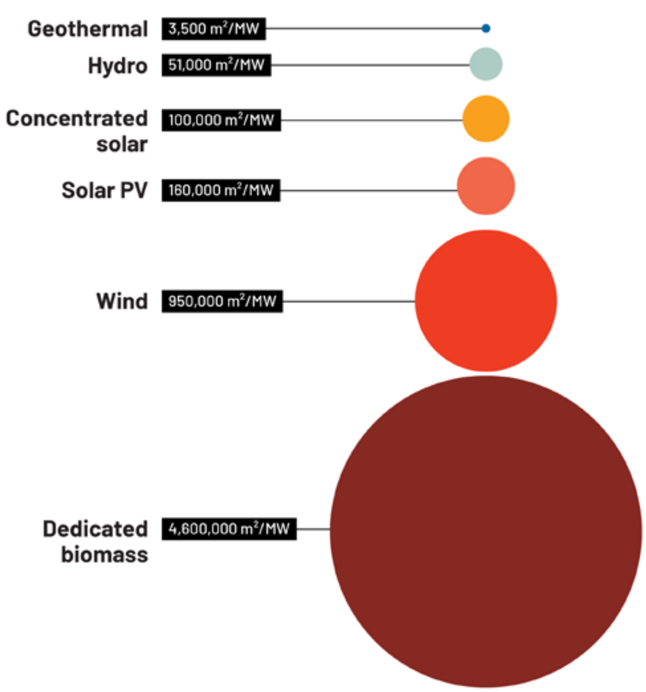


Figure 1.2: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. PV = photovoltaic. Source: Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). [Land-use intensity of electricity production and tomorrow's energy landscape](). *PLOS ONE*, *17*(7), e0270155; National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology*.

Geothermal has the advantage of being a 24/7/365 clean baseload energy source. Unlike wind and solar, it is always on. Unlike natural gas and coal, it has no emissions or fuel costs. And unlike nuclear power, there is no need to dispose of radioactive material. Add to that, as shown in Figure 1.2, it has the smallest footprint of any power source.

close to the surface. Indonesia is the second-largest producer of utility-scale hydrothermal power in the world, at 2,653 megawatts.[5] Since its first power plant came online in 1983,[6] Indonesia has been a global leader in conventional geothermal electricity production, yet only 5% of the grid is powered by hydrothermal systems, indicating a major opportunity for growth.[7]

But now, adoption of geothermal for various uses can be higher in many other locations as well. How?

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas sector and a new generation of geothermal entrepreneurs, we can now access that heat in regions outside of the sensitive volcanic ecosystems that have previously defined geothermal potential in Indonesia. Geothermal projects that use these technologies are referred to as *next-generation geothermal*. These new approaches—such as advanced geothermal systems and geothermal for cooling—are expanding the future of geothermal energy beyond all of the previous geographical limitations. (See "The Evolution of Geothermal: From Constraints to Possibilities" later in this chapter.)

These newer technologies—directional drilling, deeper drilling, hydraulic fracturing techniques that create additional pore space for fluid flow, more efficient drill bits, or the introduction of fluids into subsurface areas where they may not naturally be present—can be very effective for electricity generation. They can enable us to create an artificial heat reservoir.

GEOTHERMAL ELECTRICITY GENERATION

With these new technologies, in general, the hotter the geothermal resource, the more efficient a geothermal power plant will be at producing electricity. The more efficient the production, the lower the cost. As shown in **Figure 1.4**, geothermal electricity generation is possible with fluid temperatures as low as 90°C using "binary" cycle power plants (in other words, two fluid cycles).[8,9] In these binary plants, hot water extracted from the reservoir passes through a heat exchanger to boil a separate low-boiling-point liquid; the vapor from this liquid spins a turbine to make electricity, while the geothermal water never enters the turbine.[10] Both fluids circulate in closed loops—the working fluid is cooled and reused, and the geothermal water is reinjected—keeping emissions to a minimum while enabling power generation from low to moderate temperatures. Flash steam and dry steam electric turbines (see **Figure 1.5**) can be used when the fluid temperature rises above 180°C.[11] And some higher-temperature installations have started using novel binary-type configurations.

A report published in 2024 by the International Energy Agency (IEA) says "the potential for geothermal is now truly global" and next-generation geothermal systems have the technical potential "to meet global electricity demand 140-times over."[12] That analysis also notes that by 2035, geothermal could be highly competitive with solar photovoltaics and wind when paired with battery storage.

DIRECT USE: GEOTHERMAL HEATING, COOLING, AND INDUSTRIAL PROCESS HEAT

Approximately three-quarters of all heat used by humans—from building heating and cooling to industrial processes—is produced by directly burning oil, gas, and coal.[14] The rest is produced from other sources, like burning biomass, or via the electrification of heat—meaning electricity that is produced using solar, wind, or other fuels and then converted back into heat (for instance, electric strip heaters).

In Indonesia, the cooling and heating of buildings consumes about 60% of all energy use in both residential and commercial sectors.[15] The good news is that

COMPARING CAPACITY FACTOR

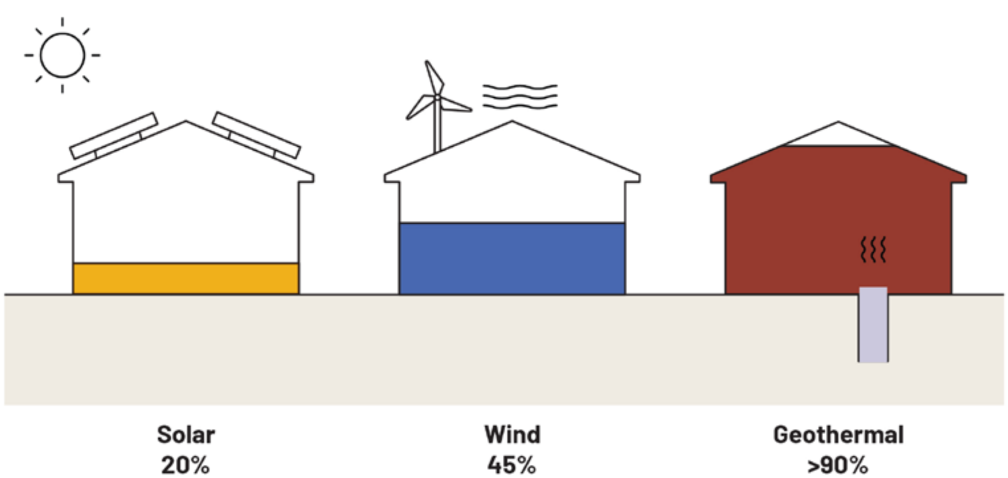


Figure 1.3: Capacity factor is the percentage of time that a power plant is generating electricity in a given day. Source: Adapted from International Energy Agency (IEA). (2024). [The future of geothermal energy](). IEA.

GEOTHERMAL APPLICATIONS AND TEMPERATURE REQUIREMENTS

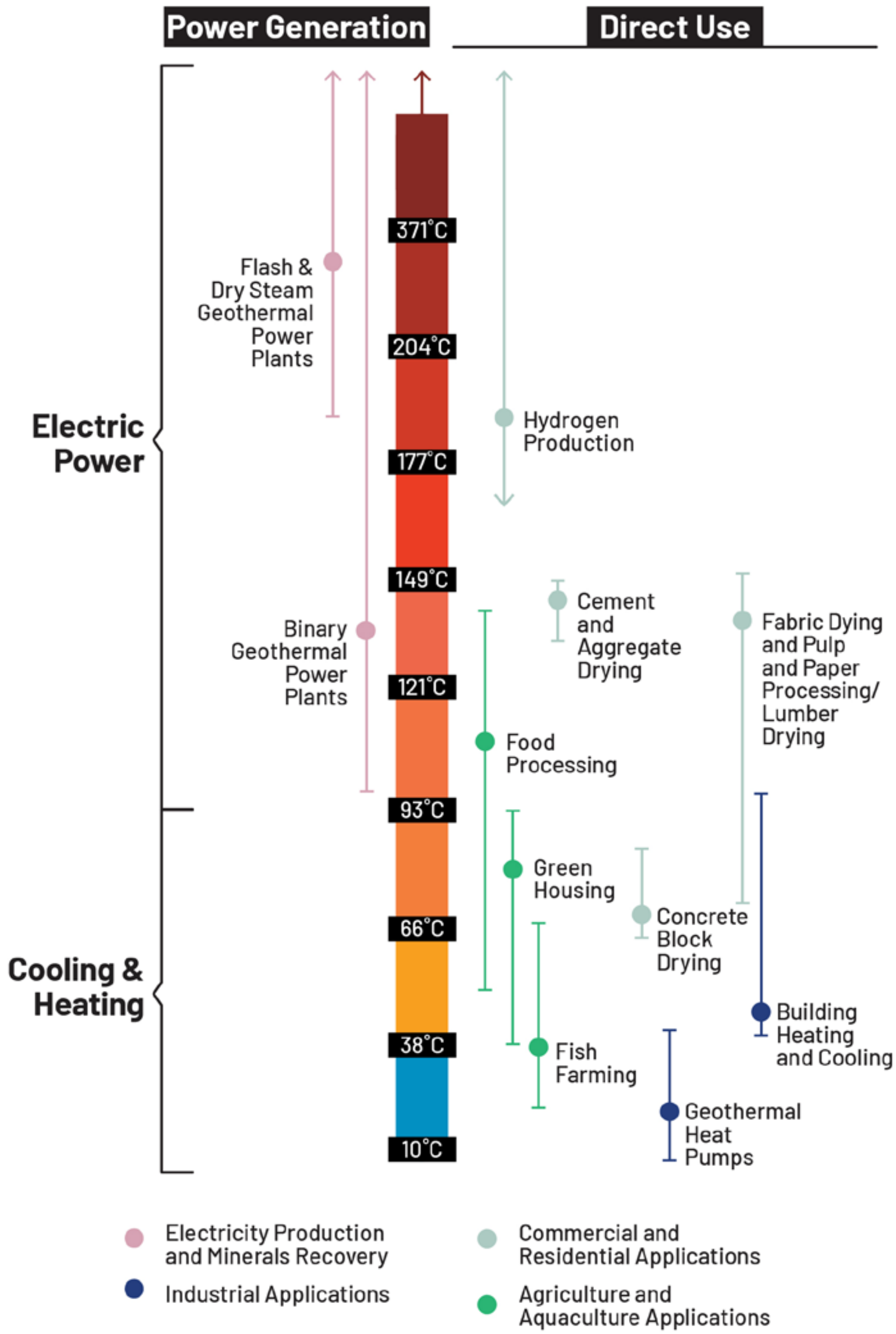


Figure 1.4: Geothermal energy can be used for generating electricity, heating and cooling homes and offices, and manufacturing. There are also new and emerging applications such as geothermal energy storage, where the subsurface serves as an earthen battery, and geothermal critical minerals extraction, for rare elements such as lithium. Source: Adapted from Porse, S. (2021). *Geothermal energy overview and opportunities for collaboration*. Energy Exchange.

TYPES OF GEOTHERMAL ELECTRICITY GENERATION

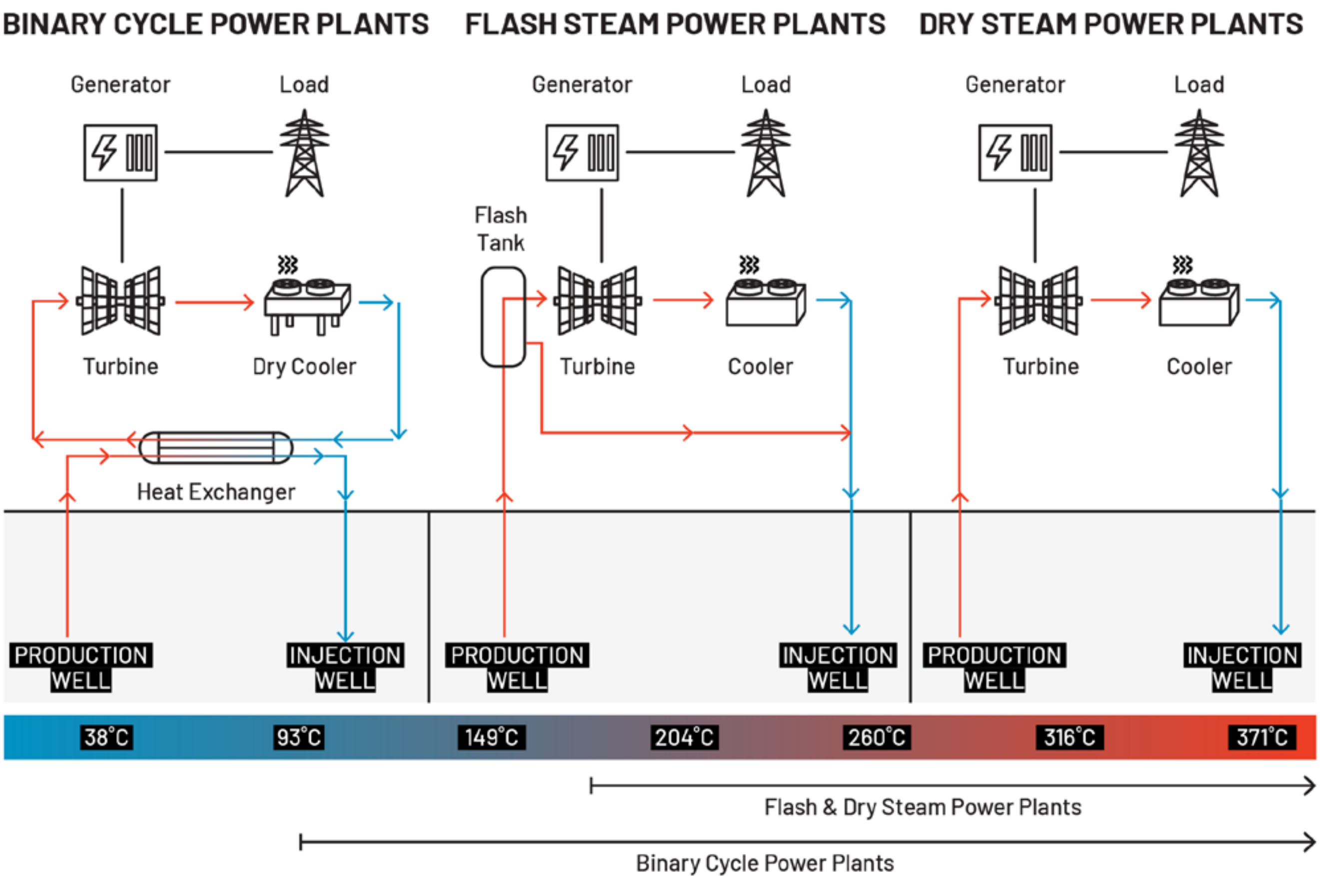


Figure 1.5: There are three primary configurations for generating electricity using geothermal: binary, flash, or dry steam. In general with these new technologies, the hotter the underground geothermal resource—whether conventional hydrothermal or next-generation geothermal—the more efficient the surface equipment will be at producing electricity. Binary geothermal electricity generation is possible with fluid temperatures as low as approximately 95°C. Flash and dry steam geothermal electric turbines can be used when fluid temperature rises above 182°C. Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin.

Globally, heat energy makes up about half of all energy consumption and contributes to about 40% of energy-related emissions.[13] To put it another way: Clean geothermal can address almost half of the world's energy demand. Until recently, this opportunity has been almost entirely overlooked.

geothermal technologies that can help meet this demand already exist: ground source heat pumps (geothermal heat pumps; see **Figure 1.6**), geothermal district cooling (large-scale connected heat pumps that are also known as *thermal energy networks*, or TENS), and absorption chillers (see the chapter on direct-use geothermal in this report for more information).

Industrial process heat is used to make everything from pens to paper, pasteurized milk to pharmaceuticals. Four of

GEOTHERMAL COOLING AND HEATING NETWORK

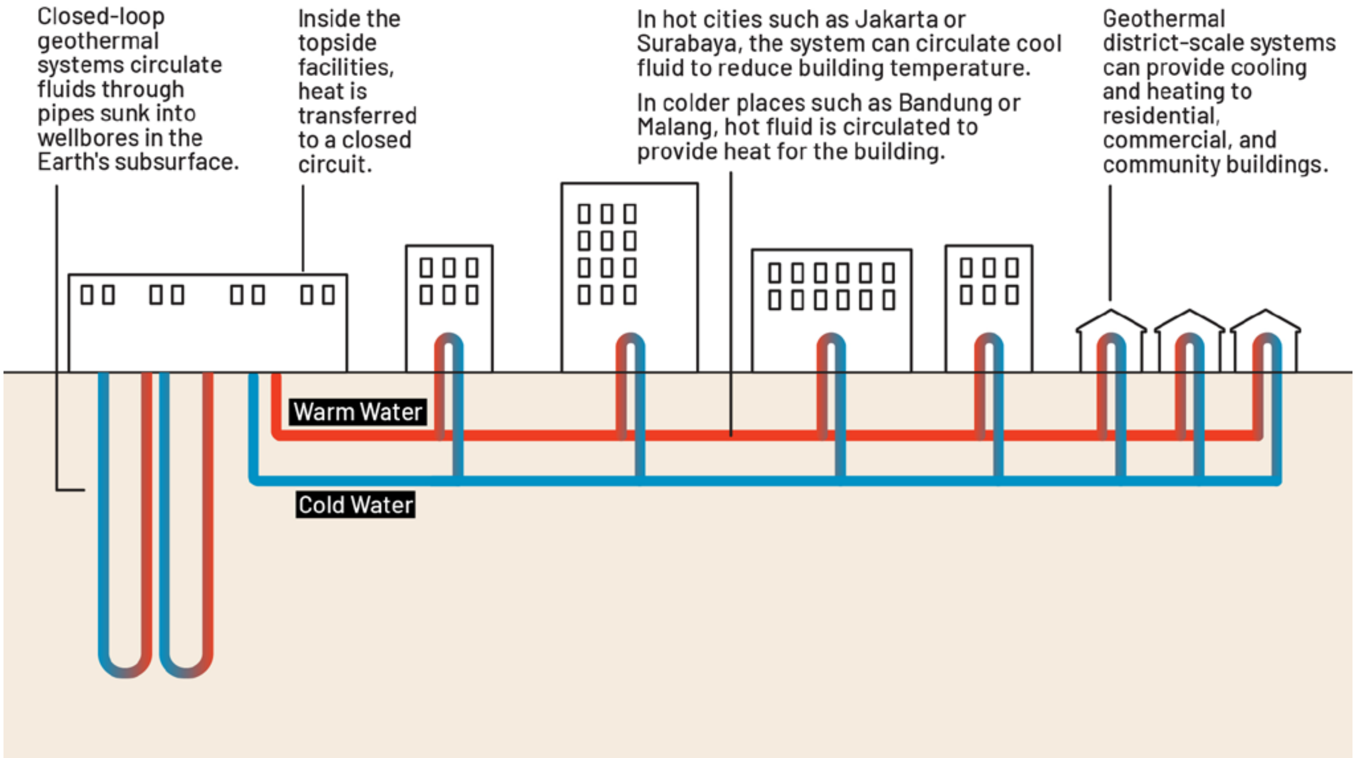


Figure 1.6: District cooling system fluid is typically brought to the surface at a target temperature of around 21°C. That fluid is then passed through a heat pump to provide cold water in the summer for cooling and hot water in the winter for heating. This style of cooling and heating can be more than twice as efficient as traditional HVAC systems as the thermal load is shared between buildings. Source: Adapted from U.S. Department of Energy. *Geothermal district heating & cooling*.

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the most critical materials in the modern world—fertilizer, cement, steel, and plastics—all require significant amounts of heat to produce. In the industrial sector, thermal consumes more than half of total energy use and contributes the majority of the sector's emissions.[16]

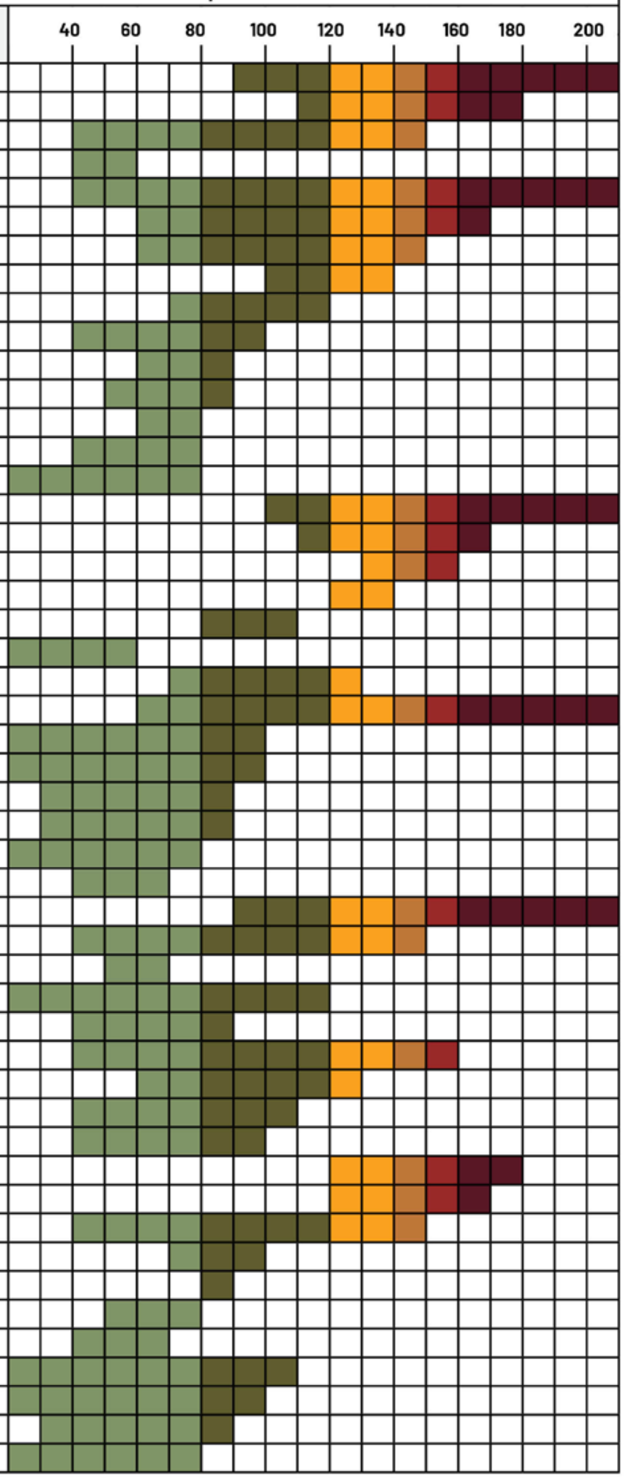
All building cooling and heating (heating, ventilating, and air-conditioning; HVAC) and 30% of heat used for manufacturing processes worldwide use temperatures below 150°C.[17] In many parts of the world, geothermally derived heat at this temperature is currently comparable in cost with coal, biomass, solar, and wind. The IEA report estimates that next-generation geothermal could economically satisfy 35% of all global industrial thermal demand for processes requiring temperatures below 200°C. The use of next-generation geothermal could thus save about 750 megatons of carbon dioxide (CO_2) emissions—equivalent to the annual emissions of Canada, the world's 12th-largest emitter.[18] **Figure 1.7** illustrates the range of sectors and processes that could use geothermal heat, with or without heat pumps, depending on whether a facility can reach the necessary heat at a reasonable subsurface depth.

Beyond space conditioning, geothermal energy can be used for refrigeration and commercial cooling operations, via a technology known as an *absorption chiller*. Absorption chillers are cooling systems that mainly use heat instead of electricity to drive refrigeration.

As illustrated in **Figure 1.9**, low-pressure liquid ammonia draws heat out of a cold storage or air-conditioned space, turning the ammonia into low-pressure vapor. This vapor is then absorbed by water, creating an ammonia solution,

INDUSTRIAL PROCESS TEMPERATURES AND HEAT PUMP TECHNOLOGIES

Sector	Process	Temperature°C
Paper	Drying	90°C-240°C
	Boiling	110°C-180°C
	Bleaching	40°C-150°C
	De-inking	50°C-70°C
Food and beverage	Drying	40°C-250°C
	Evaporation	40°C-170°C
	Pasteurization	60°C-150°C
	Sterilization	100°C-140°C
	Boiling	70°C-120°C
	Distillation	40°C-100°C
	Blanching	60°C-90°C
	Scalding	50°C-90°C
	Concentration	60°C-80°C
	Tempering	40°C-80°C
	Smoking	20°C-80°C
Chemicals	Distillation	100°C-300°C
	Compression	110°C-170°C
	Thermoforming	130°C-160°C
	Concentration	120°C-140°C
	Boiling	80°C-110°C
	Bioreactions	20°C-60°C
Automotive	Resin molding	70°C-130°C
Metal	Drying	60°C-200°C
	Pickling	20°C-100°C
	Degreasing	20°C-100°C
	Electroplating	30°C-90°C
	Phosphating	30°C-90°C
	Chromating	20°C-80°C
	Purging	40°C-70°C
Plastic	Injection molding	90°C-300°C
	Pellets drying	40°C-150°C
	Preheating	50°C-70°C
Mechanical engineering	Surface treatment	20°C-120°C
	Cleaning	40°C-90°C
Textiles	Coloring	40°C-160°C
	Drying	60°C-130°C
	Washing	40°C-110°C
	Bleaching	40°C-100°C
Wood	Gluing	120°C-180°C
	Pressing	120°C-170°C
	Drying	40°C-150°C
	Steaming	70°C-100°C
	Cocking	80°C-90°C
	Staining	50°C-80°C
	Pickling	40°C-70°C
Several sectors	Hot water	20°C-110°C
	Preheating	20°C-100°C
	Washing/Cleaning	30°C-90°C
	Space heating	20°C-80°C



Conventional heat pump less 80°C, established in industry

Commercially available high-temperature heat pump 80°C-120°C

Prototypes and technology demonstration, 120°C+

Ongoing laboratory research and development, 150°C+

Figure 1.7: Rough technology readiness levels of high-temperature heat pumps as of July 2023. Geothermal can enable industrial processes without heat pumps; however, combining the two technologies may prove even more useful. High-temperature industrial heat pumps above 100°C have seen significant advances in recent years. Sources: Arpagaus, C., et al. (2023). *Industrial heat pumps: Technology readiness, economic conditions, and sustainable refrigerants*. American Council for an Energy-Efficient Economy (ACEEE).

COOLING AND HEATING WITH GROUND SOURCE HEAT PUMPS

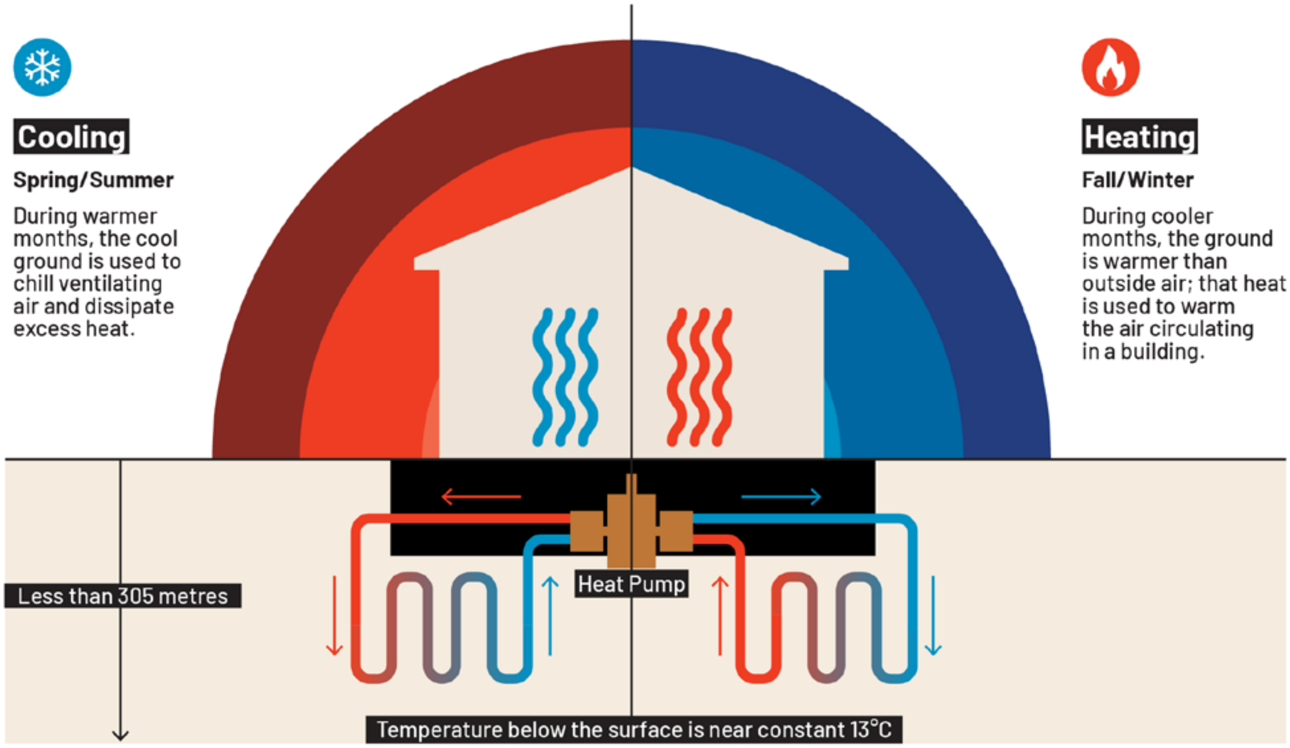


Figure 1.8: The constant temperature of the ground helps improve the efficiency of ground source heat pumps relative to other HVAC methods. Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin.

which is then pumped to a generator. There, geothermal heat can be used to boil the pressurized ammonia solution into high-pressure ammonia vapor, which will reject the heat into a cooling tower and turn it into low-pressure liquid ammonia to repeat the cooling cycle again.

By harnessing the Earth's heat in this way, absorption chillers provide cooling without the need for conventional electric compressors or burning fossil fuels. For Indonesia, where cooling already consumes between 40% and 60% of electricity in major cities,[19] geothermal absorption chillers offer a sustainable solution to meet the country's refrigeration and air-conditioning needs while easing the burden on the power grid and reducing greenhouse gas emissions.

GEOTHERMAL ENERGY STORAGE

The modern electricity grid is a delicate, vital system requiring constant monitoring to balance electricity production against electricity demands. With more electrons flowing onto the grid from intermittent energy sources such as wind and solar—which are only available when the sun shines or the wind blows—concerns about having power when needed have highlighted the need for energy storage.[20] Today, hydroelectric storage provides most global energy storage capacity,[21] and recent years have seen a significant expansion in the deployment of batteries for energy storage. A new approach—underground thermal energy storage, also known as *geothermal energy storage* (GES)—may offer an additional option.

GES systems capture and store waste heat or excess electricity by pumping fluids into natural and artificial subsurface storage spaces (e.g., aquifers, boreholes, mines). GES can be primarily mechanical, with hydraulic fracturing techniques storing pressurized fluid in subsurface reservoirs. Or it can be mechanical and thermal, with pressure and heat combined to return more energy than was required to pump the fluid underground.

CRITICAL MINERALS EXTRACTION

Fluids, or brines, are often produced from geothermal systems. These brines are rich in dissolved minerals, including lithium, which can be harvested to meet the growing demand for lithium-ion batteries in electric vehicles and electric-grid storage solutions. This dual-purpose approach—providing clean energy and a domestic lithium source—could reduce lithium extraction's environmental impact compared with traditional mining and improve the economics of a geothermal project.

At the Dieng Geothermal Field in Central Java, geothermal brines are moderately to highly saline and contain measurable concentrations of lithium and other dissolved minerals. Traditionally, these minerals were viewed as operational challenges, requiring costly mitigation to prevent scaling and mineral buildup that could obstruct fluid flow and damage infrastructure. Today, however, direct lithium extraction offers the possibility that these critical minerals can instead be extracted and sold, providing power plant operators with an additional revenue stream. A pilot project led by PT Geo Dipa Energi is exploring the feasibility of extracting lithium from Dieng's geothermal brine. Early estimates suggest the reservoir could yield up to 2,200 tons of lithium annually.[22]

ABSORPTION CHILLERS

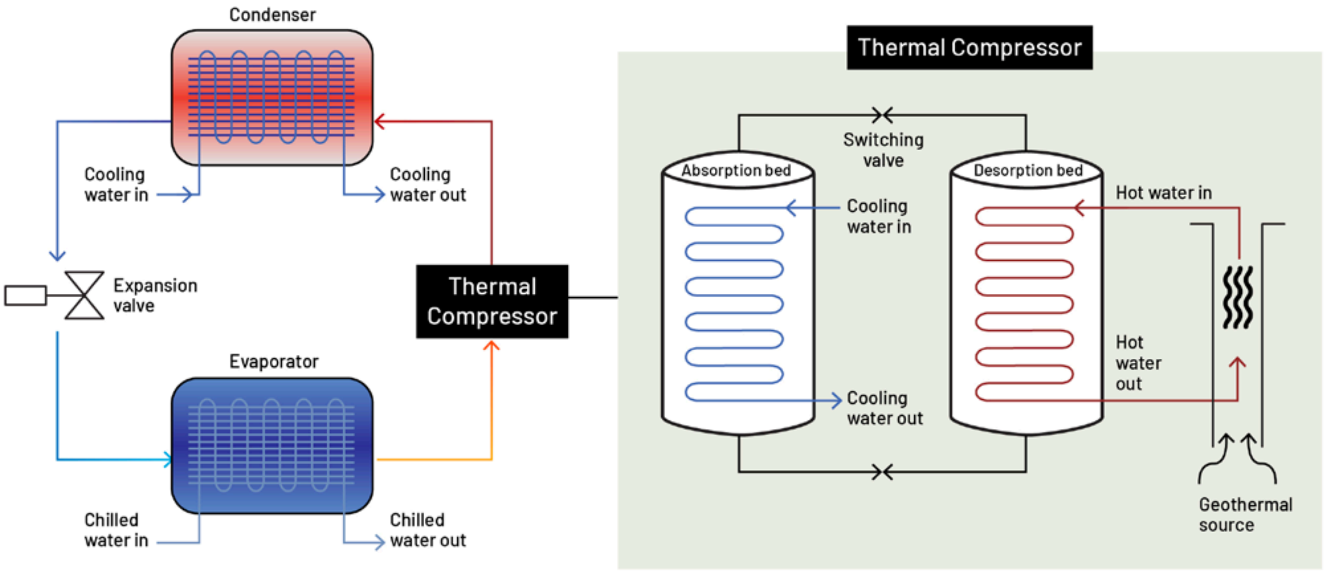


Figure 1.9: Energy flow and balance in the absorption coolers. Source: Modified from Ebrahimi, M., & Keshavarz, A. (2015). [CCHP technology]. In *Combined cooling, heating and power: Decision-making, design and optimization* (pp. 35–91). Elsevier.

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

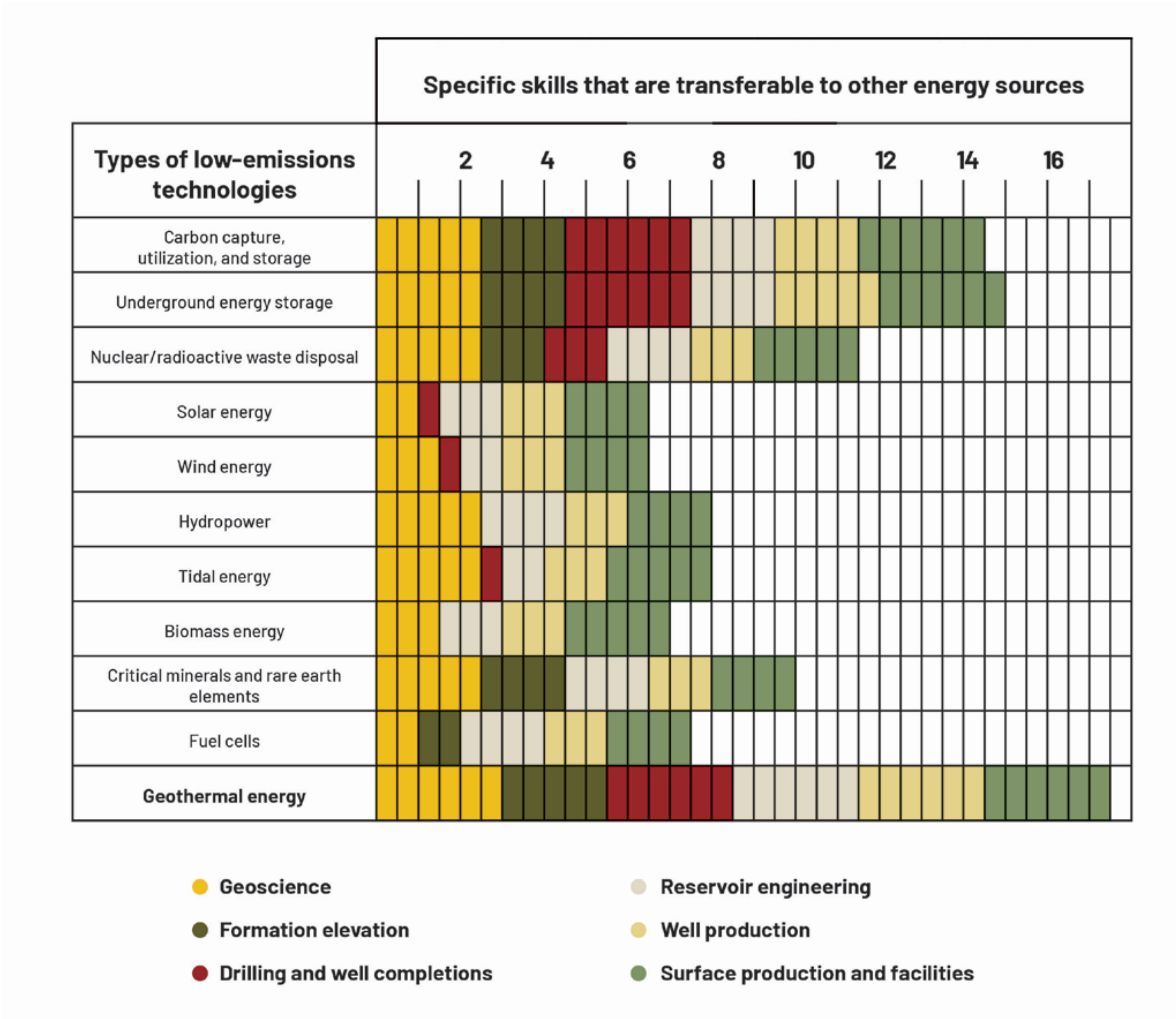


Figure 1.10: As shown, geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). *Oil and gas skills for low-carbon energy technologies.* Society of Petroleum Engineers Annual Technical Conference and Exhibition.

As shown in **Figure 1.11**, the Earth's crust contains more potential thermal energy than is present in all fossil fuels and natural nuclear fissile material combined. The challenge, then, is how to identify the areas and technologies that can tap into that potential energy most efficiently and economically.

Figure 1.12 summarizes the latest geothermal extraction technologies. The following sections describe these technologies in greater detail.

Advanced geothermal system (AGS): Like an engineered geothermal system (EGS), an AGS eliminates the need for permeable subsurface rock. Instead, an AGS creates and uses sealed networks of pipes and wellbores closed off from the subsurface, with fluids circulating entirely within the system in a "closed loop."

Today, many AGS geothermal well designs are in development, including single well, U-shaped well "doublets" with injection and production wells and subsurface radiator designs. All of these designs use only their own drilled pathways; none require a conventional hydrothermal resource or hydraulic fracturing to create fluid pathways.

All geothermal energy extraction relies on conduction, the heat transfer from hot rock to fluid (see "Geothermal Geology and Heat Flow" for more details). Thus, unlike an EGS, which benefits from the substantial surface area created by hydraulic fracturing, an AGS has only the walls of its wells to conduct heat. As such, an AGS must drill deeper, hotter, or longer well systems than an EGS to conduct similar amounts of heat energy. Because an AGS does not exchange fluids with the subsurface, it can more easily use engineered, nonwater working fluids, such as supercritical CO_2. Along with advances in technology, the AGS is also being scaled for use in industrial-size projects. XGS Energy and Meta recently partnered to construct a first-of-its-kind 150 megawatt AGS power plant in the United States that will target approximately 250°C hot rock to deliver power for data center projects in New Mexico.[23]

An AGS can be developed in virtually any geological condition with sufficient subsurface heat. While an AGS guarantees a more definitive pathway for fluid flow in the subsurface relative to fracked EGS wells, drilling sufficiently long and deep AGS wells can be challenging and expensive.

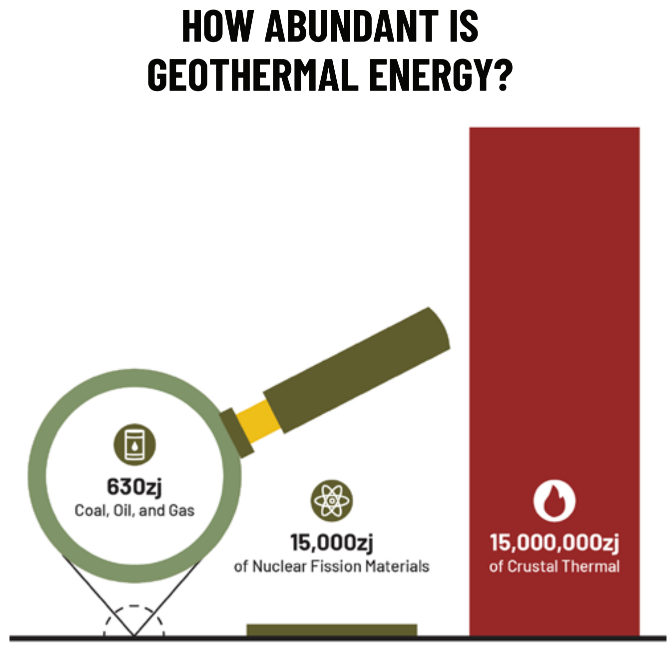


Figure 1.11: Total heat energy in Earth's crust, compared to that contained in fossil fuels and naturally occurring fissile materials. Note that total fossil fuels, when compared with crustal thermal energy, is the equivalent of less than one pixel at the bottom of the graphic, shown magnified to illustrate scale. Measurements in zettajoules (zj). Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin. Adapted from Dourado, E. (2021). *The state of next-generation geothermal energy.*

Engineered geothermal system (EGS): This kind of system uses both directional drilling and hydraulic fracturing to create artificial permeability, allowing for the use of geothermal energy far beyond the regions with naturally occurring hydrothermal. An EGS extracts heat by introducing fluids into the subsurface, breaking open fissures in relatively impermeable rock, and circulating fluid between one or more wells. The more fractures there are, the greater the surface area for the flowing fluid to conduct heat from rock.

Although the EGS was conceived as early as the 1970s,[24] its scalability has only been possible because of cost reductions and technological advances in drilling and fracturing techniques commercialized by the oil and gas industry over the past few decades. However, unlike hydraulically fractured oil and gas wells—which are only intended for one-way extraction of oil and gas—an EGS

TYPES OF GEOTHERMAL ENERGY SYSTEMS

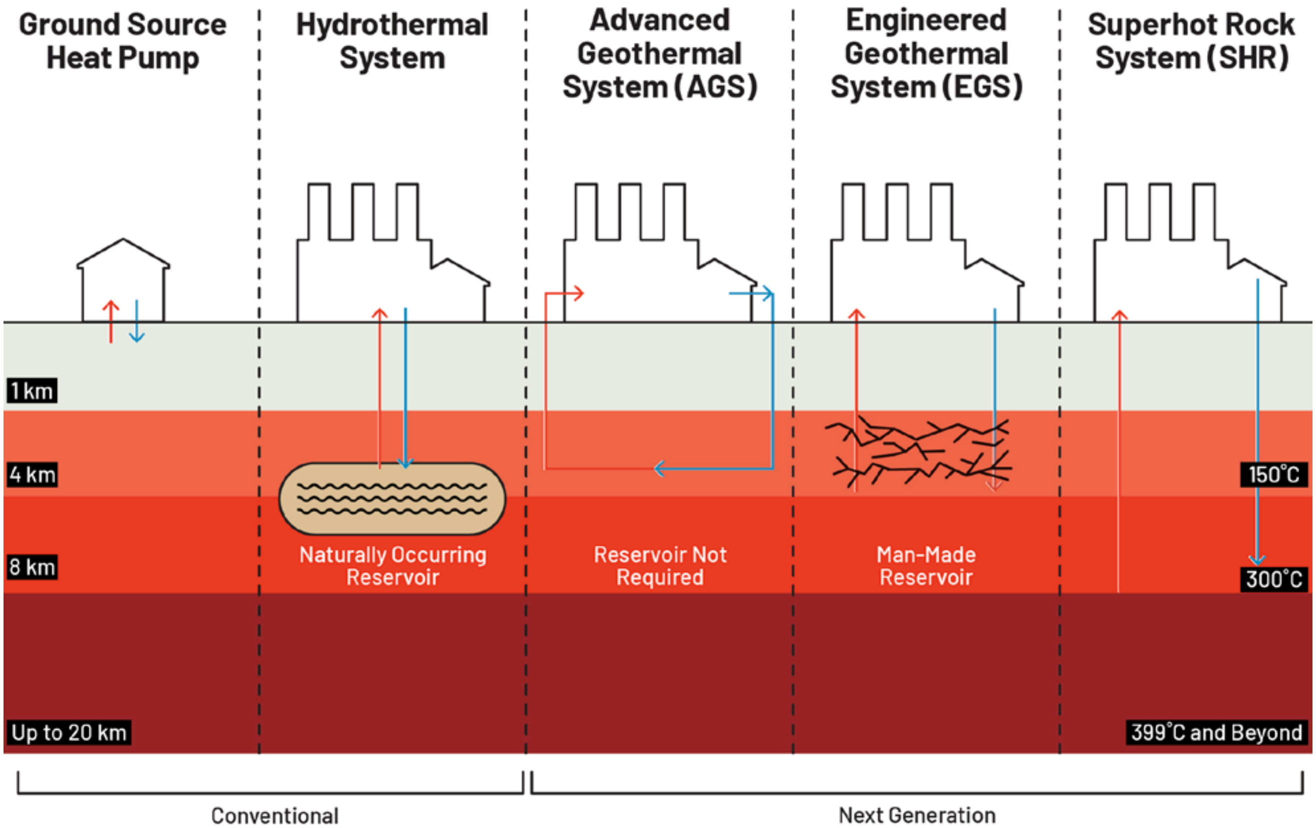


Figure 1.12: Comparison of key geothermal power generation technologies illustrating variations in resource type and heat extraction method for electricity production and industrial direct use. Ground source heat pumps (GSHPs) are also shown, illustrating a building heating scenario. In the GSHP scenario, fluid flow can be reversed to provide cooling. Source: Adapted from D'avack, F., & Omar, M. (2024). *Infographic: Next-generation technologies set the scene for accelerated geothermal growth*. S&P Global.

is designed to reuse fluids, so the same liquid flows continuously through hot rock in a convective loop.

An EGS generally targets shallow hot-rock formations with few natural fractures and limited natural permeability to minimize uncontrolled fluid loss. Well depths can vary depending on where sufficient temperatures and appropriate stress conditions are found.[25]

Fracturing methods are subject to some uncertainty; even the most accurate engineering model cannot perfectly predict how a subsurface rock will crack or how fluids will flow. Because of Indonesia's location along the volcanically active Sunda Arc, it already hosts abundant high-enthalpy hydrothermal resources with natural permeability.[26] In this context, an EGS is less suited for the near term, while scaling hydrothermal and AGS pilots will better match Indonesia's geology and community considerations.

Superhot rock (SHR): SHR is a type of next-generation geothermal that targets extremely deep, high-pressure rocks above approximately 373°C, the temperature at which water goes supercritical. SHR has the potential to revolutionize power production globally with superheated, supercritical geothermal steam capable of highly efficient heat transfer from the subsurface. Theoretically, SHR can employ either EGS or AGS well technologies, but no commercial SHR geothermal project has yet been developed because advances are needed in drilling technologies, rates, and costs to enable the economically competitive development of this next-generation concept.[27]

GEOTHERMAL GEOLOGY AND HEAT FLOW

The movement of heat from Earth's hot interior to the surface—what geologists call *heat flow*—is controlled by the geology of the planet. Heat from the core and mantle, as well as the decay of naturally occurring radioactive deposits in the Earth's crust, combine and emanate toward the surface of the planet.

Conduction, Advection, Convection, and Radiation

Heat flow in the Earth results from physical processes that contribute, to varying degrees, to the available heat in a geothermal resource.

- **Conduction:** The transfer of energy between objects in physical contact through molecular vibrations without the movement of matter. Conduction is efficient in some materials (like metals) and inefficient in others. Rock is a relatively poor conductor, but conduction is nonetheless considerable in the interior of the Earth.

- **Advection:** The transfer of heat due to the movement of liquids from one location to another. In geology, advection occurs in the movement of magma and groundwater, where the fluid carries heat as it moves through cracks, fractures, and porous rock formations. Advection is different from conductive heat transfer, which relies solely on direct contact between particles to transfer heat.

- **Convection:** A cycle of heat transfer involving conduction and advection that occurs when matter is heated, becomes less dense, rises, cools, increases in density, and sinks. Convection typically creates circulating loops of rising and sinking material. The Earth's mantle is almost entirely solid but behaves as a highly viscous fluid, thus allowing for convective heat transfer. The mantle's movement is extremely slow relative to human life but becomes significant over geologic periods.

- **Radiation:** Energy that moves from one place to another as waves or particles. Certain areas in the Earth's crust have higher concentrations of elements with natural radiation, such as uranium-238, uranium-235, thorium-232, and potassium-40.

Geology and Energy Extraction

The geological processes described interact to contribute to geothermal energy extraction under three common geological settings:

Convection-Dominated

1. Geologically open geothermal systems: In these systems, water circulates freely (e.g., the Great Basin in the United States). These systems are typically targeted for power generation and open-loop heat.

Conduction-Dominated

2. Geologically closed systems, with limited porosity/permeability: Water does not flow naturally in these systems, and geothermal energy extraction requires engineered "enhancements" (e.g., hydraulic fracturing).

3. Geologically closed systems, with natural porosity/permeability: These systems have natural pore spaces to a certain depth, allowing some fluid flow. This is beneficial when considering storage for heating and cooling.

Existing Geographies, Applications, and Technologies			
	Conventional Hydrothermal Geothermal	District Heating	Ground Source Heat Pumps
Basic Concept	Relies on natural hydrothermal systems with hot water and porous rock	Provides heating through interconnected building networks, using centralized geothermal systems	Uses shallow ground temperature stability to heat and cool buildings
Working Fluid	Naturally occurring fluids	Water or steam circulated through centralized pipes to buildings	Typically, water or antifreeze or refrigerant in a closed-loop system
Reservoir Type	Open to natural hydrothermal reservoir	Central reservoir supplying district buildings with hot water or steam	Closed-loop system buried at shallow depth
Geological Requirements	Natural hot aquifers in porous rock formations	Typically, sedimentary aquifers but can be used near conventional geothermal systems such as Iceland	No special geology; suitable for almost any location
Temperature Range	150°C - 350°C	Generally, around 80°C-100°C	All ranges
Drilling Depth	Shallow or deep, depending on hydrothermal location	Shallow to medium depth, depending on temperature requirements	Very shallow, typically between 3 meters and 152 meters for residential to deeper for industrial heat pumps
Scalability	Limited to those few regions with natural hydrothermal conditions	Scalable anywhere concentrated clusters of buildings can share interconnected hot water or steam	Highly scalable; can be installed almost anywhere
Environmental Impact	Lower impact but dependent on natural resource conditions	Low impact; minimal drilling required and low emissions	Minimal impact; closed system without subsurface interaction
Examples of Use	Traditional geothermal power plants, direct-use heating in regions with hydrothermal conditions	Geothermal district heating in Iceland, Paris, and some U.S. cities	Commonly used for residential and commercial building heating and cooling but increasing in use for industrial heat when combined with industrial heat pumps
Primary Advantages	Established technology in areas with existing hydrothermal resources	Efficient and cost-effective heating for multiple buildings in urban or suburban networks	Proven, simple, reliable system for year-round building climate control and a key technology for data center cooling
Challenges	Limited to specific geographical areas with natural conditions	High initial setup cost, complex infrastructure needed to connect multiple buildings	Higher upfront cost relative to conventional HVAC

Figure 1.13: Existing and new geographies, applications, and technologies.

New Geographies, Applications, and Technologies

	Superhot Rock	Sedimentary Geothermal System	Engineered Geothermal System
Basic Concept	Exploits extremely high temperatures at great depths	Utilizes sedimentary rock formations that may contain hot water in pores; can involve low-porosity rocks	Uses hydraulic fracturing to create artificial permeability for heat extraction
Working Fluid	Water, potentially reaching supercritical state	Typically, water from aquifers in sedimentary rocks; may require pumped circulation	Recirculates same fluid (water or otherwise) through fractures in hot rock
Reservoir Type	Open, targeting superhot rock	Open, with naturally porous and permeable rock acting as the reservoir for fluid flow	Open to reservoir with engineered fractures
Geological Requirements	High temperatures (above 373°C)	Sedimentary rock formations with some porosity and permeability for water flow	Requires heat and engineered permeability; benefits from high rock surface area for heat transfer
Temperature Range	373°C + (targeting supercritical steam)	Can vary (from low ~ 20°C to > 200°C)	Typically, 50°C -300°C
Drilling Depth	Significant depth (potentially 10+ kilometers)	Variable depth range, from 500 meters to 8,000 meters	Typically < 3,000 meters, as high pressure and high drilling would incur additional costs
Scalability	Potentially scalable with improved deep-drilling technology	Scalable; 73% of continental land mass contains sedimentary basins	Scalable with advances in hydraulic fracturing and drilling but potentially limited to areas where hot dry rock is < 3,000 meters and does not contain natural fractures that will increase uncertainty and potential fluid losses
Environmental Impact	High-impact drilling; needs tech improvements for feasibility	Typically low	Possible induced seismicity, depending on geology; significant water use despite reuse of working fluid
Examples of Use	Experimental; no large-scale deployment yet	Residential and industrial heat applications: Southampton, United Kingdom; Paris	Department of Energy's FORGE project, Fervo's Project Red in Utah
Primary Advantages	High efficiency in power generation due to superheated steam	Cost-effective and scalable, particularly in well-explored basins. Stacked aquifer systems mean these basins could supply tiered geothermal, ranging from low-temp direct use to higher-temp electricity generation—and geothermal energy storage.	Unlocks geothermal potential in non-ideal rock formations with artificial permeability
Challenges	High-cost drilling; significant research and development required	Limited to areas with sufficient sedimentary rock in basins with moderate temperatures	Subsurface unpredictability in fracturing; possible seismic risks; high initial costs; high water use

New Geographies, Applications, and Technologies			
	Advanced Geothermal System	**Geothermal Cooling**	**Thermal Storage**
Basic Concept	Closed-loop system with no fluid exchange with subsurface	Uses ground or subsurface temperatures to provide cooling in buildings or industrial processes	Stores thermal energy in subsurface reservoirs for later use in heating, cooling, or power generation
Working Fluid	Circulates fluid (water, supercritical CO_2, or otherwise) entirely within sealed, engineered system	Water or refrigerant circulated to transfer cool temperatures to buildings	Water or other heat-transfer fluid for thermal storage; optimal recovery in pressurized reservoirs
Reservoir Type	Closed to reservoir; uses sealed pipes and engineered pathways	Closed or open loop with pipes in shallow ground, utilizing ground cooling	Closed underground reservoirs or aquifers for energy storage, utilizing natural or engineered pathways
Geological Requirements	No permeability needed; functions anywhere with heat availability	Generally, no special requirements; suitable for most shallow grounds with stable temperatures	Requires subsurface space with adequate pressure retention for heat and energy storage
Temperature Range	Variable; typically requires hotter rock (> 100°C) to achieve competitive heat extraction	Utilizes both the shallow natural ground temperature (~13°C) for cooling purposes and the deep ground temperature with absorption cooling technology	Flexible; can be adapted for seasonal thermal storage or for high-temperature dispatch
Drilling Depth	Potentially deeper to access high heat, as system is inherently limited in the surface area available for conductive heat transfer	Both shallow, typically between 3 meters and 152 meters, as cooling requires lower temperatures, and deeper >100°C with absorption cooling technology	Depth varies; can be shallow for seasonal storage or deep for high-temperature storage
Scalability	Scalable, as system is independent of subsurface permeability	Scalable for residential, commercial, and industrial applications	Scalable; suitable for integration with renewable sources for energy balancing
Environmental Impact	Low impact; closed system with no interaction with surrounding rock fluids	Minimal impact; closed-loop systems ensure no ground contamination	Low impact; relies on pressure management for safe thermal storage
Examples of Use	Various closed-loop designs in development, technologies such as Eavor-Loop and GreenFire Energy's GreenLoop	ADNOC, in collaboration with the National Central Cooling Company PJSC (Tabreed), has initiated operations at G2COOL in Masdar City, Abu Dhabi.	Underground thermal energy storage, borehole thermal energy storage, and aquifer thermal energy storage
Primary Advantages	No fluid exchange with subsurface; suitable for areas lacking natural aquifers	Cost-effective cooling in regions with high air conditioning demand; reduces HVAC costs; could be used to optimize data center cooling	Provides energy storage to balance renewable power and support grid stability
Challenges	Expensive drilling costs; reduced heat transfer area compared with EGS; requires wells to touch more rock for heat exchange	Installation and initial costs; suitable ground area needed for installation	Requires specific geological settings for pressure control; drilling costs can be high

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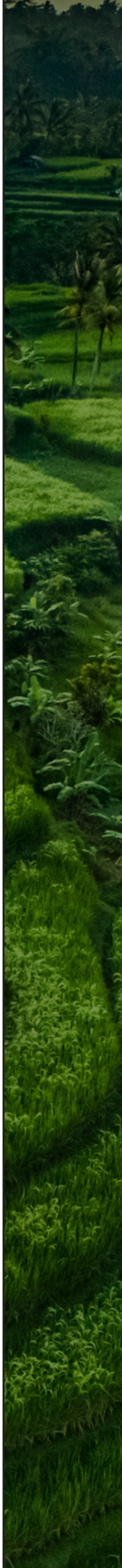
Part II

Indonesia's Geothermal Landscape and Pillars of Growth



Chapter 2

Powering the Transition: Indonesia's Geothermal Market

Raditya Wiranegara and His Muhammad Bintang
Institute for Essential Services Reform

The Indonesian government's estimate for conventional hydrothermal is 23.7 gigawatts of geothermal potential. But a recent estimate by Project InnerSpace shows that Indonesia has a technical potential of 2,160 gigawatts of geothermal at a depth of up to 5 kilometers, outside of protected areas—making Indonesia one of the most promising regions for next-generation geothermal development in the world.[1]

For many years, agencies in Indonesia have been setting goals to increase the amount of renewable energy used in its primary energy mix. But the work is complicated, so it moves slowly.

Historically, the Emerald of the Equator—as Indonesia is known—has run on fossil fuels. In 2000, oil, gas, and coal provided just more than 69% of the energy demand in Indonesia. By 2013, that figure had grown to a little more than 91%.[2,3] Oil was predominant, but as crude oil production declined and consumption rose, Indonesia had to flip from exporting oil to importing it. This shift led to issues such as trade imbalances and declining revenues. In 2005, oil and gas contributed 28% of national revenue; 10 years later, it was 8.5% (based on analysis of data from several sources by the Institute for Essential Services Reform [IESR])[4,5,6]—so the government decided to invest heavily in coal and natural gas and to pass regulations in the National Energy Policy[7] for "a minimal utilisation" of petroleum products.[8] By 2024, coal accounted for 40% of the primary energy supply, oil for 28.6%, and gas for 16% (**Figure 2.1**).[9] Even though development in renewable energy was steadily increasing (mainly in bioenergy, hydropower, and geothermal), it only accounted for the remaining 15.4% of the energy mix by 2024, which was only two-thirds of the National Energy General Plan goal (**Figure 2.2**).[10]

Of that renewable energy mix, only 1.5% came from geothermal.

That number represents a massive missed opportunity. The government estimates the country will generate 23 gigawatts of conventional hydrothermal electricity by 2060.[11] A recent estimate by Project InnerSpace, however, shows that Indonesia has a technical potential of 2,160 gigawatts of next-generation geothermal resources at a depth of up to 5 kilometers (outside of protected areas). This is 94 times the currently identified potential of 23 gigawatts of hydrothermal resources. This potential makes Indonesia one of the most promising regions for geothermal development in the world.[12] (See Chapter 1, "Geothermal 101: Overview of Technologies and Applications," and the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities.")

Unfortunately, roadblocks to unlocking all those resources are compounded:

- Various national policies set out different renewable energy targets, including the implementation of conventional geothermal power, yet no roadmap for achieving this target exists.

- Indonesia has 100 times more geothermal resources for direct-use applications and next-generation technologies than for conventional. These resources could significantly reduce the need for fossil

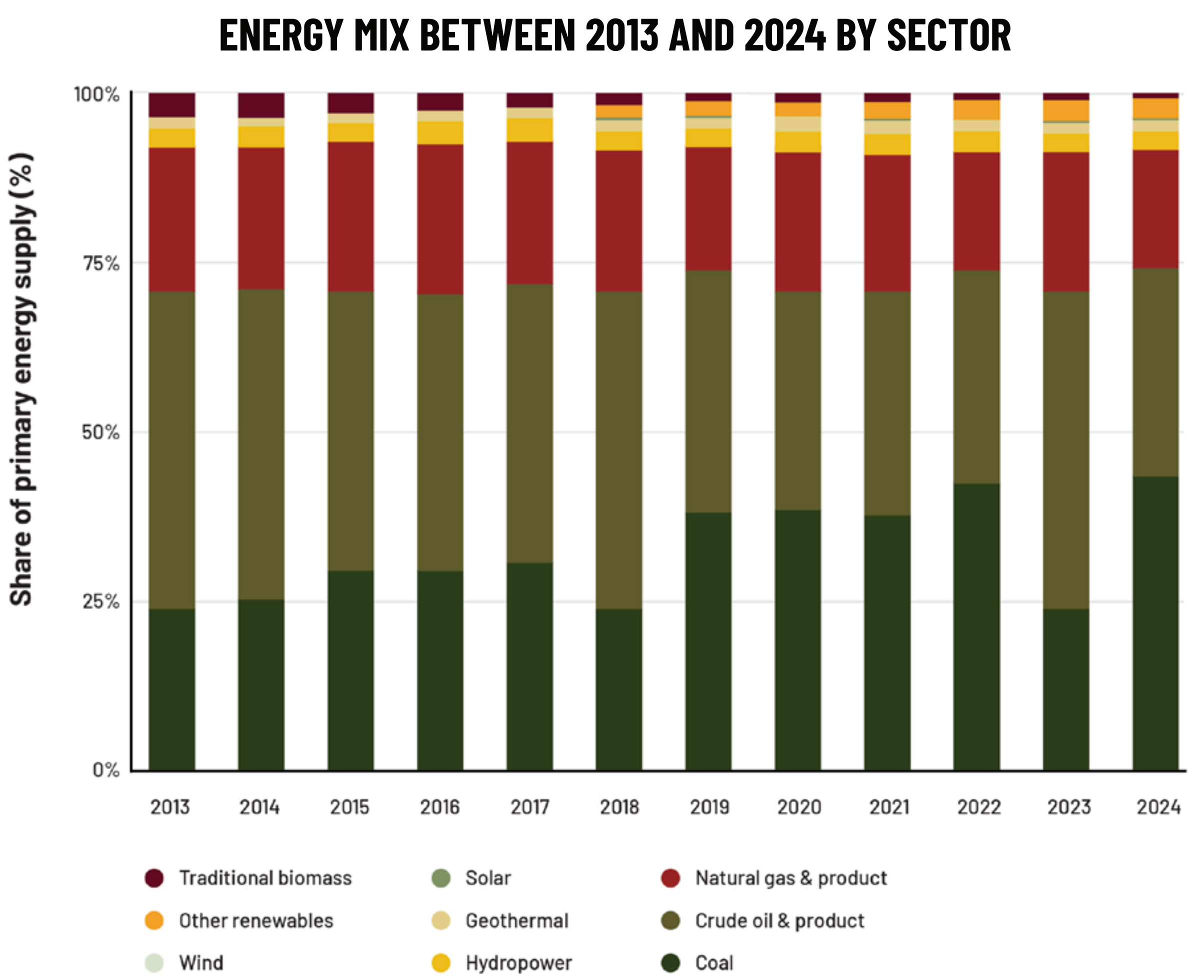


Figure 2.1: The share of primary energy mix by energy generation type between 2013 and 2024. Source: Adapted from Ministry of Energy and Mineral Resources. (2025). *Handbook of energy and economic statistics of Indonesia 2024*. Government of Indonesia.

NATIONAL ENERGY GENERAL PLAN TARGETS BY SECTOR VERSUS ACTUAL ENERGY MIX

Sector	Aspects	2025	2024 Use	2023 Use
Power	% RE share	31.8%	17.7%	18.4%
Transport	% Direct RE	12.8%	13.8%	13.5%
	% Electrification	0.3%	0.1%	0.1%
Industry	% Direct RE	11.4%	9.9%	4.5%
	% Electrification	24.1%	12.4%	12.7%
Comm-HH	% Direct RE	1.9%	1.7%	1.6%
	% Electrification	73.3%	61.0%	59.8%

Figure 2.2: Comparison of renewable energy mix by sector, between use in 2023-24 and the National Energy General Plan's 2025 target. Comm-HH = commercial and household; Direct RE = activities or processes powered through directly consuming renewable energy resources; electrification = activities or processes powered by electricity. Source: Prepared by IESR using data from Ministry of Energy and Mineral Resources. (2025). *Handbook of energy and economic statistics of Indonesia 2024*. Government of Indonesia.

fuels, improve the nation's air quality and energy security, and offer an economic boon. But there is no regulatory or policy structure in place to develop these resources and no mention of them in future goals or planning.

- Few plans are in place to address the country's infrastructure needs so that it could support a geothermal energy industry.

This chapter looks at Indonesia's complicated energy landscape and potential ways forward to develop the immense resources available across the country.

LAWS AND REGULATIONS GOVERNING ENERGY TRANSITION

Two laws form the legal framework for energy policies, development, and governance in Indonesia today: the Energy Law 30/2007,[13] and the Electricity Law, 30/2009.[14] (A New and Renewable Energy Draft Law is currently in development.[15])

Indonesia's Energy Law provides the legal framework for energy use and resource management. It mandates the formulation of the National Energy Policy, which sets long-term goals for national energy security and sustainability. To implement these goals, the government enacts the National Energy General Plan, which establishes projections, targets, and roadmaps across all energy types, including electricity, oil, gas, coal, and renewables.[16] The Ministry of Energy and Mineral Resources (MEMR) develops and manages everything related to implementation. The Energy Law also stipulates that renewables, including geothermal development projects, are eligible for incentives such as easier license processing, fiscal incentives, tax waivers, and capital assistance.

Continuing down the legislative hierarchy, the National Energy Policy and National Energy General Plan serve as the basis for the formulation of the National Electricity General Plan (RUKN). The RUKN is updated every five years to accommodate evolving techno-economic conditions, policy shifts, and international energy trends. The 2025 iteration set the goal for geothermal in the Indonesia electricity mix at between 4.9% and 5.2% by 2060 (or between 21 gigawatts and 23 gigawatts).

In Government Regulation 40/2025,[17] which serves as the national energy policy framework under the Energy Law, geothermal is listed as a resource for electric generation and a possibility for repowering coal-fired power plants to produce hydrogen and ammonia. The regulation has nothing explicit, however, about geothermal for non-electricity uses or direct use. (For details on the nation's direct use potential, see Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential"; for details on the policy gaps that need to be filled to unlock this potential, see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation.")

The Electricity Law, reissued as Law No. 30 of 2009,[18] provides the regulatory framework for Indonesia's electricity market, covering generation, transmission, distribution, and sales. It promotes domestic energy resources and broadens the participation of regional governments and enterprises in electricity supply activities within their jurisdictions.

Government Regulation 23/2014 reinforces that MEMR is the authority responsible for national electricity planning through the preparation of the RUKN and the Electricity Supply Business Plan (RUPTL). This framework enables licensed private utilities to operate self-contained electricity networks that supply several major industrial areas.[19] For the geothermal sector, this feature allows private developers to supply power directly to captive users within a designated business area. Broader sales to the public grid remain subject to PLN's national planning and procurement process.

Several recommendations have been developed to classify and regulate other uses of geothermal, such as direct use (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation").

INDONESIA'S NET-ZERO TARGETS

The most recent version of the National Energy Policy, developed in September 2025,[20] has a cascading effect. From this policy, the following goals have been established:

- **National Energy Policy (National Energy Council):** Renewables will account for between 19% and 23% of the primary energy mix by 2030, and between 70% and 72% by 2060 (the policy also estimates that emissions will peak in 2035).[21]

- **National Electricity General Plan (MEMR):** The RUKN 2024–2060 plan projects the share of renewable energy generation at 29.4% by 2034 and 50% by 2060 (both on the main grid, in Java, and off-grid on micro and regional grids).[22] This plan estimates that there will be 2 gigawatts of geothermal power plant capacity by 2035 and 21 gigawatts electric by 2060.

- **Electricity Supply Business Plan (PLN):** The RUPTL 2025–2034 plan projects renewable energy generation at 34.3% for on-grid (the Java region) by 2034,[23] with geothermal power plant capacity reaching 5.2 gigawatts.

For the National Energy Policy's 2060 goals, two scenarios were developed based on slightly different estimates of GDP growth.[24] In both scenarios, the energy sector would still be using a considerable amount of coal, oil, and natural gas in 2060 (see **Figure 2.3**). As it stands now, the government plans to retrofit remaining fossil fuel-powered plants, particularly coal and natural gas plants, with carbon capture, utilization, and storage. In both scenarios, geothermal's contribution to the primary energy mix—in other words, all energy sources used—would be 5% in 2060 (up from 2% today). Geothermal capacity is projected to grow from 2.68 gigawatts in 2025 to between 18 gigawatts and 22 gigawatts in 2060.

Electricity Demand and the Renewable Mix

As for electricity demand, the most recent RUKN, released in March 2025, projects a demand of 5,038 kilowatt-hours per capita in 2060. To meet that demand, the supply needs to reach 443 gigawatts in 2060, with 63.5% of electricity capacity generated from renewables: solar at 24.6%, wind at 16.6%, hydro at 15.9%, biomass at 1.3%, and geothermal at

2025 NATIONAL ENERGY POLICY EMISSIONS TARGETS

Key results	Scenario	2025	2030	2035*	2040	2050	2060
CO_2 emissions ($MtCO_2e$)	S1	877	1,017	1,069	925	676	129
	S2	954	1,184	1,242	1.086	744	129
Renewable energy primary energy share (%)	S1	17	19	25	36	53	70
	S2	19	23	27	40	55	72
Electricity demand per capita (kWh/capita), including captive	S1	1.896	2.346	2.920	3.328	4.444	5.038
	S2	2.231	3.075	3.957	4.809	5.994	6.526

*** Emissions are expected to peak in 2035**

Figure 2.3: Summary of the current National Energy Policy targets. CO_2 = carbon dioxide; kWh = kilowatt-hours; $MtCO_2e$ = metric tons of carbon dioxide equivalent. Source: Adapted from International Energy Agency (IEA). (2022). *An energy sector roadmap to net zero emissions in Indonesia*.

INDONESIA'S TARGETED VERSUS REPORTED RENEWABLE ENERGY MIX, 2015–2025

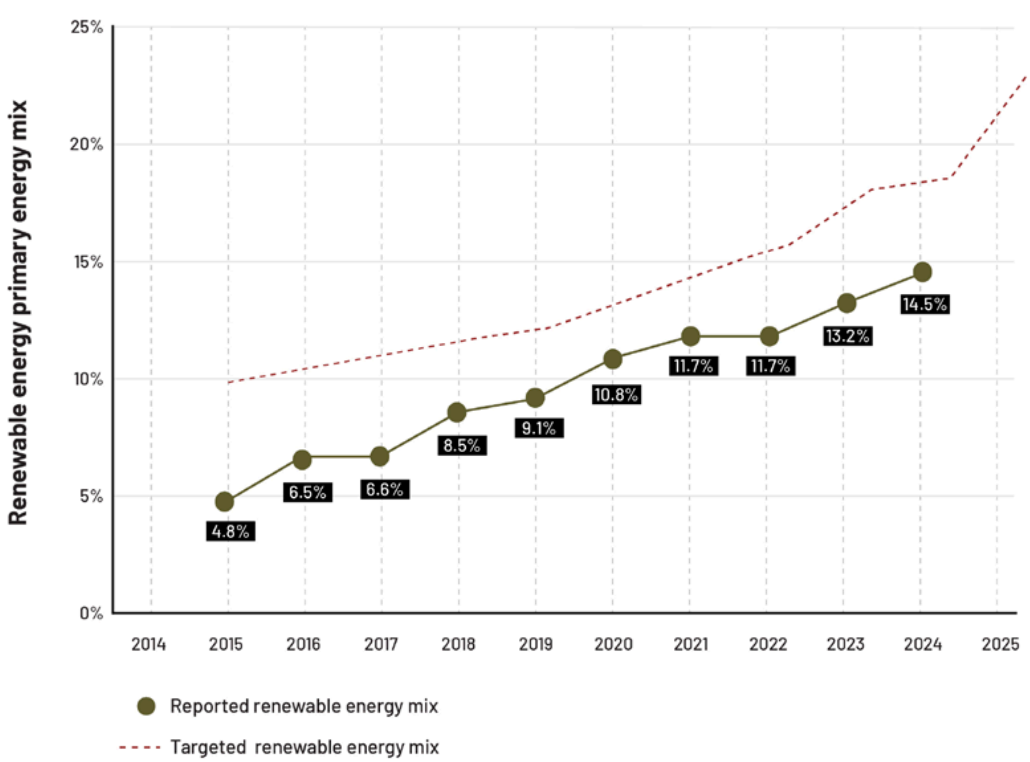


Figure 2.4: Comparison of renewable energy mix between realization and target between 2015 and 2025. Source: Prepared by IESR using data from Ministry of Energy and Mineral Resources. (2025). *Handbook of energy and economic statistics of Indonesia 2024*. Government of Indonesia.

RENEWABLE ENERGY PROJECT PROGRESS IN 2023 AND 2024 BY ENERGY SOURCE

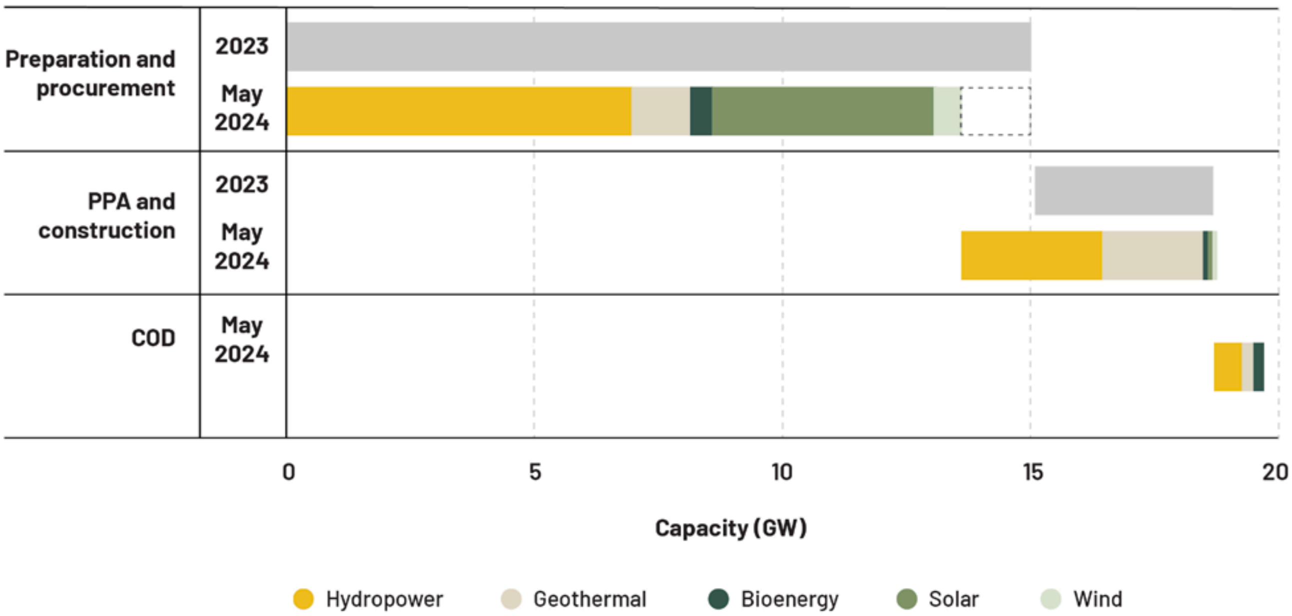


Figure 2.5: Progress of renewable projects development between 2023 and 2024 (May) by energy and project development life cycle. COD = Commercial Operation Date; GW = gigawatts; PPA = Power Purchase Agreement. Source: Sisdwinugraha, A. P., et al. (2024). *Indonesia energy transition outlook 2025: Navigating Indonesia's energy transition at the crossroads: A pivotal moment for redefining the future*. IESR.

5.1%. (To maintain grid stability, that projection of approximately 443 gigawatts includes energy storage with a capacity of 34 gigawatts.)

For the approximately 5% provided by geothermal, the projected total generation capacity is around 21 gigawatts, which the government estimates would use close to 89% of the hydrothermal potential identified by the MEMR.[25] Yet, as seen in the supplement to Chapter 3, "Expanding the Scope: Next-Generation Geothermal Opportunities," Indonesia has far more geothermal potential. By including next-generation potential from hot dry rock, the nation's geothermal technical potential jumps to 2,160 gigawatts. Unlocking a fraction of this potential would increase energy projections exponentially for every year projected. Additionally, investing in geothermal cooling would significantly reduce projected energy demand.

Demand for electricity has been growing at an average annual rate of 4.36% since 2013, according to analysis by IESR.[26,27] Much of this demand comes from the commercial (3.80%), household (5.73%), and transportation (10.48%) sectors.[28]

However, by 2024, on-grid installed capacity for all renewables in Indonesia had reached only 9.2 gigawatts.[29] As of that year, projects covering a total of 5 gigawatts were in the Power Purchase Agreement (PPA) and construction stages (**Figure 2.5**).[30] As Figure 2.5 shows, hydro and geothermal were dominating the on-grid renewable projects.

The off-grid—or micro and regional grid—renewable capacity reached an estimated 4.7 gigawatts in 2024.[31] Bioenergy and hydro dominated the renewable resources utilized by off-grid power plants.[32] While this is good progress, there is still a huge gap to fill to reach the electricity sector planning target of 37 gigawatts by 2030.

ENERGY CONSUMPTION BETWEEN 2013 AND 2024 BY SECTOR

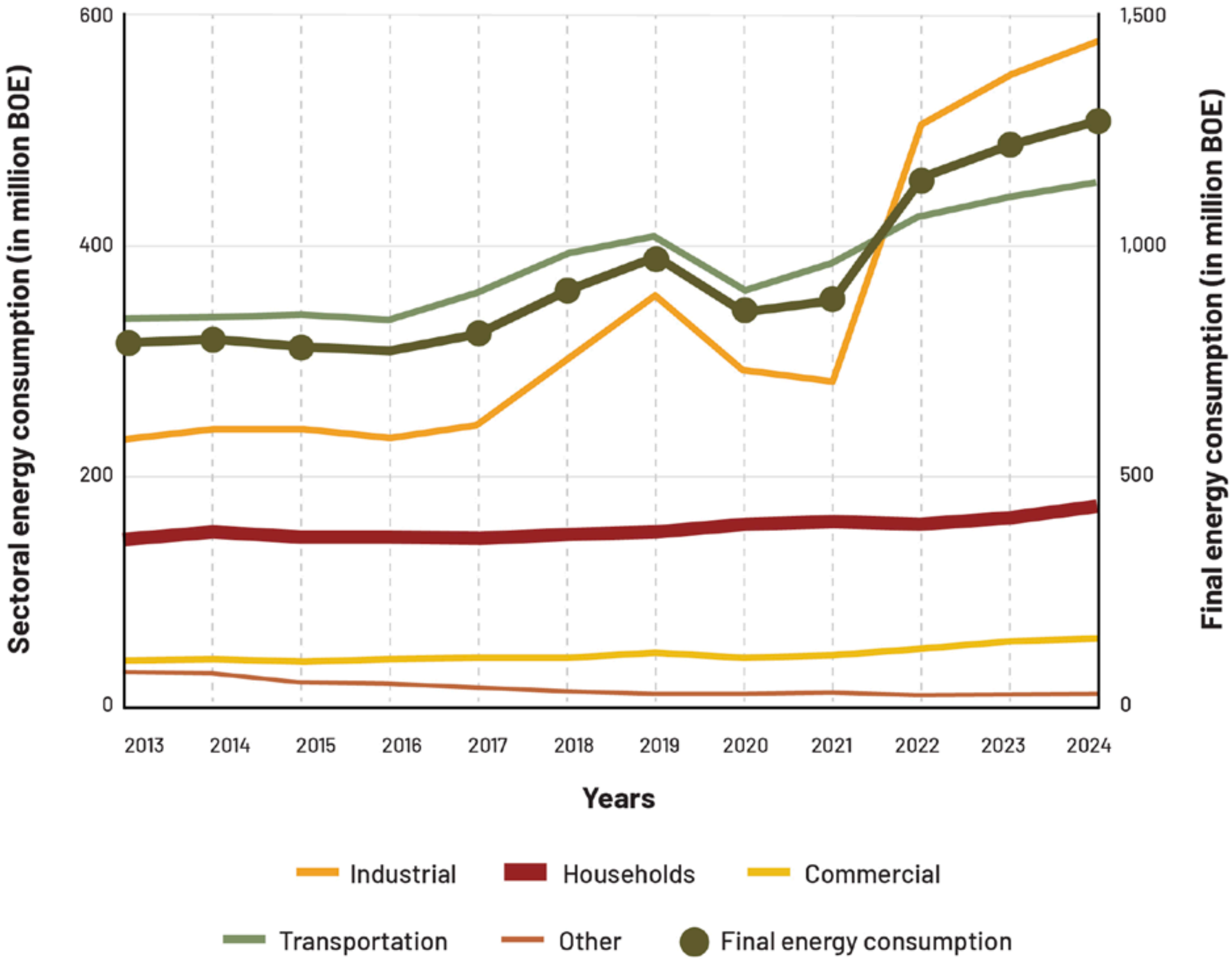


Figure 2.6: Indonesia's sectoral and final energy consumption between 2013 and 2024 by sector. BOE = barrel of oil equivalent. Source: Prepared by IESR using data from Ministry of Energy and Mineral Resources. (2024). *Handbook of energy and economic statistics of Indonesia 2023*. Government of Indonesia; Ministry of Energy and Mineral Resources. (2025). *Handbook of energy and economic statistics of Indonesia 2024*. Government of Indonesia.

CONSUMPTION GROWTH IN DIRECT-USE HEATING SECTORS: A HUGE OPPORTUNITY

Since 2016, energy consumption in Indonesia has grown at an average annual rate (except for early in the COVID-19 pandemic) of 6.35% (**Figure 2.6**). After the initial years of the pandemic, Indonesia saw a sharp increase of more than 30% in energy consumption.

In the industrial sector, consumption growth had a year-over-year growth rate of 4.6%.[33] Driving this growth was the manufacturing of basic metals and the food and beverage industries (**Figure 2.7**). Chemical, pharmaceutical, and traditional medicine manufacturing grew as well. These subsectors are known as energy-intensive industries that require high-pressure steam and heat to support their core industrial processes. Currently, a lot of that demand is met by coal (see **Figure 2.8**). Additionally, as explained in Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," agriculture and dairy, pulp and paper, and textiles are also steam- and heat-intensive.

CONSUMPTION GROWTH IN THE INDUSTRIAL SECTOR, 2020-2024

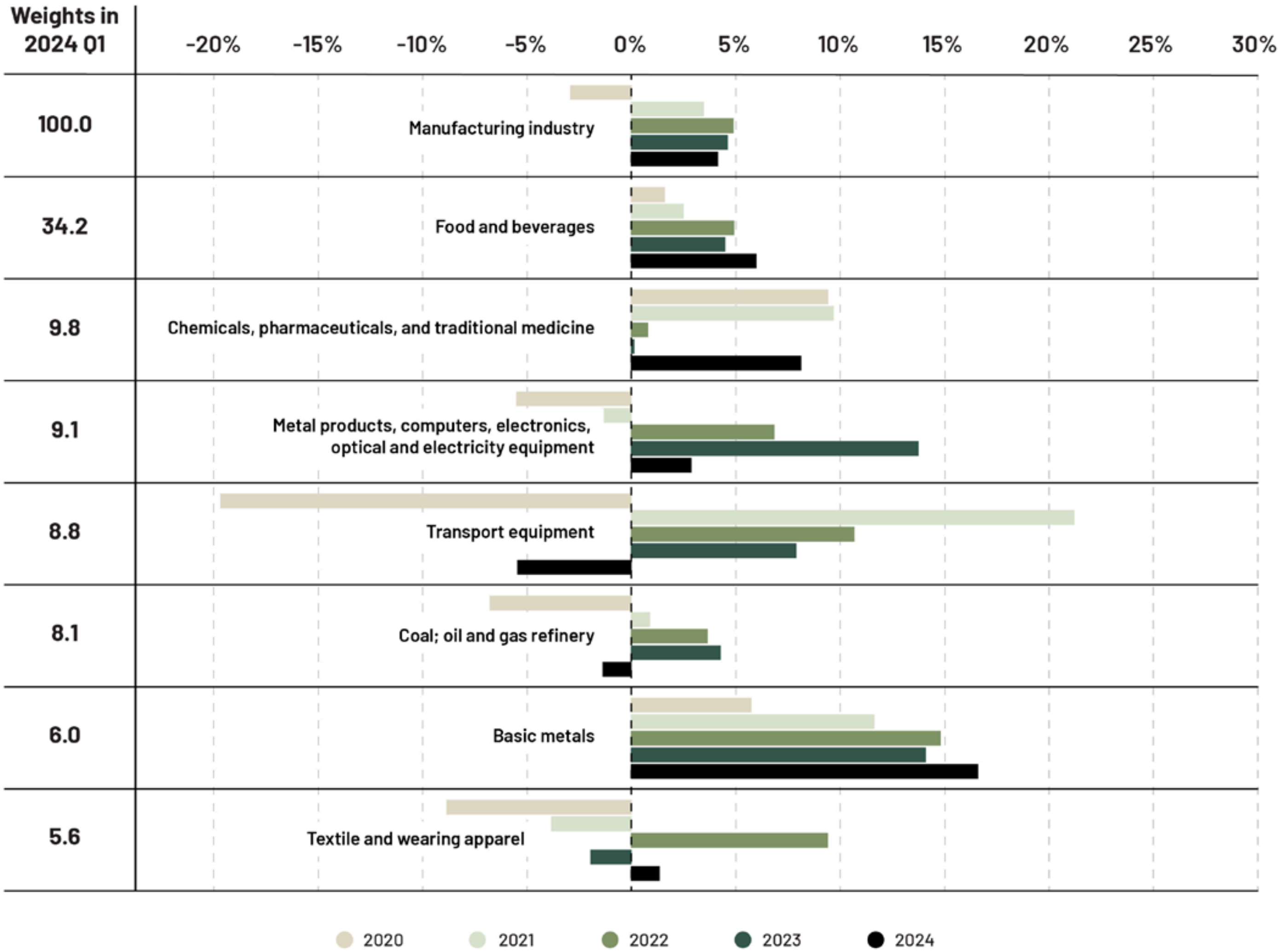


Figure 2.7: Growth of the industrial sector and its subsectors between 2020 and 2024 (first quarter). Weights in 2024 Q1 = the size of the sub-industries under the manufacturing industry. Source: Adapted from Ravindo, M. D. (2024). *Premature deindustrialization in Indonesia (?)*. Institute for Economic and Social Research (LPEM), Faculty of Economics & Business (FEB), University of Indonesia; CEIC. (n.d.). [*Indonesia*].

In Indonesia's industrial sector today, the use of renewables hinges on the use of biofuel and industrial biomass, which together accounted for 10% of the industrial sector's final energy consumption in 2024.[34] In the textiles and food and beverage industries, solar and biomass are touted for their roles in decarbonizing these industries.

The ministry's pathway to decarbonization, however, is missing the direct use of geothermal—a source that has been used in the sector for a few years. Recent statistics from MEMR show that the direct use of geothermal has only been recorded at 6 gigawatt-hours since 2022—a tiny fraction in the industrial sector.[35] That said, some researchers estimate that the figure is just under 12 gigawatt-hours, which would rank Indonesia at 74 out of 88 countries in direct-use geothermal, a number that has not changed since rankings were first reported in 1999.[36,37]

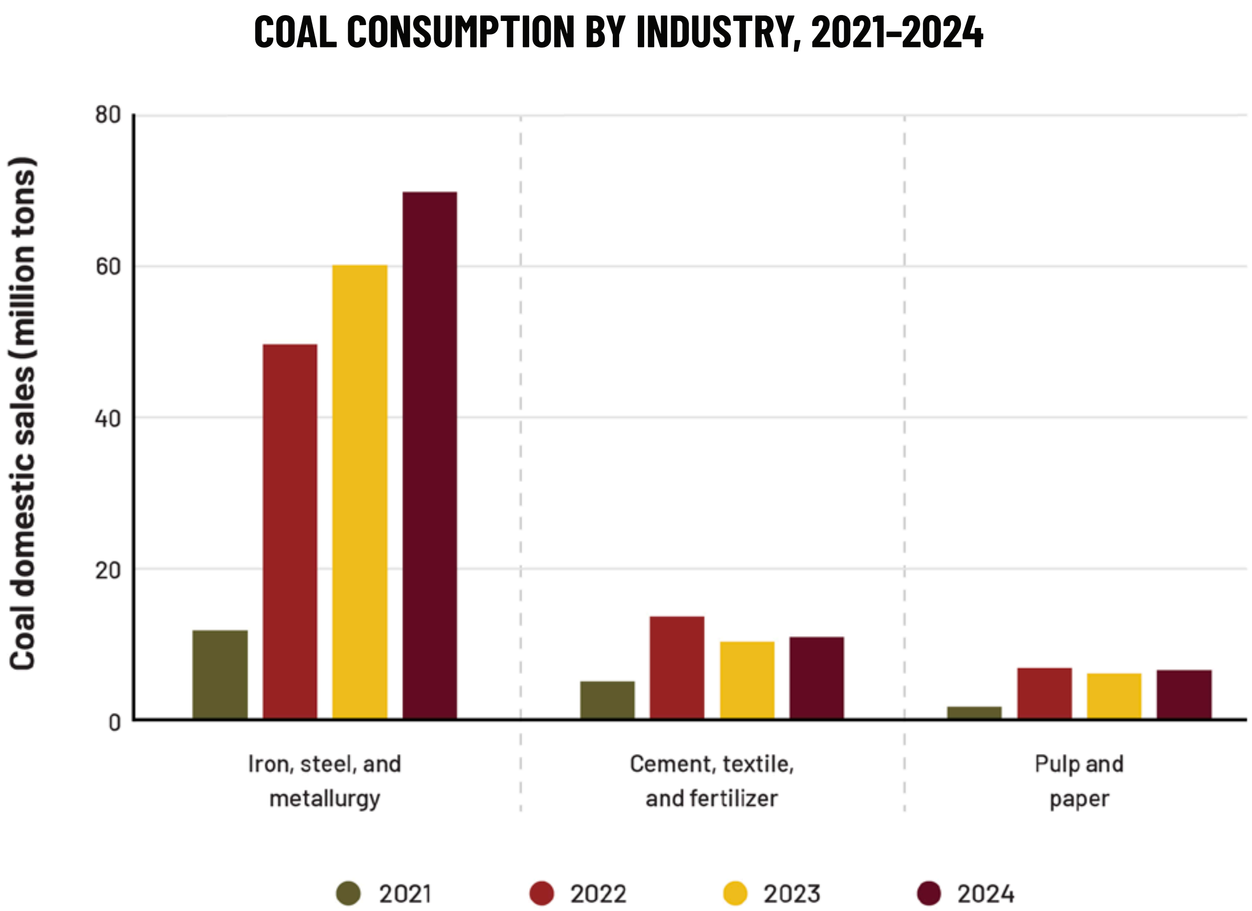


Figure 2.8: Coal consumption by industry between 2021 and 2024. Source: Prepared by IESR using data from Ministry of Energy and Mineral Resources. (2025). *Handbook of energy and economic statistics of Indonesia 2024*. Government of Indonesia.

Considering the resources and potential of direct-use geothermal in Indonesia (see Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential"), the nation has a huge opportunity—one that is particularly promising for industries such as agriculture and dairy, pulp and paper, and textiles. As mapped out more extensively in Chapter 4, a potential 89.8% of the thermal demand from process heating in manufacturing, refrigeration and cold storage, and residential and commercial HVAC could be replaced by geothermal energy by 2050. Notably, by 2050, the entire process heat demand of Indonesia's pulp and paper sector is projected to be within geothermal reach, and even today, all of the textile industry's heat requirements fall below 100°C—meaning these industries could fully switch to geothermal heat, slashing fuel costs and enhancing industrial productivity. Harnessing this potential could yield significant cost savings for businesses by substituting costly imported fuels with stable, domestically available geothermal energy, thereby improving industrial competitiveness and productivity.

A booklet recently published by the Ministry of Industry explains the nation's decarbonization pathway to 2050. The booklet lists the priority industries: cement, iron and steel, pulp and paper, textiles, ceramic, ammonia, chemical, food and beverage (cooking oil and sugar refining), and automotive.[38,39]

POWER GENERATION AND NEXT-GENERATION GEOTHERMAL POTENTIAL

Beyond direct use, Indonesia has a number of other sectors—particularly ones that require thermal energy and electricity—that can benefit from the nation's incredible resources and the advancement of next-generation geothermal technologies.[40] These technologies, such as engineered geothermal systems (EGS) and advanced geothermal systems (AGS), enable the geothermal industry to expand beyond conventional volcano-hosted hydrothermal resources and use the heat from hot dry rocks. (See Chapter 1, "Geothermal 101: Overview of Technologies and Applications," and Chapter 3, "Beneath the Archipelago: Indonesia's Geothermal Systems.")

As mentioned, the National Electricity General Plan projects the share of renewable energy generation at 29.4% for on-grid and off-grid by 2034, with geothermal power plant capacity at 6.7 gigawatts. The plan also states that by 2060, the government expects to exhaust 96% of conventional geothermal potential (23.7 gigawatts).[41] Java remains the hot spot for these projects, followed by Sumatra, Nusa Tenggara islands, Sulawesi, Maluku Islands, and Bali—all islands sitting on top of the Ring of Fire formation.

The Electricity Supply Business Plan projects the nation will reach 34.3% renewables on-grid by 2034, with geothermal power plant capacity at 5.2 gigawatts.[42] It also limits electricity supply companies to generating, transmitting, and distributing power only within their approved business areas. Yet, the plan does not lay out a roadmap for development, nor does it take into consideration the massive next-generation geothermal potential in the country.

On the other hand, if the nation's abundant technical potential was developed and enabling policies were enacted, in just 10 years, Indonesia could deploy 15 gigawatts of firm geothermal electricity and 15 gigawatts of geothermal heat—far faster than current plans. Those figures could rise to 25 gigawatts of electricity and 35 gigawatts thermal by 2045. (See Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation.") With an additional capacity of 25 gigawatts electric from geothermal in

INDONESIA'S GRID TO DATE

500 km

300 mi

MV line

HV line

Figure 2.9: Indonesia's transmission network, highlighting Java's interconnection and the smaller, isolated grids of other islands. HV = high voltage; MV = medium voltage. Source: Arderne, C., Zorn, C., Nicolas, C. & Koks, E. E. (2020). [Predictive mapping of the global power system using open data](). *Scientific Data, 7*, 19; OpenStreetMap contributors. (2023). [Planet OSM](); OpenStreetMap. (n.d.). [OpenStreetMap]().

With an additional capacity of 25 gigawatts electric from geothermal in 2045, the share of renewables in the electricity sector could climb to 67%, nearly 19% higher than the current MEMR pathways.

2045, the share of renewables in the electricity sector could climb to 67%, nearly 19% higher than the current MEMR pathways.[43]

HURDLES TO DEVELOPING POWER AND DIRECT USE

The country, of course, faces a number of hurdles in trying to meet these numbers. As mentioned earlier, there is no current policy or regulatory structure and no mention of direct-use pathways in place to reach the goals. Indonesia has regulatory, permitting, and pricing uncertainty; bureaucratic complexity; and conflicting land-use policies.[44] Development of geothermal can be expensive without the right support and financing, and estimating an accurate levelized cost of energy has proven difficult in Indonesia in recent years. The country also has few plans in place to address infrastructure needs so that it can support the expansion of geothermal use.

Grid Reliability

Due to its archipelagic geography, Indonesia's grid is fragmented. Today, interconnections only exist between the islands of Java, Madura, and Bali. Java's grid is by far the most advanced and well-connected power system in Indonesia; it hosts two high-voltage electricity transmission lines spanning from the eastern to western parts of the island, each with a capacity of 500 kilovolts. The next advanced system is in Sumatra, where transmission lines with a capacity of 275 kilovolts connect the northern parts of the island to the southern parts. The grids on the remaining islands (such as Kalimantan, Sulawesi, and Papua) are isolated and operate on their own (see **Figure 2.9**).

The idea "no transition without transmission" represents the conditions in Indonesia. A mismatch exists between the locations that have huge renewable energy potential and the hot spots of demand. According to the 2021 MEMR estimate, almost 98% of the renewable supply is scattered across the islands outside of Java,[45] but in 2024, about 68% of the entire country's electricity consumption was in Java.[46] This finding comes as no surprise, as the island is the most populous in Indonesia and home to very energy-intensive industries.[47]

Without building infrastructure, the nation will not meet its energy transition goals. According to a recently published plan, PLN hopes to build almost 48,000 kilometers of new transmission and 108,000 substations across Indonesia.[48] These would also facilitate the interconnection of islands and intraconnection on islands.

PLN has estimated that US$35 billion is needed to build all of this infrastructure in the next 10 years. With a rate of return of only between 2% and 4%, the business of transmission and distribution network development is financially unattractive, requiring alternative financing sources. PLN cannot cover these investment amounts from its own budget.[49]

High Building Costs

Development of a geothermal plant is capital-intensive because of the lengthy and complex processes to bring a plant from exploration to operation. In Indonesia, geographic conditions and an imbalance in grid strength significantly increase the cost of geothermal exploration. Limited data also exacerbate uncertainty and risk.[50]

Building a geothermal power plant with a capacity of between 50 megawatts and 100 megawatts can take 5 to 10 years, with a lot of complexity in each phase.[51,52,53] (See Chapter 6, "Common Ground: Building Trust and Transparency in Indonesia's Energy Transition," and Chapter 8, "Keeping Geothermal Green: Safeguarding Nature and Communities in a New Era of Growth," for more). Drilling exploration and production and reinjection wells constitute between 35% and 46% of the total investment cost of geothermal development.[54] The next most expensive process is the construction of surface facilities, including the design and size—or optimization—of a site-specific steam turbine.[55,56] For conventional geothermal development, site-specific corrosive chemical compositions in geothermal fluids such as hydrogen sulfide and carbon dioxide also complicate the design of steam turbines.[57,58]

Four conventional geothermal projects with different generating capacities were built between 2016 and 2019. Drilling costs for these plants varied from between 32% and 55% of the total price tag (see **Figure 2.10**).[59] Based on a review of 203 wells completed between 2011 and 2019, the cost varied from US$1.3 to US$18 million.[60]

Additionally, estimating the cost of building a

CONVENTIONAL GEOTHERMAL PROJECT COSTS IN INDONESIA, 2016–2019

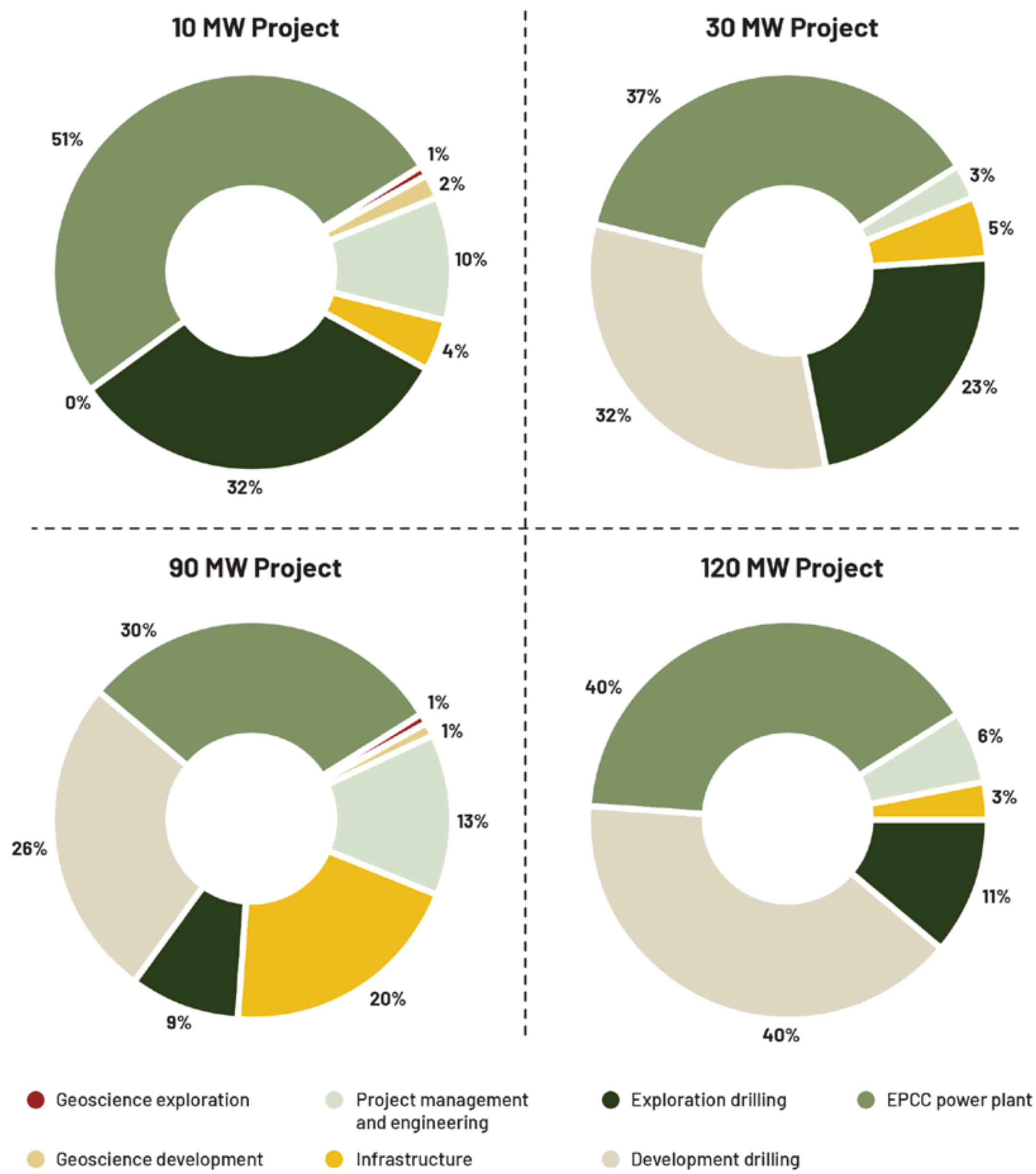


Figure 2.10: Cost structure of conventional geothermal power plant development in Indonesia between 2016 and 2019, showing that drilling accounted for between 32% and 55% of total project costs. MW = megawatts. Source: Purwanto, E. H., Suwarno, E., Hakama, C., Pratama, A. R., & Herdiyanto, B. (2021). [An updated statistic evaluation of drilling performance, drilling cost and well capacity of geothermal fields in Indonesia](). In *Proceedings World Geothermal Congress 2020+1*. Reykjavik, Iceland.

geothermal power plant in Indonesia using the levelized cost of energy (LCOE) can be complicated because of underestimated financial assumptions. Using a simple LCOE calculation method,[61] the Institute for Essential Services Reform (IESR) looked at financial data on conventional geothermal projects from MEMR documents published in 2017,[62] 2021,[63] and 2024[64] (**Figure 2.11**). The recommended values appear lower when using data from earlier versions of documents.[65] That said, more recent data from the *Technology Data for the Indonesian Power Sector* report show an LCOE that seems to align more closely with newly commissioned projects.[66] The report also includes significant corrections in capital expenditures and operational cost estimates. The estimated operating expenditures in the 2024 document are up to six times higher, and capital expenditures are 25% higher than 2017 estimates. These changes are reasonable considering inflation and rising costs for skilled labor and technological components.

Because of the uncertainty in these figures, which can translate to potential uncertainty for geothermal project costs, developers should conduct comprehensive cost and risk analyses. Policymakers should also strengthen risk mitigation support mechanisms. *Technology Data for the Indonesian Power Sector* is a key reference for many power sector studies in Indonesia and is frequently used to support the development of national roadmaps and regulations. The data should serve as an important reference for potential investors when assessing opportunities, particularly geothermal projects. Interestingly, the calculated recommended LCOE values, which represent a central or average estimate, consistently appear lower when using financial data from earlier versions of the report.

In the IEA's recent *The Future of Geothermal* report, it finds that the LCOE of next-generation geothermal in "the low-cost case" would decrease to around US$50 per megawatt-hour in 2035 and US$30 per megawatt-hour in 2050."[67] In the report, the IEA also notes that "because the LCOE takes no account of power system impacts and interactions, it is not a reliable indicator of competitiveness when comparing technologies with very different operational characteristics, notably in the case of dispatchable and variable renewables"—meaning that an LCOE undervalues the benefits of geothermal (e.g., clean, firm, no fuel costs, ancillary services).[68] The IEA analysis finds that when accounting for these benefits, geothermal "is more competitive than stand-alone solar PV [photovoltaics] and wind by 2035."[69]

OVERCOMING THE HURDLES: GEOTHERMAL OPPORTUNITIES

In an attempt to streamline geothermal development, at the beginning of 2025, the government started to revise existing geothermal indirect-use regulations (Government Regulation 7/2017). The revision includes 17 issues for consideration, including changes in auction schemes, by-product minerals from geothermal activities, and environmental recovery guarantees (reclamation).[70] The revision is expected to be published by December 2025.[71]

Repurposing Coal-Fired Power Plants

In 2022, the government established regulations that provide the legal framework to transition away from fossil fuels, especially coal. These regulations mandate MEMR to draft a roadmap to retire coal-fired power plants,[72] and they stipulate that a plant could be replaced by renewable-based power plants to sustain the electricity production.[73] (The regulation also introduced new ceiling tariffs according to the location and type of renewable energy.) The regulations also include details on government support and incentives for geothermal development, such as the following during exploration:[74]

- Appointment of a public service agency or state-owned company to compile additional geothermal data
- Appointment of a developer to carry out a preliminary survey and exploration in exchange for the right to match in the Geothermal Working Area tender
- Measures to take the risk out of projects for businesses and contractors working on geothermal projects
- Financing facility

The regulation requires the use of time-limited tendering processes. PLN is indirectly tasked with purchasing electricity from geothermal power plants to confirm there is an offtaker and remove uncertainty for tariffs.[75]

ESTIMATED LCOE OF CONVENTIONAL GEOTHERMAL POWER PLANTS, 2017-2024

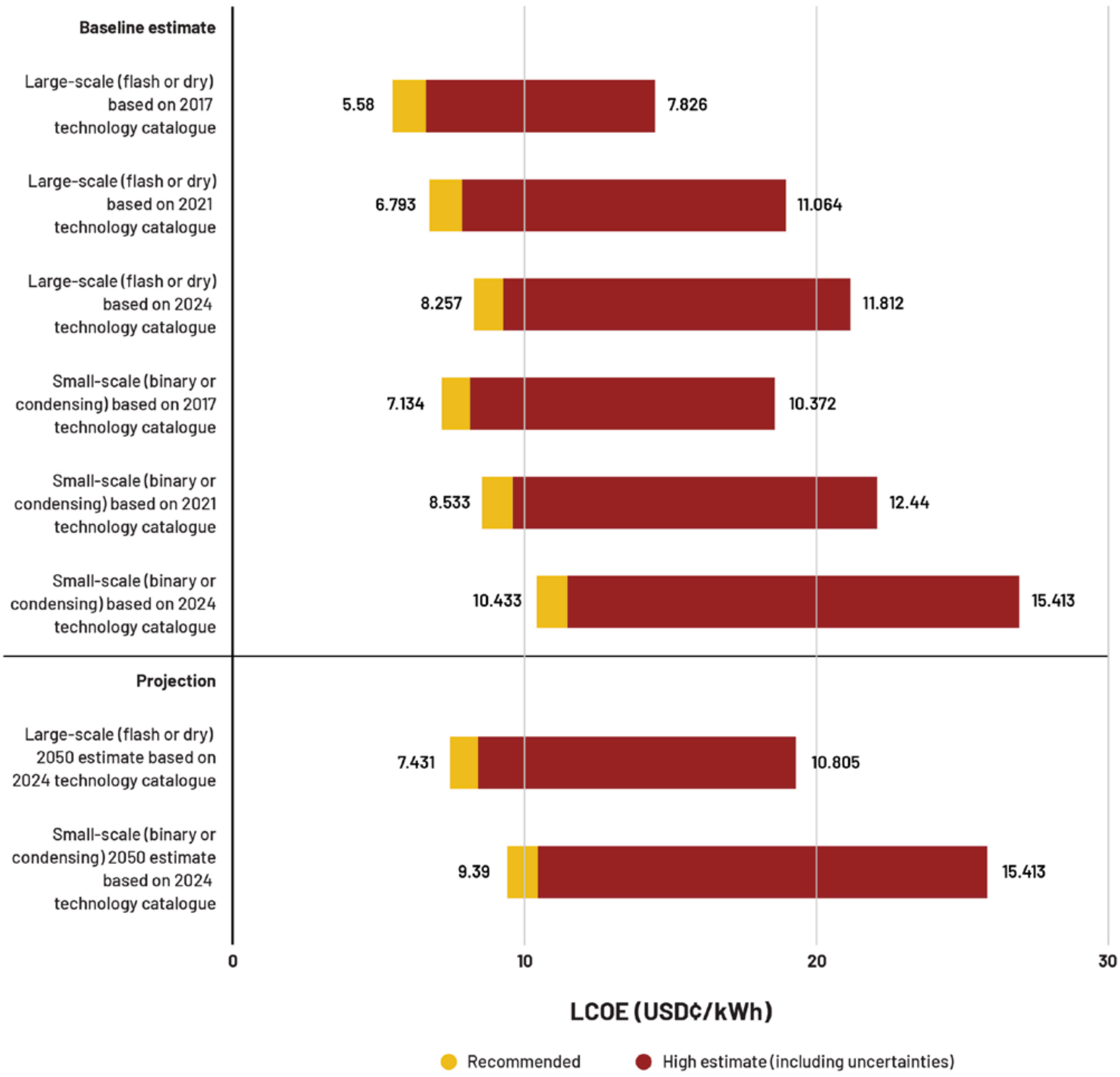


Figure 2.11: Estimated levelized cost of electricity (LCOE) for small- and large-scale conventional geothermal power plants. kWh = kilowatt-hours. Source: Institute for Essential Services Reform (IESR), using methodology in Bintang, H. M. (2023). *Making energy transition succeed: A 2023's update on the levelized cost of electricity (LCOE) and levelized cost of storage (LCOS)*. IESR. Additional data from Ea Energy Analyses. (2017). *Technology data for the Indonesian power sector: Catalogues for generation and storage of electricity*; Ea Energy Analyses. (2021). *Technology data for the Indonesian power sector: Catalogue for generation and storage of electricity*; Ea Energy Analyses. (2024). *Technology data for the Indonesian power sector: Catalogue for generation and storage of electricity*.

Another regulation, MEMR 10/2025, provides the legal basis for the power sector to transition away from its reliance on coal and greenhouse gas emissions. Strategies to achieve the pledged reduction include retrofit fossil (coal and gas) power plants, accelerated development of variable renewable energy and additional power generation capacity that comes from new and renewable energy, production of green hydrogen or green ammonia, improved grid infrastructure via increased capacity and smart-grid technologies, and early retirement of coal-fired power plants.[76] (See Recommendation #2 in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for more.)

These strategies are all relevant to geothermal. Next-generation geothermal technologies enable former coal-fired power plants to be not only retrofitted but also repurposed into geothermal power plants by replacing the coal-fired boiler component with geothermal water-steam cycles.

As a start, developers could co-locate geothermal near coal power plants; there is potential to use waste water from coal plants to create, charge, and operate an EGS reservoir.[77] The same approach could also be applied to the early retirement of coal-fired powered plants, particularly in Java and Sumatra—two regions with hot spots of geothermal resources (see **Figure 2.12**).[78] In fact, data show that two of the oldest coal-fired plants in Indonesia, Suralaya and Bukit Asam, have great potential for being converted into geothermal power plants.

Geothermal for Green Hydrogen Production

Geothermal resources can also be used to produce green hydrogen. The MEMR roadmap estimates that geothermal currently could only produce about 4.6 tons of hydrogen per year because it assumes that the majority of current geothermal potential will be exhausted for electricity generation.[79] The new estimate of geothermal next-generation resources—at 2,160 gigawatts—upends that assumption. Research

COAL FACILITIES OVERLYING GEOTHERMAL RESOURCES

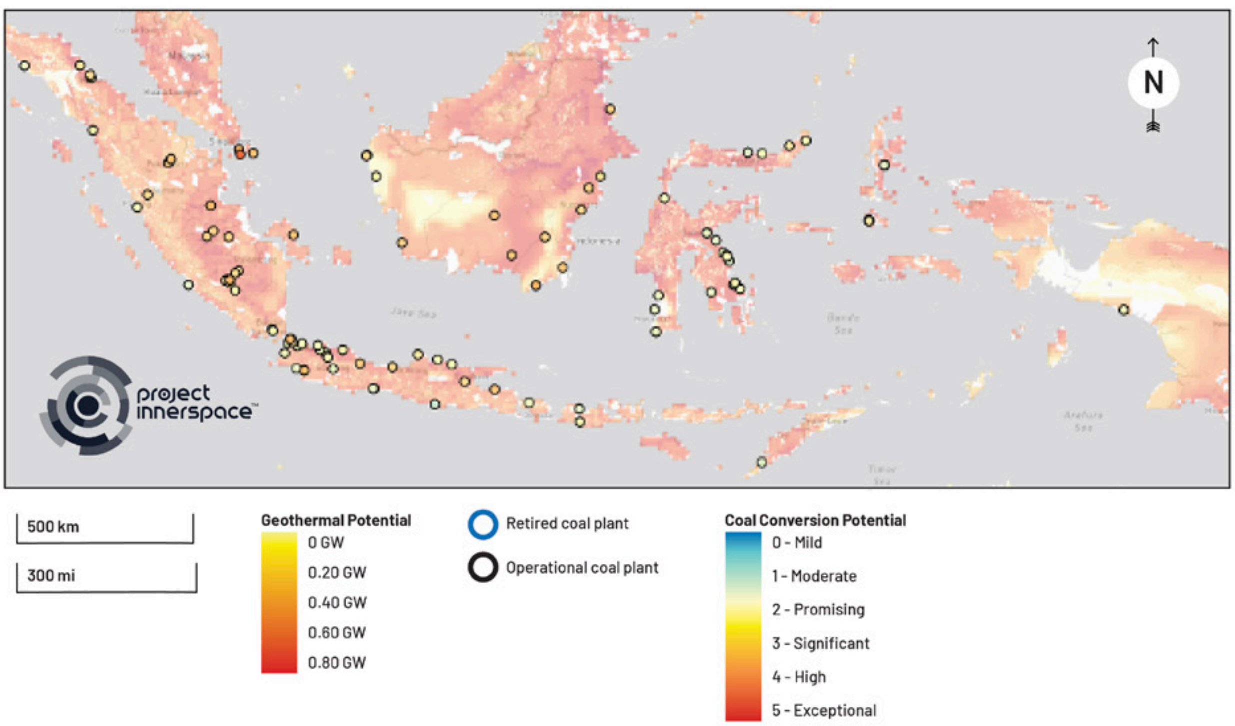


Figure 2.12: Map showing the cumulative geothermal potential between 0 meters and 5,000 meters, with a 150°C temperature cutoff, representing the minimum threshold for power generation, overlaid with coal-fired power plants and their suitability for geothermal conversion. GW = gigawatts. Source: Project InnerSpace. (n.d.). *Today's Power Potential GW 5000m* [Power Generation Module]. GeoMap; Project InnerSpace. (n.d.). *Coal Plant WOA* [Indonesia Module]. GeoMap.

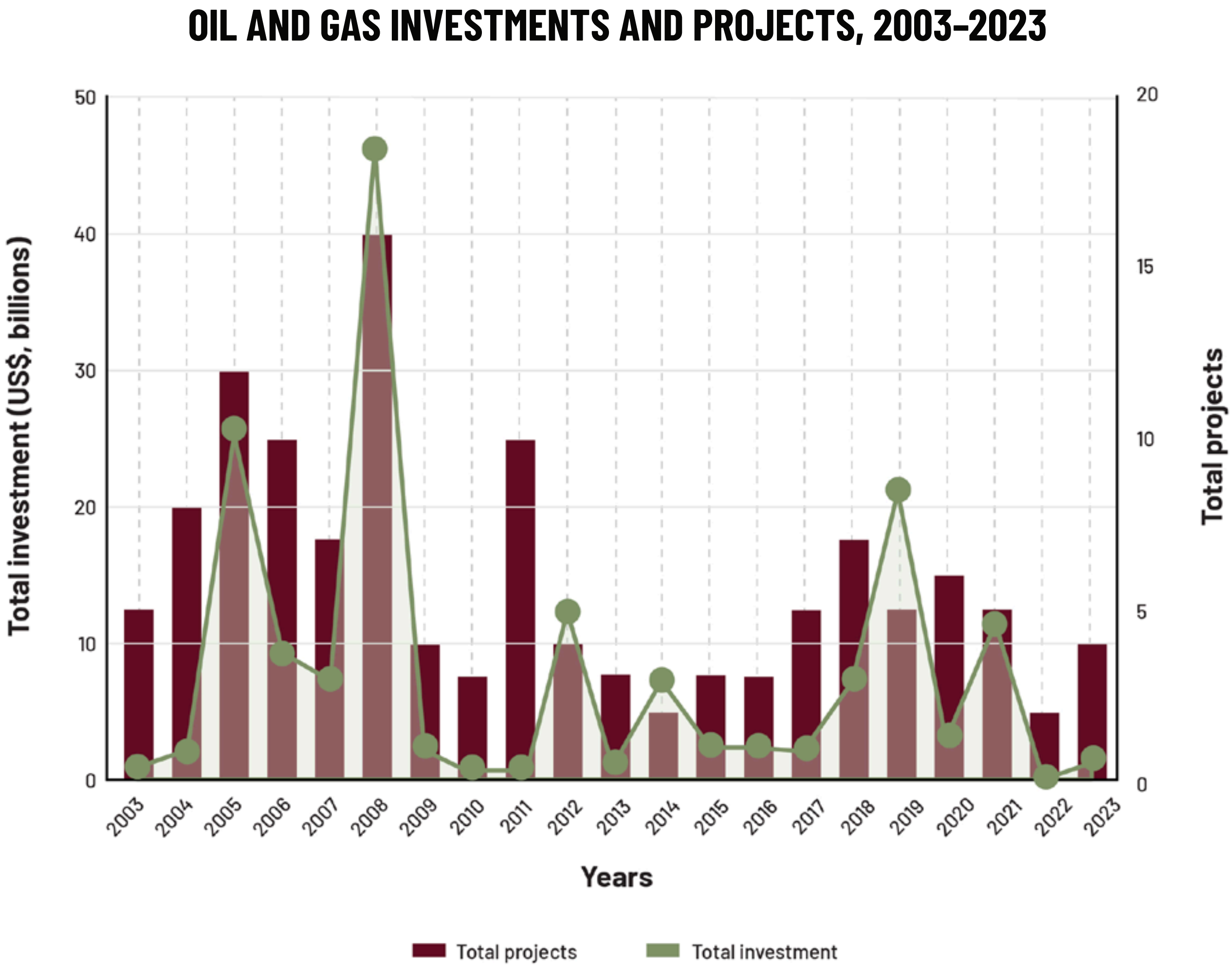


Figure 2.13: Total investment values and project counts in Indonesia's oil and gas sector between 2003 and 2023. Source: Baker Hughes. (n.d.). *Rig count overview and summary count*.

has also shown that geothermal may be able to produce green hydrogen through thermolysis and direct use of steam.[80] Since early 2024, the Kamojang geothermal power plant has operated a green hydrogen pilot facility that produces approximately 4.3 tons of hydrogen per year with a reported purity of up to 99.9%.[81]

Geothermal Data Centers

Co-locating data centers with geothermal resources can provide direct, always-on, low-carbon power at the source. A recent analysis in the United States suggests this approach can lower levelized electricity costs by between about 31% and 45% compared with grid-dependent models, and Indonesia is well positioned to lead this change.[82] As of May 2023, PLN served 128 data center customers with nearly 1 gigawatt of load, with demand projected to reach 4 gigawatts by 2033[83] and potentially accelerate with artificial intelligence. PLN projects that Indonesia's data center electricity needs could even be between two and three times higher than current projections.[84] GeoMap shows favorable geothermal zones beneath major corridors such as Jakarta, Purwakarta, Surabaya, Batam, and Medan, enabling behind-the-meter generation and geothermal-assisted cooling near fiber and industrial nodes. By implementing targeted policies and next-generation systems, Indonesia can anchor a clean, reliable digital infrastructure. (See Recommendation #3 in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for more.)

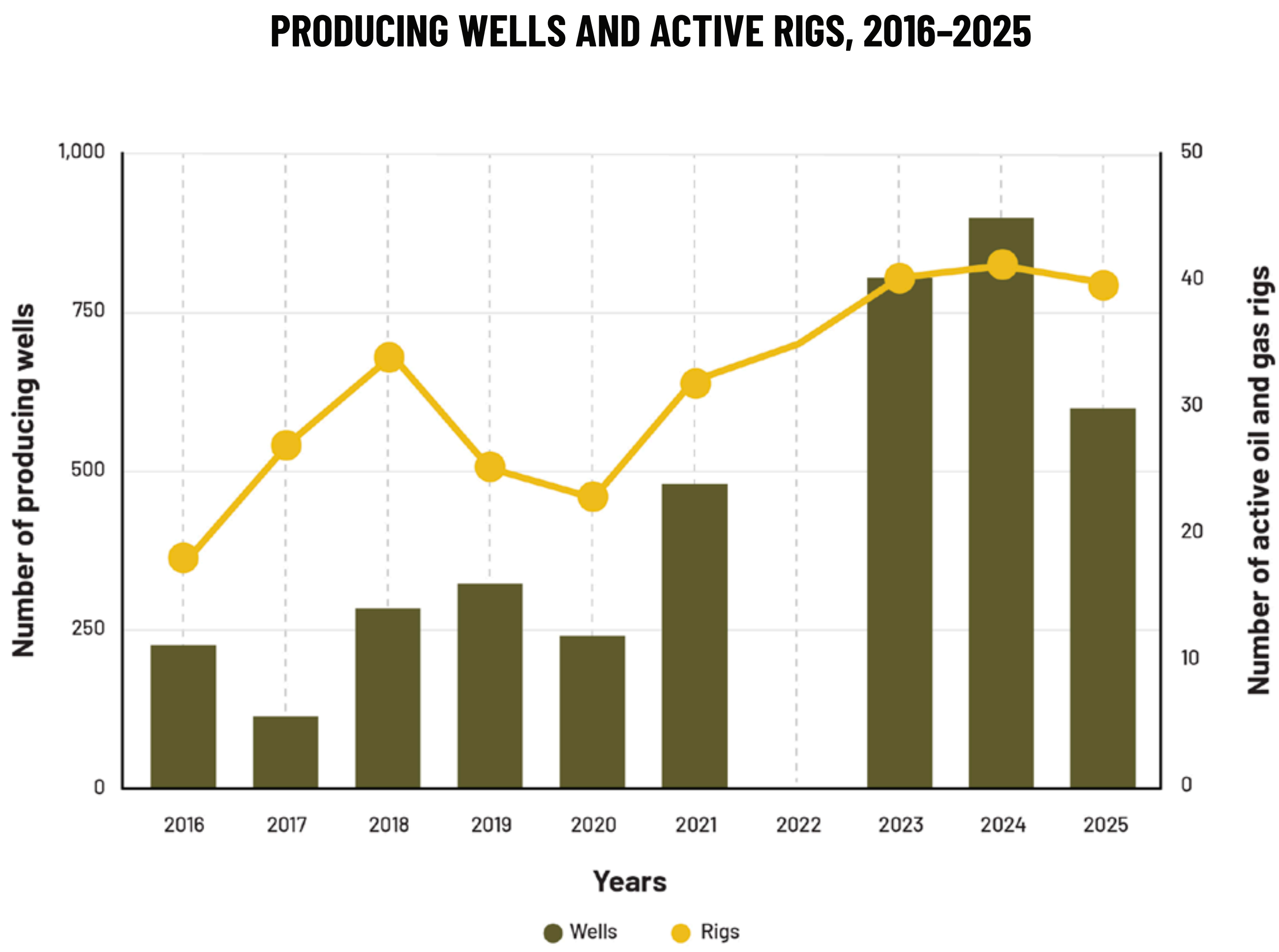


Figure 2.14: Number of exploitation wells and active oil and gas rigs in Indonesia between 2016 and 2025 (data through August 2025 for wells and July 2025 for rigs; 2022 well data unavailable). Source: Baker Hughes. (n.d.). [Rig count overview and summary count](#).

Partnerships with the Oil and Gas Industry

The processes used in Indonesia's oil and gas industry—including drilling rigs used in the exploration and exploitation of wells, pumps, well pads, heat exchangers, and more—share benefits with geothermal energy development.[85] Benefits include the opportunity to repurpose oil and gas industry assets such as down-well sensors, geophysical mapping tools, reservoir stimulation, and management technologies to reach hot metamorphic or sedimentary rock for next-generation development.[86] Among all renewable technologies, geothermal has the strongest technical and workforce crossover with the oil and gas sector, as they leverage similar subsurface expertise, drilling practices, and infrastructure.[87,88]

In an effort to boost Indonesia's oil and gas production work, 39 field development plans and similar initiatives for the exploration and production of hydrocarbons were approved in 2023.[89] Continued work has also been done to optimize development wells, workover wells, and well maintenance activities.[90] By August 2025, 599 development wells had been drilled by 28 oil rigs, 2 gas rigs, and 10 miscellaneous rigs operating in the country.[91] Those numbers are in addition to the 799 wells drilled in 2023 and 899 wells drilled in 2024 (**Figure 2.14**).[92] (For more information on geothermal and the oil and gas industry, see Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions.")

RECOMMENDATIONS

The following recommendations can help Indonesia overcome some of the hurdles mentioned in this chapter.

Conduct Surveys and Assessments

Given the substantial potential of heat and generation capacity offered by next-generation geothermal technologies, the government should lead firsthand surveys and economic assessments, then include the findings in the next edition of the technology report as a reference for investors.

Bridge the Gap for Economic Viability

The government can help bridge the gap between developers' expected returns and consumers' affordability, which is protected by a ceiling tariff by facilitating access to low-cost financing and support mechanisms such as viability gap funding. The government can prioritize projects in regions where improved electricity access can foster economic growth. (See Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for recommendations.)

The following strategies could help lower the costs of plant development:

- Allow the extension of long-term and/or high-quantity contracts without another tendering process.
- Carry out extensive and ongoing drilling campaigns within the same Geothermal Working Area.
- Enable developers to own drilling rigs and services.

A global study commissioned by the International Finance Corporation found that the more wells are drilled, the higher the success rate, as each drilled well refines the knowledge of a resource's size and location.[93] An increased number of drilling programs and technological improvements would also reduce development time, investment costs, and financing rates. As exploration continues, more data will become available that can help define the archetypes of geothermal resources, and the data can also be used in the design of a turbine that can be operated in a certain range of conditions. Applying such a standard steam turbine design—even for as few as five units—could result in significant cost savings.[94] These strategies may not be a silver bullet, but analysis offers support for developing a geothermal drilling database, promoting data transparency and sharing among developers, standardizing drilling activities and reporting requirements, and continuing to update the study to capture trends and implement state-of-the-art drilling technology. (See Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for more information on various measures to develop the industry and bring down costs.)

Balancing the realization of geothermal development targets with the need to sustain investor appetite—without significantly impacting electricity affordability—remains a core challenge in Indonesia. Achieving this balance will require close collaboration between the government, industry players, and other stakeholders to address persistent obstacles, including exploration risks, lengthy development timelines, public acceptance issues, and shortages of skilled human resources. These factors will be critical in determining the long-term economic viability of geothermal projects in Indonesia.

TARIFFS AND PLN

Under the current Presidential Regulation 112/2022, ceiling prices are still based on capacity and location factor, but with a tariff range of between US 8.42 cents per kilowatt-hour and 10.74 cents per kilowatt-hour. Over the past decade, as the sole offtaker for geothermal electricity, PLN has managed to secure Power Purchase Agreements (PPAs) for several projects at prices about 80% lower than the applicable ceiling (with exceptions; see Figure 2.15).

GEOTHERMAL POWER PURCHASE AGREEMENT TARIFFS UNDER PLN OFFTAKE AGREEMENTS

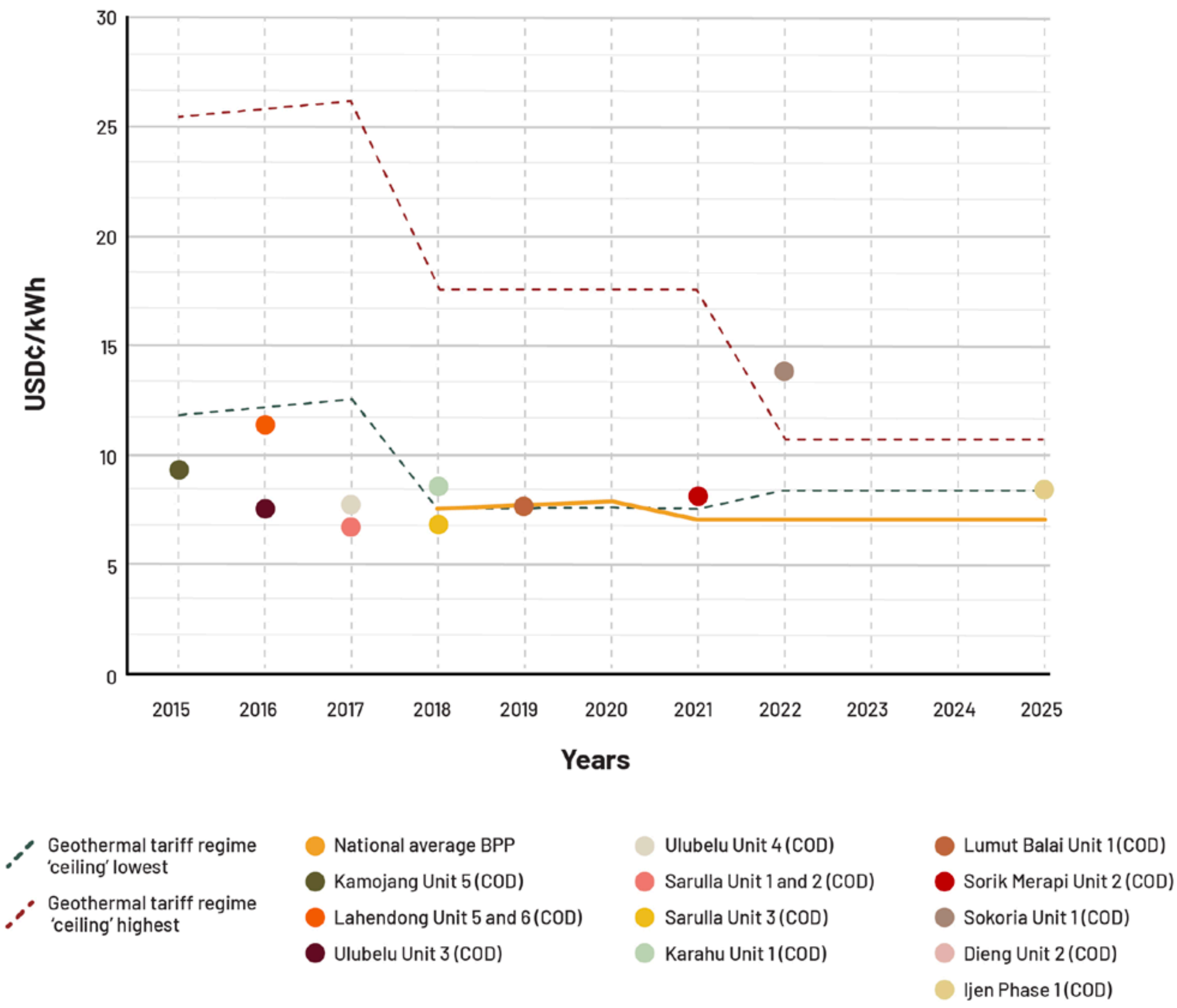


Figure 2.15: Reported PPA tariffs of selected geothermal power plants secured by PLN compared with two national tariff regimes (MEMR Regulations 17/2014 and 50/2017) and the average national generation cost (MEMR Decrees 1772 K/20/MEM/2018, 55 K/20/MEM/2019, and 169.K/HK.02/MEM.M/2021). BPP = national generation cost; COD = Commercial Operation Date. Source: Prima, B. (2019, April 25). The investment value of the Dieng and Patuha Unit II PLTP project reached US $300 million. Kontan; Arifenie, F. N. (2011, March 12). PLN signs electricity PPA for six power plants. Kontan; MedcoEnergi Geothermal. (2023). Geothermal power plant project Ijen Bondowoso: Livelihood restoration plan; Lesmana, A., Winofa, N. C., Pratama, H. B., Ashat, A., & Saptadji, N. M. (2020). Preliminary financial modelling with probabilistic approach for geothermal development project in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 417, 012024; Arifenie, F. N. (2012, April 29). PLN to sign 11 geothermal PPAs. Kontan; Meilanova, D. R. (2021, July 28). Sorik Marapi Geothermal Power Plant Unit II is operational, saving PLN Rp100 billion per year. Bisnis.

The trend toward lower geothermal ceiling tariffs aligns with the government's objective to expand renewable energy deployment while maintaining electricity affordability for the public. However, there is still a significant gap between these rates and the basic cost of electricity supply, which is kept exceptionally low due to the dominance of subsidized coal-fired power plants. This low basic cost effectively sets the pricing benchmark for every renewable power plant in the pipeline. While lower tariffs support affordability, however, excessively low rates risk undermining investor interest, particularly in the absence of a supportive environment. After Presidential Regulation No. 112/2022 was issued, several developers expressed concern that investor profit margins would be minimal.

CONCLUSION

Despite Indonesia's massive geothermal potential, the use of geothermal in the country remains extremely low. Out of approximately 2,168 gigawatts of total conventional and next-generation geothermal potential (see Chapter 3, "Beneath the Archipelago: Indonesia's Geothermal Systems," and its supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities"), only 2.68 gigawatts of conventional resources have been developed for electricity generation.[95] In direct-use applications, Indonesia currently produces 2.37 megawatts thermal, despite the nation's vast potential.[96] Additionally, even in long-term planning, use of geothermal still centers on electricity generation.

The nation has all of the elements to build a thriving geothermal industry and use its vast resources to meet its climate goals while developing a new avenue for a domestic workforce. Yet, Indonesia is at a crossroads in its energy transition ambition to reach net zero by 2060. Despite the abundance of geothermal resources, structural challenges hinder renewable energy deployment. While plans such as the National Energy Plan, the National Electricity General Plan, and Presidential Regulation 112/2022 have created enabling frameworks, the pace of geothermal integration remains slow.

To close this gap, and as laid out in more detail in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," Indonesia can treat geothermal development as a national priority within its long-term energy strategy. With its extraordinary potential, geothermal could be expanded beyond electricity production into industrial heating, data centers, hydrogen production, and other direct uses, and these uses can unlock extensive economic and environmental benefits. By accelerating geothermal deployment, Indonesia can not only reduce its heavy reliance on coal but also achieve a more resilient low-carbon energy system. In doing so, geothermal energy can become a cornerstone of Indonesia's just and sustainable energy transition, ensuring both energy security and alignment with net-zero targets. Indonesia could emerge as a world leader in the next generation of geothermal technologies and applications.

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Lahendong geothermal production field, PT Pertamina Geothermal Energy (Tbk) and geothermally heated brown sugar factory

Chapter 3, Part 1

Beneath the Archipelago: Indonesia's Geothermal Systems

Pri Utami, Kartika Palupi Savitri, and Yan Restu Freski, University of Gadjah Mada

Beneath Indonesia's complex geological framework lies a broad and largely untapped spectrum of geothermal potential. From deep superhot zones to heat-bearing sedimentary basins, radiogenic granitic formations, Indonesia's subsurface offers diverse opportunities for applications far beyond the conventional geothermal the nation uses today.

There is perhaps no better place to observe geothermal energy's massive potential than along the Ring of Fire, a tectonically active zone characterized by chains of active volcanoes and frequent seismic activity. The Indonesian archipelago, which forms the westernmost part of the Ring, is therefore blessed with abundant geothermal energy prospects. Geothermal gradients in the region exceed 30°C per kilometer, significantly above the global continental average.

The earliest attempt to develop the archipelago's geothermal resources was made by the Dutch colonial government, which began exploring areas fumaroles in Kamojang (West Java) in 1918.[1] After independence in 1945, Indonesia began exploring geothermal potential throughout its territory, primarily targeting high-temperature resources where significant underground heat supplied by recent volcanism is discharged at the surface (**Figure 3.1**).[2,3,4] Since the 1980s, the government has also expanded its focus to include medium- and low-temperature prospects, which are not always located within active volcanic regions.

Today, Indonesia is a world leader in geothermal, with more geothermal power than all but a few countries. As of 2025, Indonesia is home to 19 commercially operating high-temperature geothermal fields with a conventional total installed capacity of 2,653 megawatts of electricity,[5] making the country the second-largest producer of geothermal electricity in the world (see **Figure 3.2**). To date, all of Indonesia's geothermal capacity has been conventional

INDONESIA'S GEOTHERMAL DEVELOPMENT TIMELINE

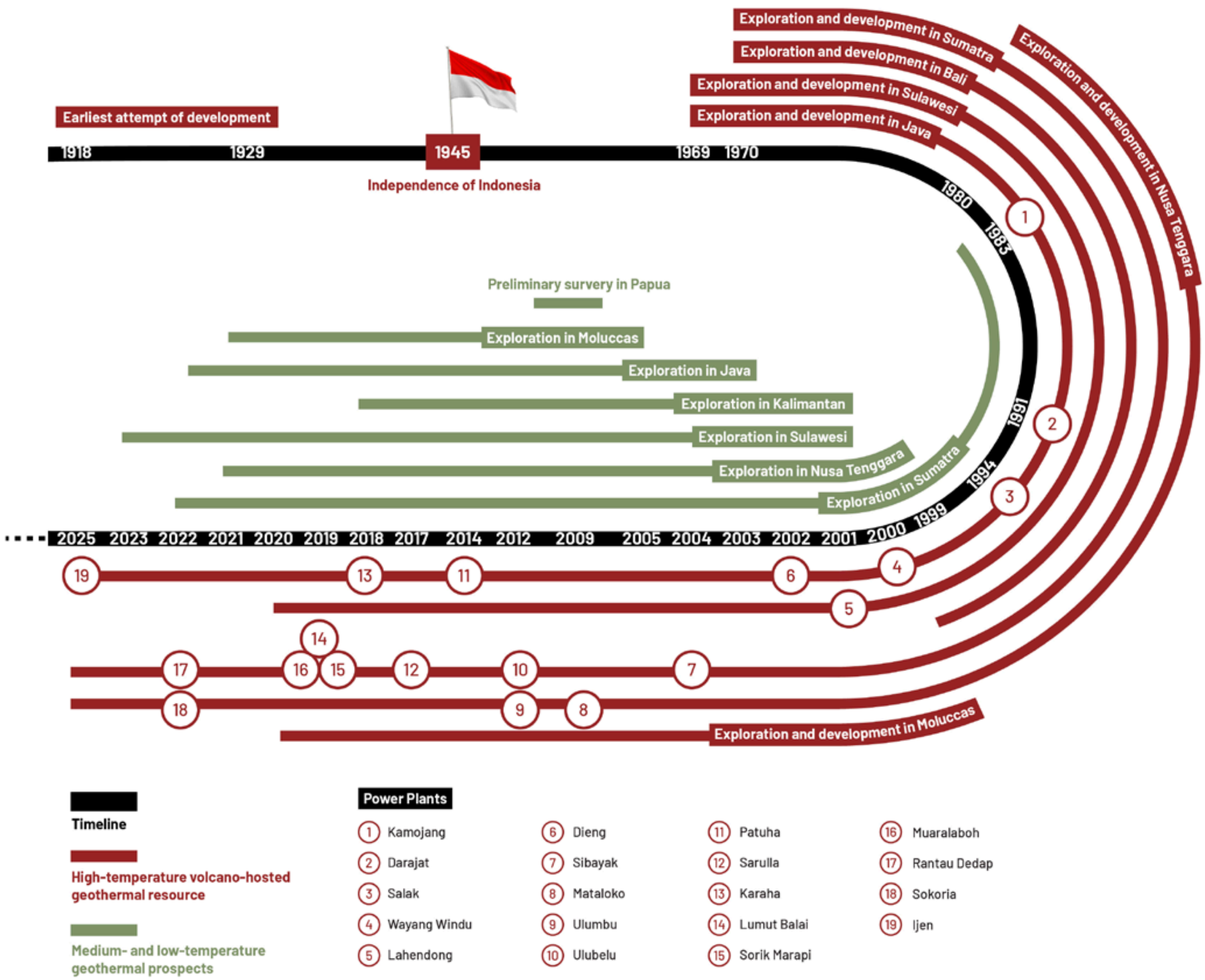


Figure 3.1: Indonesia's geothermal development milestones and the year of commissioning of geothermal power plants. Sources: Radja, V. T. (1975). Overview of geothermal energy studies in Indonesia. In *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources*. San Francisco, CA, United States; Hochstein, M. P., & Sudarman, S. (2008). History of geothermal exploration in Indonesia from 1970 to 2000. *Geothermics*, *37*(3), 220–266; Ministry of Energy and Mineral Resources. (2023). *Profile of Indonesia's geothermal potential: Volumes 1 and 2*. Directorate of Geothermal, Directorate of New, Renewable Energy, and Energy Conservation, Ministry of Energy and Mineral Resources, Republic Indonesia; Ministry of Energy and Mineral Resources. (2024). *Exploration activities by geothermal permit holder business entities* [Presentation]. Used with permission.

hydrothermal, with naturally occurring reservoirs of heat, water, and permeability—typically associated with volcanic systems—lying relatively close to the surface. Such systems are considered conventional because they rely on these near-surface attributes, unlike enhanced or engineered geothermal systems that must artificially create flow paths in hot, dry rock. (See Chapter 1, "Geothermal 101: Overview of Technologies and Application.") The existing 2,653 megawatts of electricity are only a small fraction of the nation's total conventional geothermal potential, which was estimated at approximately 23.7 gigawatts of electricity by the Ministry of Energy and Mineral Resources in 2025.[6] These estimates include speculative and hypothetical resources as well as proven reserves, primarily within hydrothermal geothermal systems. (For a discussion of additional resources that could be developed through next-generation geothermal technologies, see "Expanding the Scope: Next-Generation Geothermal Opportunities," the supplement to this chapter.)

In other words, as explored later in this chapter, Indonesia has significant opportunities to develop geothermal resources beyond conventional hydrothermal systems. These next-generation technologies leverage oil and gas technologies to bring the Earth's heat to the surface for power or heating and cooling applications. Given Indonesia's diverse geological landscape, geothermal development can include all types of geothermal resources, regardless of temperature and whether the resource is onshore or offshore, as long as it is located within Indonesia's exclusive economic zone (EEZ), extending up to 200 nautical miles from the coast.

This chapter looks at Indonesia's enormous geothermal development potential and identifies locations for further site-specific study. With rising energy demand and a national commitment to both energy independence and 100% renewable energy, proactive research will help the country unlock new resources and support a resilient, sustainable energy future.

The potential for geothermal prospects beyond volcanogenic hydrothermal systems is based on an integrated analysis of geological conditions and regional geophysical data sets, including geothermal gradient maps. Where available, this information is further supported by published temperature data gathered from both geothermal and petroleum drilling, as well as additional fieldwork conducted to validate specific geological parameters. This chapter also includes examples from field exploration in countries with analogous geological settings. At the end of this chapter, we also attempt to qualitatively assess the Technological Readiness Level (TRL) of each geothermal system.

GLOBAL INSTALLED CAPACITY (MWE): TOP 10 COUNTRIES FOR POWER GENERATION

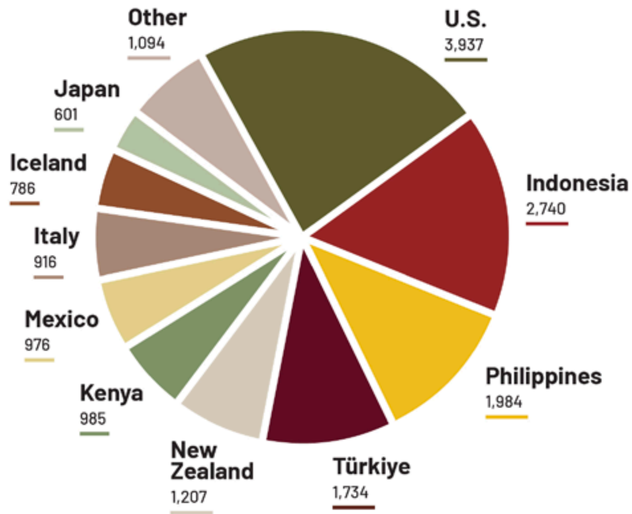


Figure 3.2: Geothermal installed capacity shows that Indonesia is second in the world for producing geothermal power but 74th in deploying direct-use geothermal resources. MWe = megawatts electrical. Source: Adapted from Al Asy'ari, M. R., Adityatama, D. W., Brilian, V. A., Erichatama, N., & Purba, D. (2024). Beyond electricity: Geothermal direct use business models and potential applications in Indonesia. In *Proceedings of the 49th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States; Cariaga, C. (2025, January 20). *ThinkGeoEnergy's top 10 geothermal countries 2024-power*. ThinkGeoEnergy.

GEOLOGY OF INDONESIA IN BRIEF

Indonesia's geological complexity can be traced to its unique position in the Earth's tectonic landscape. This includes interactions between three large tectonic plates—the Eurasian, Indo-Australian, and Pacific plates—as well as smaller plates such as the Caroline and Philippine Sea plates (**Figure 3.3**).[7,8]

This tectonic configuration reflects a long and dynamic geological evolution. Over the past 160 million years, the Indonesian region has been shaped by intermittent tectonic movements, resulting in the closure of ancient oceans and the gradual accretion of continental fragments.[9]

GEOLOGIC MAP OF INDONESIA

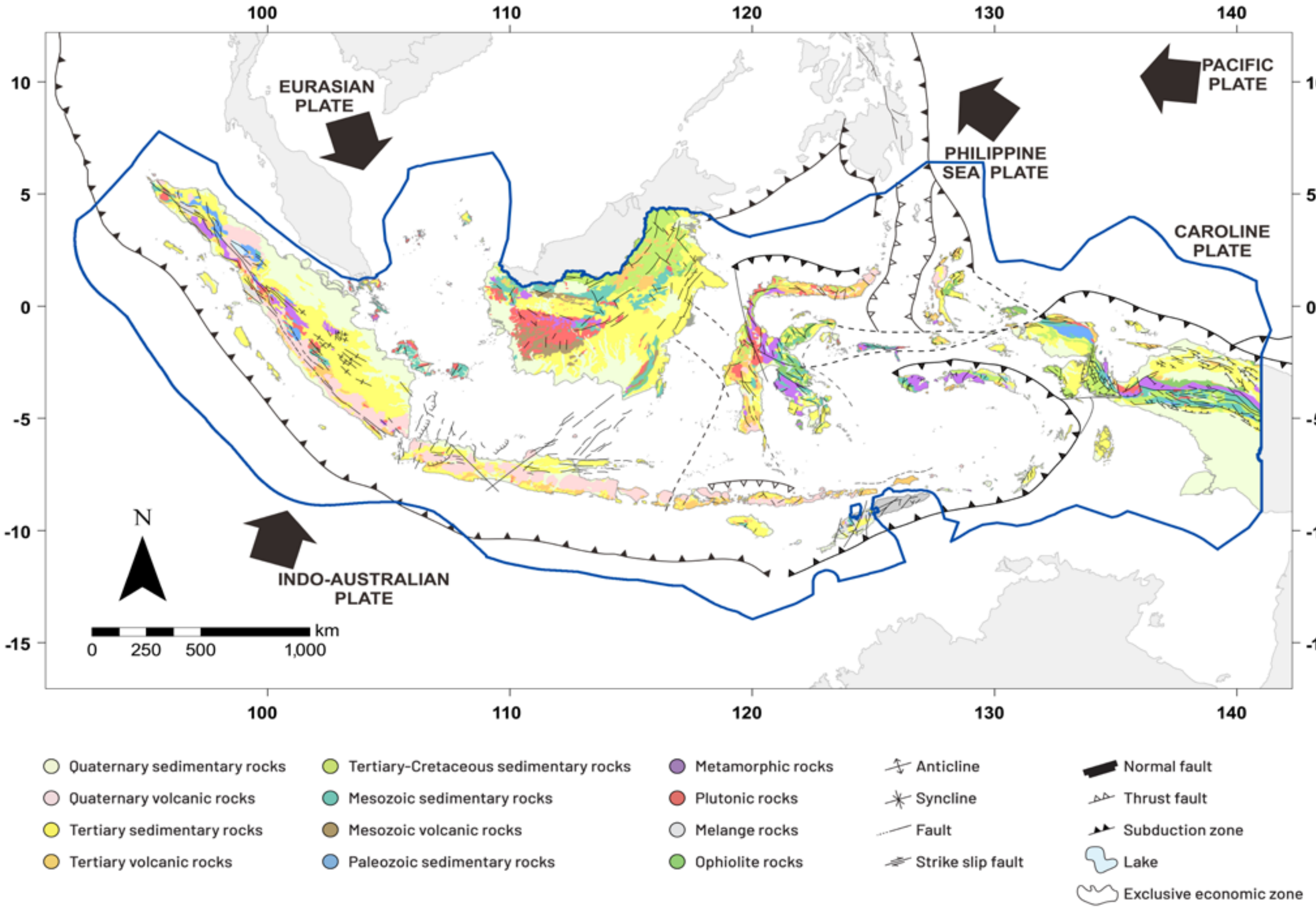


Figure 3.3: Map of the geology of Indonesia showing major tectonic plate boundaries, rock formations, and geologic structures. Sources: Sukamto, R. (2010). *Regional geological map* (D. Sukarna, Ed.). Ministry of Energy and Mineral Resources, Republic of Indonesia; Sukamto, R., Ratman, N., & Simandjuntak, T. O. (Eds.). (2011). *Geological map of Indonesia*. Ministry of Energy and Mineral Resources, Republic of Indonesia; Macpherson, C. G., & Hall, R. (2002). *Timing and tectonic controls in the evolving orogen of SE Asia and the western Pacific and some implications for ore generation*. Geological Society, London, Special Publications, *204*, 49–67; Setiawan, N. I., Osanai, Y., Nakano, N., Adachi, T., Yonemura, K., Yoshimoto, A., Setiadji, L. D., Mamma, K., & Wahyudiono, J. (2012). *Geocehmical characteristic of metamorphic rocks from South Sulawesi, Central Java, South and West Kalimantan in Indonesia*. *ASEAN Engineering Journal*, *3*(1), 107–127; Simandjuntak, T. O., & Barber, A. J. (1996). *Contrasting tectonic styles in the Neogene orogenic belts of Indonesia*. *Geological Society, London, Special Publications*, *106*, 185–201; Raharjo, P., Mellawati, J., & SBS, Y. (2016). *Analysis of supposed capable faults as supporting data for the proposed site of the Bojonegara Nuclear Power Plant, Banten Province*. *Journal of Nuclear Energy Development*, *18*, 39–48; Flanders Marine Institute. (2025). *MarineRegions.org*.

Around 45 million years ago, renewed northward movement of the Australian Plate initiated subduction beneath the Sunda Arc, which has remained active to the present day. The subducted lithosphere beneath much of Indonesia is Cretaceous or older, except in the westernmost Sunda Arc, where Cenozoic oceanic crust has been subducted within the last 20 million years.[9]

These complex plate interactions have produced an exceptional variety of geological features, including deep-sea trenches, thrust and strike-slip faults, volcanic arcs, sedimentary basins, and accreted terranes. The resulting rock assemblages contribute to Indonesia's diverse geothermal landscape, ranging from igneous intrusions to varied sedimentary and metamorphic types. This landscape includes high-temperature volcanic systems along active arcs and non-volcanic geothermal resources (explained in the next section).

INDONESIA'S GEOTHERMAL RESOURCES

Geothermal resources are thermal energy stored in the Earth's crust beneath a given area (measured from mean annual surface temperature) that could reasonably be extracted at costs that are competitive with other forms of energy at some specified time in the future. These resources are further classified as "economic" or "sub-economic" based on the conditions at the time of their assessment.[10] A geothermal resource is contained in a geothermal system—a natural configuration within the Earth's crust that allows heat to be stored, transferred, and potentially extracted for energy use.

Based on knowledge of the geologic setting and supported by regional geophysical data and, where available, downhole temperature measurements, we identify and explore at least five distinct types of geothermal resources in Indonesia:

1. Volcano-hosted hydrothermal-type geothermal resources (on land and submarine)

2. Subvolcanic supercritical geothermal resources (on land and submarine)

3. Granitic rock-hosted radiogenic geothermal resources: hydrothermal and hot dry rock (HDR) (on land and submarine)

4. Sedimentary rock-hosted geothermal resources (on land and submarine)

5. Metamorphic rock-hosted geothermal resources (on land)

These resource types are classified according to their host lithology, geologic environment, temperature, and the presence or absence of fluids within the system (**Figure 3.4**). While some of these resource types remain undiscovered or have low geological confidence, they are all considered accessible through drilling and potentially viable for future energy development.

VOLCANO-HOSTED HYDROTHERMAL-TYPE GEOTHERMAL RESOURCES (ON LAND AND SUBMARINE)

Reports of both on-land and submarine volcanoes and hydrothermal vents in Indonesia were first consolidated in *A Catalog of Active Volcanoes of the World* by Neumann van Padang in 1959. Updates, including real-time volcanic activity, are now monitored and published by the Center of Volcanology and Geological Hazard Mitigation (PVMBG) of Indonesia.[11]

On-Land Volcano-Hosted Hydrothermal-Type Geothermal Resources

Hydrothermal-type geothermal resources in volcanic terrain have historically been targeted for development in Indonesia. Typically, these systems involve igneous rock reservoirs containing hydrothermal fluids, mostly derived from rainwater, heated with or without direct magmatic input. The systems are commonly capped by impermeable hydrothermal clay. High-temperature systems often exhibit abundant surface expressions or thermal manifestations such as fumaroles, hot springs, steaming grounds, and hydrothermally altered grounds.

According to a 2023 inventory by the Geological Agency of Indonesia, there are 336 on-land hydrothermal-type geothermal prospect locations along the volcanic chains of Indonesia. Of these, 94 are classified as high-temperature.[12] Nineteen fields of this resource type currently produce electricity (see **Figure 3.5**).

GEOTHERMAL RESOURCE TYPES IN INDONESIA

No.	Geothermal Resource Type	Geologic Region	Environment and Prospective Locations	Temperature Class	Fluid
1	Volcano-hosted hydrothermal	Active volcanic chains	On land: Sumatra, Java, Bali, Nusa Tenggara, The Moluccas, North Sulawesi Submarine: Sabang Waters, Sangihe Arc; Banda Sea	High, medium, and low	Hydrothermal, with or without trace of magmatic fluids
2	Subvolcanic supercritical	Region beneath active volcanic chains	On land: Sumatra, Java, Bali, Nusa Tenggara, The Moluccas, North Sulawesi Submarine: Sabang Waters, Sangihe Arc; Banda Sea	Ultra-high	Supercritical fluid
3	Granitic rock-hosted radiogenic **hydrothermal**	Granite Tin Belt Granitic provinces	On land and submarine: Bangka and Riau Islands On land: Sumatra, Kalimantan, Sulawesi, East Nusa Tenggara, Halmahera, Sula Islands, Papua	Medium, low	Hydrothermal
	Granitic rock-hosted radiogenic **hot dry rock**	Granite Tin Belt Granitic provinces	On land and submarine: Bangka and Riau Islands On land: Sumatra, Kalimantan, Sulawesi, East Nusa Tenggara, Halmahera, Sula Islands, Papua	Medium, low	Fluid absence or scarce
4	Sedimentary rock-hosted	Sedimentary basins	On land, magmatically influenced: Sumatra, northern part of Java On land, hot sedimentary aquifer: Sumatra, Java, Kalimantan, Natuna, Sulawesi, northern part of Papua Submarine: the east of Sumatra, Riau Islands, the North Java Sea, and the Malacca Strait	Medium, low	Saline thermal fluids
5	Metamorphic rock-hosted	Metamorphic provinces	On land: Sumatra, Kalimantan, Sulawesi, Sula, Buru, Seram, Papua	Medium, low	Hydrothermal with metamorphic contribution, fluid possibly scarce

Figure 3.4: Summary of geothermal resource types in Indonesia. Source: the authors, based on the information they provided in Chapter 2.

In addition to prospects with obvious surface expressions, there are also prospects where surface manifestations are limited or even absent. These may represent parts of some deep-seated system with long lateral outflow, such as the Cisolok-Cisukarame geothermal field,[13] or waning systems that are gradually losing their heat supply or energy output over time.

GEOTHERMAL POTENTIAL INDICATORS IN INDONESIA

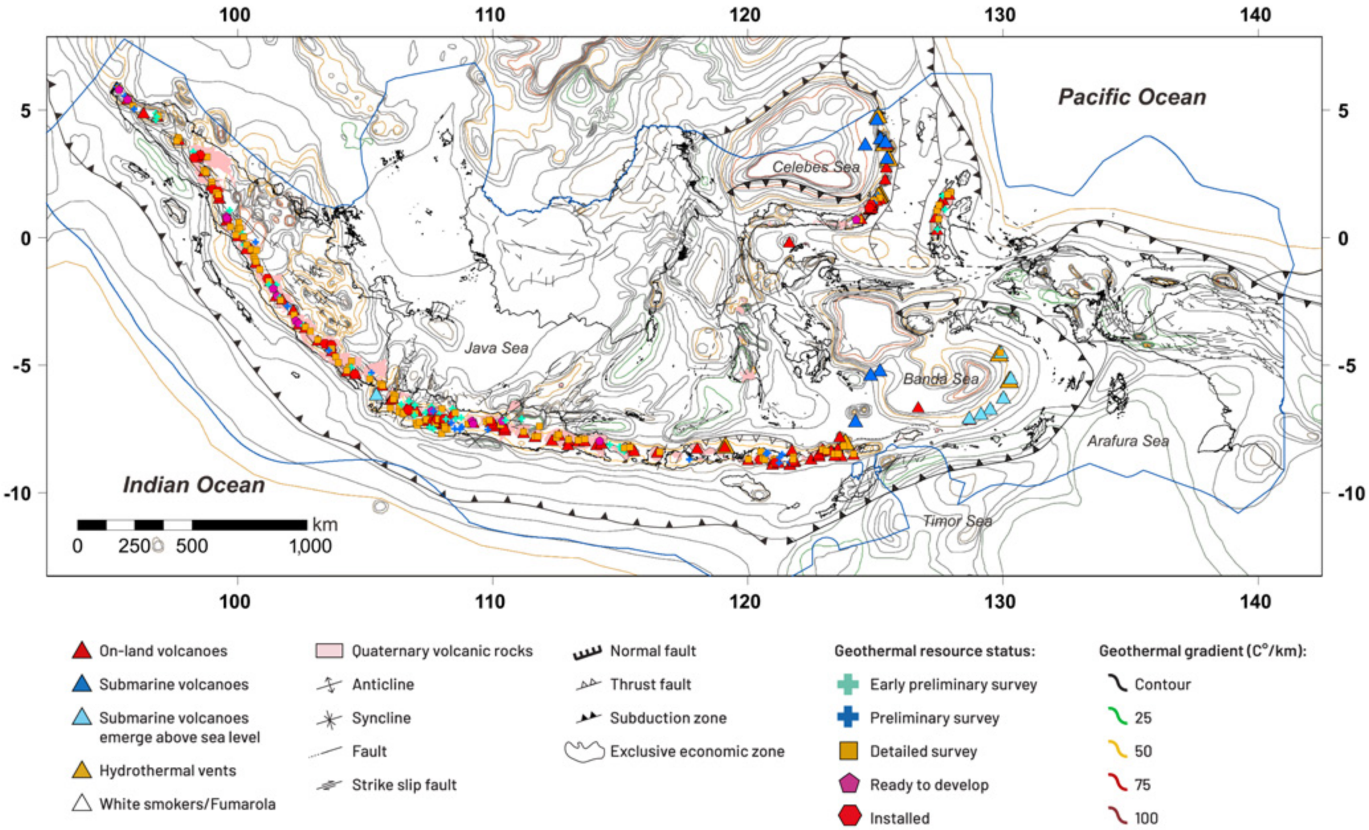


Figure 3.5: Map showing the distribution of on-land (Center for Volcanology and Geological Hazard Mitigation, 2021) and submarine volcanoes; hydrothermal vents (Abbott et al., 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); known and underexplored volcano-hosted hydrothermal resources (Indonesian Geological Agency, 2023); geothermal gradients (Darman, 2021), Quaternary volcanic rocks (Sukamto, 2010); major regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); and the boundary of Indonesia's exclusive economic zone (EEZ; Flanders Marine Institute, n.d.). See full reference information at the end of this chapter.

Submarine Volcano-Hosted Hydrothermal-Type Geothermal Resources

Submarine geothermal resources hold vast, untapped energy with immense potential to provide a sustainable energy supply. Volcano-hosted submarine geothermal systems share similar characteristics with their onshore counterparts but offer significantly greater energy potential. Due to this higher potential, these resources have recently gained attention as promising candidates for energy extraction.[14,15] Although the submarine geothermal systems remain poorly studied, the preliminary explorations described in this section highlight their potential.

Based on the occurrence of submarine volcanoes and hydrothermal vents, along with high geothermal gradients (**Figure 3.6**), there are at least three main zones of prospective resources:

1. **Pulau Weh**, at the western end of the Indonesian Archipelago, hosts the Jaboi geothermal system, an on-land, volcano-hosted hydrothermal site with submarine fumarole activity indicating the presence of underwater geothermal potential. The water depth reaches approximately 0.5 kilometers, and the area exhibits relatively high geothermal gradients, ranging from 50°C to 60°C per kilometer. Studies by Kurnio et al.[16,17] have explored rare earth element transport and enrichment around the fumarolic vents.

DISTRIBUTION OF SUBMARINE VOLCANOES AND HYDROTHERMAL VENTS

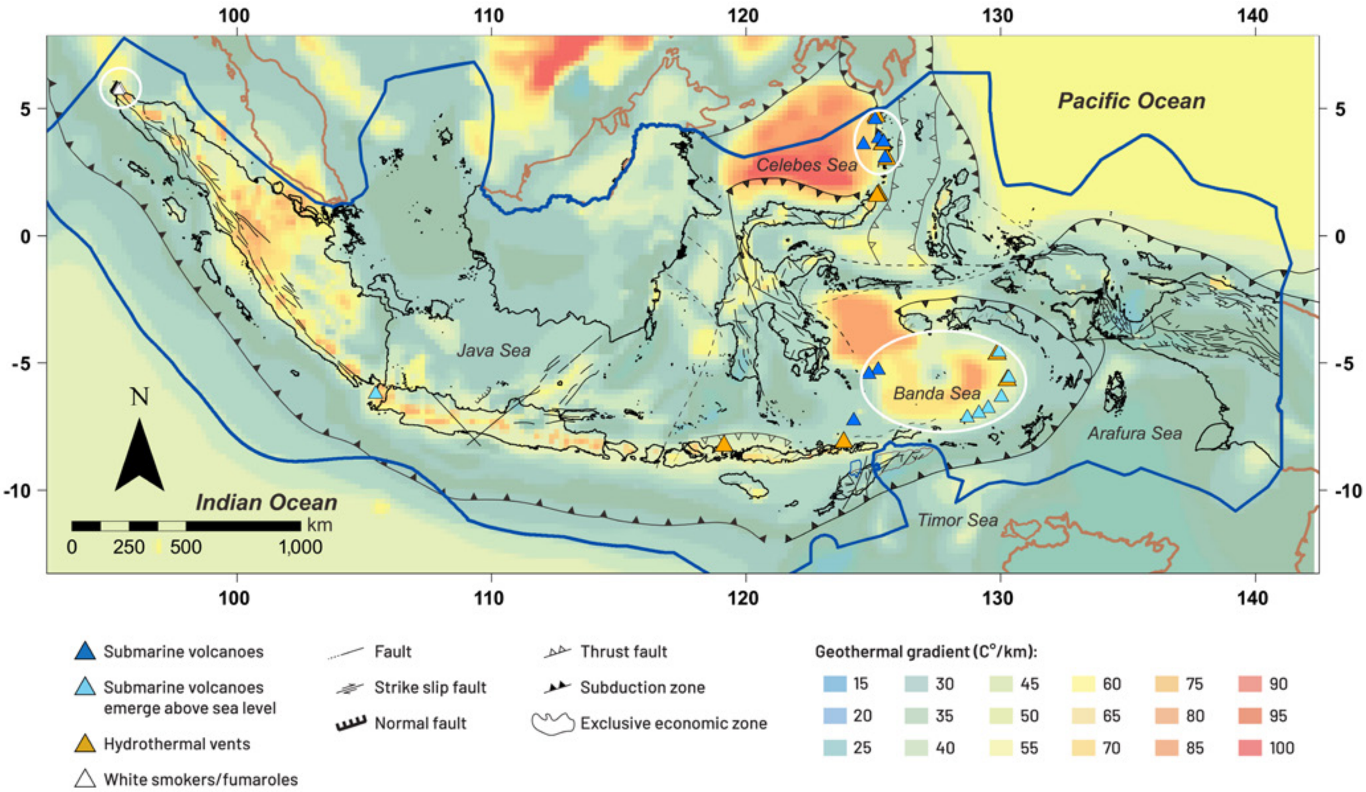


Figure 3.6: Map showing the distribution of submarine volcanoes and hydrothermal vents (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013), superimposed with maps of geothermal gradients (Darman, 2021); major regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); and the EEZ boundary (Flanders Marine Institute, 2025). White circles indicate the prospective sites for further exploration. On-land volcanoes are omitted for clarity. See full reference information at the end of this chapter.

2. **The Sangihe Arc**, in northern Sulawesi, also exhibits high geothermal gradients (50°C–75°C per kilometer), with seafloor depths reaching up to 4.5 kilometers. Submarine volcanoes and hydrothermal sites in the region include Banua Wuhu (0 kilometers to 2.5 kilometers below sea level), Naung (0.5 kilometers to 1.5 kilometers), Kawio Barat (1.5 kilometers to 4.5 kilometers), and the suspected Maselihe old hotspot (1.5 kilometers to 4.5 kilometers, as explored by McConachy et al.[18]).

3. **The Banda Arc**, a horseshoe-shaped volcanic arc, features active volcanoes such as Banda Api, Wetar, Manuk, Damar, Emperor of China, Nieuwerkerk, and Romang, of which the last three are offshore. The Banda Sea's depths range from 0.5 kilometers to 5.5 kilometers, with geothermal gradients ranging from 50°C to 60°C per kilometer. Hydrothermal activity has been documented in the offshore volcanoes of the Emperor of China and Nieuwerkerk.[19]

In addition to these three prospect zones, other potential submarine geothermal sites in Indonesia include areas in the Sunda Strait and in the Bay of Tomini, where hydrothermal manifestations have also been observed.[19]

Further geological, geophysical, and geochemical research is crucial for modeling these systems. Offshore development minimizes land disruption and avoids conflicts over land use; however, the feasibility of geothermal extraction requires thorough assessments of submarine volcanic hazards and environmental impacts. International submarine geothermal studies—such as those conducted in Mexico,[20,21] Papua New Guinea,[22] New Zealand,[23,24] Japan,[25] and California[26]—provide valuable exploration insights for Indonesia. By leveraging advanced on-land geothermal and offshore hydrocarbon production technologies, submarine geothermal resources can offer a cost-effective and scalable energy solution for various applications.

Sub-Volcanic Supercritical Geothermal Resources (On Land and Submarine)

Supercritical geothermal resources are hosted by geothermal systems in which a fluid is present in a state above a critical threshold (>374°C and >22 megapascals) where distinct liquid and gas phases do not exist. These systems can yield much higher energy than conventional hydrothermal systems. They are thought to be located at the roots of volcano-hosted hydrothermal systems at depth near or below the brittle-ductile transition zone (BDT), where rock behavior changes from brittle fracturing to ductile flow due to increasing temperature and pressure with depth.[27]

Exploration of supercritical geothermal resources in several countries has yielded significant results. For example, in Kakkonda, Japan, researchers have developed a technology to estimate subsurface temperatures[28] where deep drilling has reached the BDT.[29] Exploratory drilling in Krafla and Reykjanes, Iceland, has successfully discharged supercritical fluids and identified the transition zone between hydrothermal systems and magma.[30] Research in Larderello, Italy—the birthplace of geothermal power production—has discovered supercritical fluids using seismic methods and contributed to the advancement of drilling technologies.[31]

However, drilling into supercritical conditions presents significant challenges, particularly in managing fluids at very high temperatures and pressures. Addressing these issues requires advancements across multiple areas of geothermal development. Key priorities include improving resource assessment methods, conducting laboratory studies on fluid and rock behavior under supercritical conditions, developing advanced drilling technologies, and enhancing logging and monitoring strategies. In addition, robust numerical simulations and the establishment of dedicated field laboratories are essential for a better understanding of these types of resources.

A comprehensive plan for the exploration and development of the supercritical geothermal resources has been undertaken in New Zealand through its Geothermal: The Next Generation program in the Taupo Volcanic Zone. The program includes geoscientific research and engineering modelling to investigate subsurface conditions deeper than the known hydrothermal systems. It also includes resource inventory, the development of strategic pathways, assessments of economic viability, regulatory considerations, and stakeholders' engagement and communication efforts.[32]

By learning from these international experiences, Indonesia could explore its own supercritical geothermal resources, which are expected to occur beneath high-temperature hydrothermal systems along volcanic chains (**Figure 3.5**).

Similarly, large calderas in Indonesia—such as Tondano (North Sulawesi), Toba (North Sumatra), Batur (Bali), and Rinjani (West Nusa Tenggara)—are believed to host supercritical geothermal resources at depth. Notably, Tondano and Toba have yielded voluminous rhyolites comparable to those found in the Taupo Volcanic Zone, suggesting geothermal potential.

Tondano Caldera is one of Indonesia's largest historically active calderas,[33] hosting two productive geothermal systems: Lahendong and Tompaso (**Figure 3.7**). Both fields feature productive wells with average temperatures around 250°C.[34] Lahendong belongs to a magmatic vapor-cored geothermal system and exhibits stable temperatures reaching from between 350°C and close to 400°C at depths of between 2 kilometers to 2.5 kilometers in several wells.[35] This exceptionally high heat source at relatively shallow depth highlights the immense geothermal energy potential of the region.

Meanwhile, the Toba Caldera in North Sumatra is a large silicic volcanic system formed by multiple super-

TONDANO CALDERA DEPRESSION

Figure 3.7: Tondano Caldera depression, now partly filled by a lake, seen from the Kasuratan Hill, Minahasa, North Sulawesi. Source: the authors.

Indonesia could eventually extend its efforts to include the exploration of submarine supercritical geothermal resources, tapping into the vast potential of its offshore volcanic environments.

eruptions over the past 1.3 million years.[36] Geophysical studies using receiver function methods reveal a thickened crust (depth to mantle boundary around 31 kilometers) and low-velocity zones at depths of between 8 kilometers and 25 kilometers beneath Lake Toba, indicating partial melt zones or a large crustal magma body.[37] The association with a slab tear at the western end of the Sunda Arc supports the existence of persistent high heat flux and deep magmatic input.[38] These features suggest that supercritical conditions may exist at depth under the caldera.

Looking ahead, studies and exploration of onshore supercritical geothermal systems should be prioritized to build foundational knowledge and technical expertise. As understanding of these high-temperature systems improves, Indonesia could eventually extend its efforts to include the exploration of submarine supercritical geothermal resources, tapping into the vast potential of its offshore volcanic environments.

Granitic Rock-Hosted Radiogenic Geothermal Resources, Hydrothermal and Hot Dry Rock (HDR) (On Land and Submarine)

Granitic rocks enriched in uranium, thorium, and potassium generate heat through radiogenic decay,[39,40] providing a long-lasting crustal heat source distinct from the transient magmatic pulses in volcanic systems. While other lithologies such as felsic volcanic rocks or sedimentary units may also host radiogenic heat,[41] their heterogeneity complicates exploration. Granites with elevated radiogenic heat remain the most promising and tractable lithology for focused geothermal development, ranging from naturally convecting hydrothermal systems to engineered hot dry rock (HDR) solutions.

In granite-hosted systems, geothermal heat may be accessed through natural groundwater circulation in

GEOLOGIC FEATURES RELEVANT TO RADIOGENIC GEOTHERMAL POTENTIAL IN INDONESIA

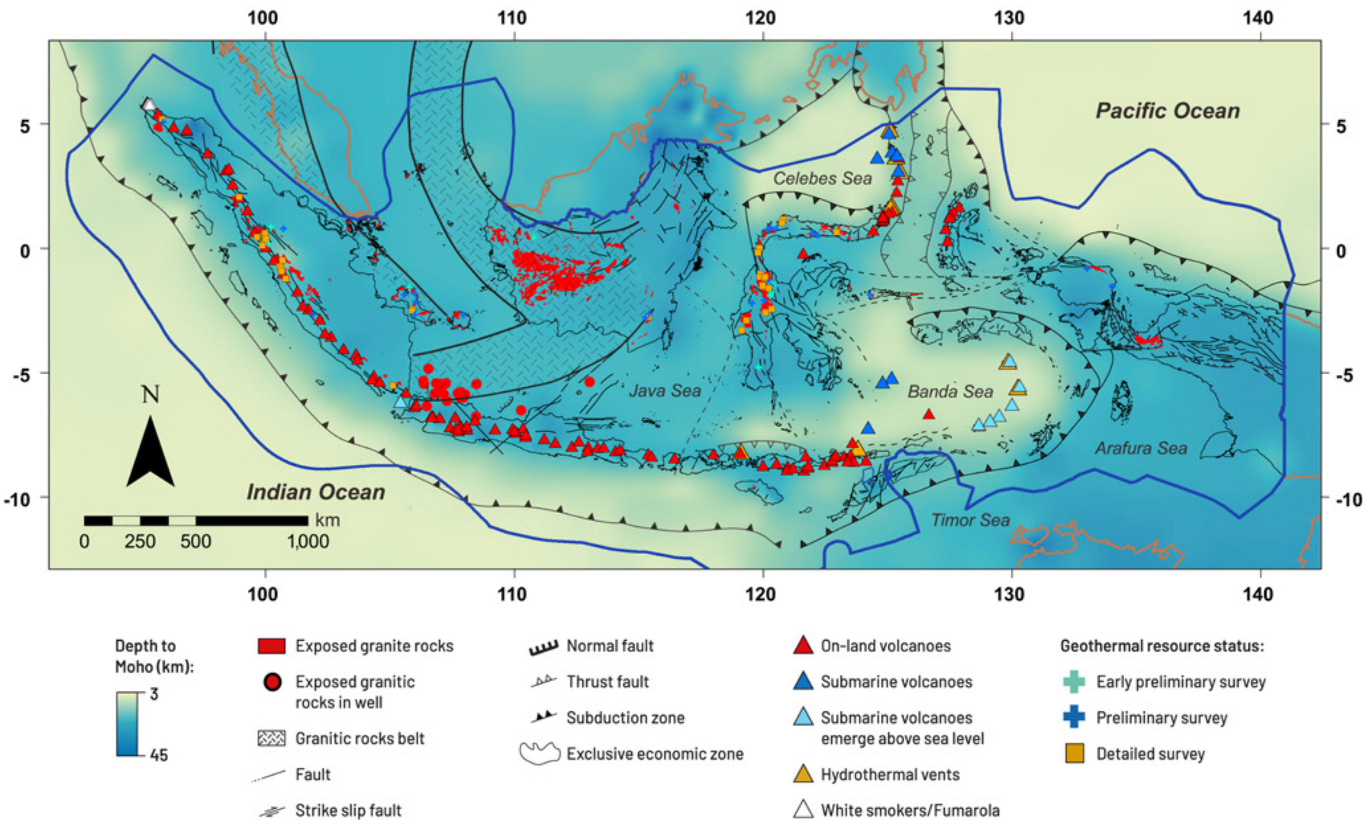


Figure 3.8: Compiled map of Moho depth (i.e., depth to mantle; Mooney et al., 2024); granitic rock distributions (Hamilton, 1979; Ng et al., 2017; Sukamto, 2010); geologic structures (Sukamto et al., 2011; Raharjo et al., 2016); on-land volcanoes (Center for Volcanology and Geological Hazard Mitigation, 2021); submarine volcanoes (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); locations of known and underexplored granite-hosted geothermal resources (Indonesian Geological Agency, 2023); and the EEZ boundary (Flanders Marine Institute, n.d.) as a guide to explore radiogenic geothermal resources. See full reference information at the end of this chapter.

fractured granites or via artificial stimulation using an enhanced or engineered geothermal system (EGS).[42] Hydrothermal systems rely on pre-existing permeability that enables fluid to circulate, heat up, and ascend, whereas HDR systems target impermeable, dry granites that require hydraulic fracturing to create flow paths.

Indonesia hosts promising and relatively underexplored granitic terrains, such as the tin-granite provinces of Bangka-Belitung, Cretaceous-to-Jurassic plutons in West Kalimantan, and granitic belts in western Papua and Central Sulawesi.

Indonesia hosts promising and relatively underexplored granitic terrains, such as the tin-granite provinces of Bangka-Belitung, Cretaceous-to-Jurassic plutons in West Kalimantan, and granitic belts in western Papua and Central Sulawesi (**Figure 3.8**). Surface indicators such as warm springs and elevated groundwater temperatures suggest the presence of shallow hydrothermal activity.

The occurrence of surface manifestations depends on permeability, which is controlled mainly by fractures in the granitic plutons, as seen in the exposed granitic rocks in the Batu Ketak Beach on Bangka Island (**Figure 3.9**). These fractures are often confined to shallow depths, leaving most of the heat retained below the hydrothermal systems. This condition points to the potential for HDR resources underlying the radiogenic hydrothermal systems in these granitic bodies. Additionally, tectonically uplifted or shallowly exposed granitic bodies—which are often associated with elevated geothermal gradients at relatively shallow depths—may serve as promising HDR sites even in the absence of surface manifestations.

Submarine granitic systems may also represent a promising frontier. Submerged plutonic outcrops along the Sunda Shelf and in eastern Indonesia (**Figure 3.8**) could support geothermal activity, especially where the subsurface is structurally fractured and fluid-saturated. These underwater granitic exposures mirror on-land systems and may harbor either convective or EGS geothermal resources.

Globally, several projects underscore the feasibility of granitic geothermal systems. In China's Huangshadong field, uranium- and thorium-rich granites support thermal springs and wells producing over 120°C at 3 kilometers depth.[43] France's Soultz-sous-Forêts and Australia's Cooper Basin represent HDR successes where hydraulic stimulation has enabled deep granite heat extraction.[44,45,46] These cases from different

BATU KETAK BEACH, BANGKA ISLAND

Figure 3.9: Exposed densely fractured granitic rocks in the Batu Ketak Beach, Bangka Island. Source: the authors.

Indonesia's granite-hosted geothermal systems, encompassing both hydrothermal and HDR, represent a promising and increasingly recognized geothermal resource.

parts of the world highlight the viability of both natural and engineered systems, particularly in tectonically stable settings.

Indonesia's granite-hosted geothermal potential remains largely untapped despite the abundance of uranium- and thorium-enriched granitoid intrusions, with systematic geothermal assessments only recently gaining momentum. Radiometric and heat flow surveys—standard in international exploration—are increasingly recognized as valuable for Indonesia's non-volcanic terrains,[47] while emerging marine geoscience technologies such as underwater gamma spectrometry, marine heat flow probes, and seabed drilling platforms offer promising avenues for exploring submarine granitic systems. Studies reporting elevated uranium and thorium concentrations in tin-granites, particularly in western Indonesia, underscore the significance of radiogenic enrichment and the need for further investigation. To advance exploration, an integrated approach combining structural mapping, radiometric and geochemical surveys, and shallow heat flow assessments—many adapted from mineral exploration—can be effective for early-stage evaluation, with remote sensing, marine geophysics, and deep-sea drilling playing a critical role in validating offshore resources.

In sum, Indonesia's granite-hosted geothermal systems, encompassing both hydrothermal and HDR, represent a promising and increasingly recognized geothermal resource. Strategic investment in exploration, resource assessment, and enabling technologies could facilitate the development of these systems and contribute to the diversification of Indonesia's geothermal sector beyond its volcanic provinces.

Sedimentary Rock-Hosted Geothermal Resources (On Land and Submarine)

The complex tectonic evolution of Indonesia has resulted in the formation of numerous sedimentary

SEDIMENTARY BASINS AND GEOTHERMAL FEATURES

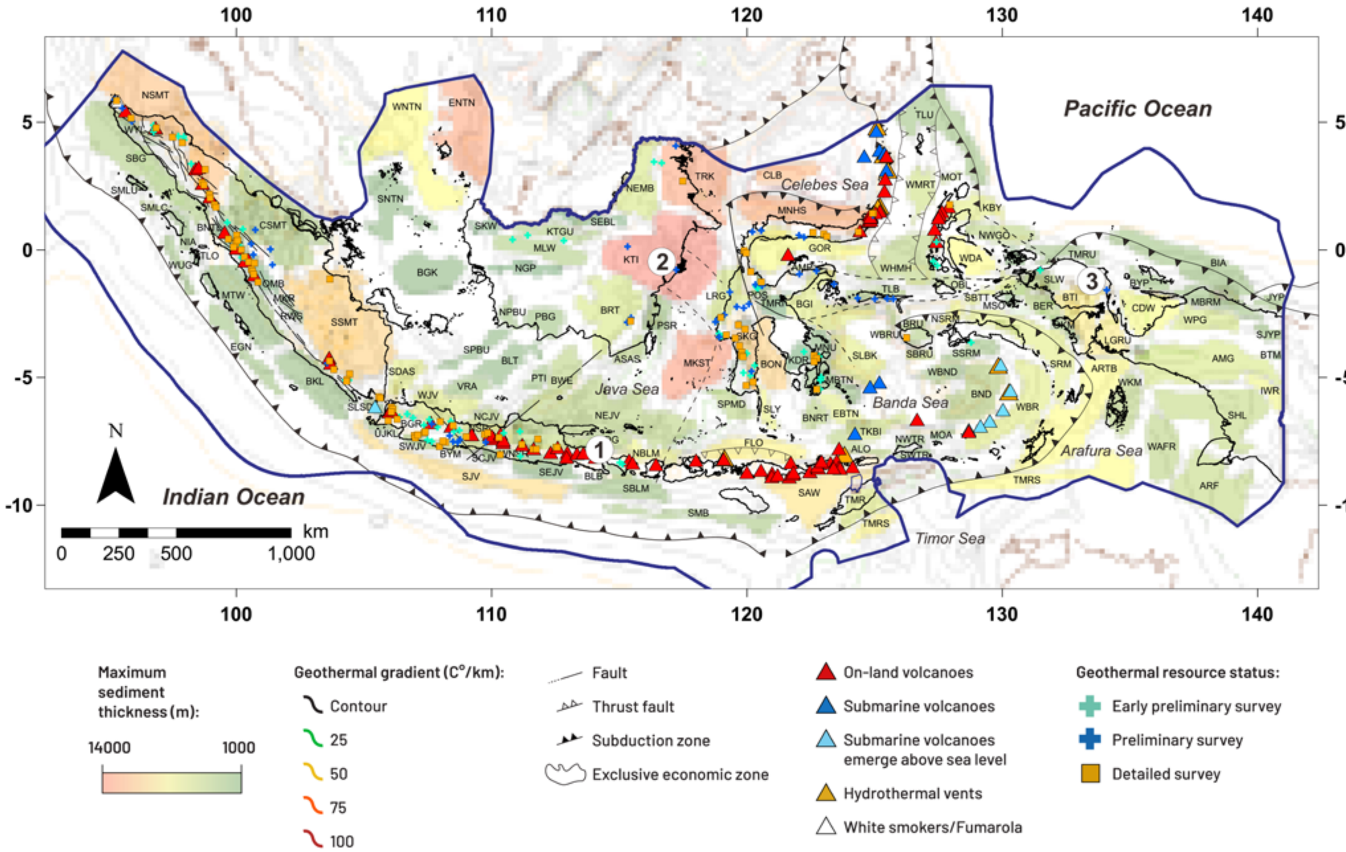


Figure 3.10: Compiled map of the sedimentary basins (Darman, 2019; MEMR, 2022); geothermal gradients (Darman, 2021); regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); distribution of on-land (Center for Volcanology and Geological Hazard Mitigation of Indonesia, 2021) and submarine volcanoes (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); locations of known and underexplored sedimentary-hosted geothermal resources (Indonesian Geological Agency, 2023); and the EEZ boundary (Flanders Marine Institute, n.d.). Numbers in circles indicate surface manifestations discussed in the text: 1. Lusi, 2. Dondang, and 3. Ransiki-Momi Waren. See full reference information at the end of this chapter.

basins across the country. While some are relatively thin, others reach substantial thickness (**Figure 3.10**). Temperature measurements from wells across these basins often indicate elevated geothermal gradients, suggesting notable geothermal potential (**Figure 3.11**). Sedimentary rock-hosted geothermal resources (SHGR) store thermal energy primarily in porous, permeable, and saturated sedimentary rocks such as sandstone. Although porosity and permeability typically decline with depth due to compaction, sandstones may retain porosities as high as 15% at 3 kilometers depth,[48] which is adequate for fluid circulation and within the viable development depth.

Magmatically influenced SHGRs are characterized by elevated temperatures from nearby magmatic activity. This influence is often detected through gas composition, particularly elevated levels of inorganic carbon dioxide (from magma degassing) and methane (from microbial activity or thermal maturation of organic matter in sedimentary rocks).[49] Regions with thick sedimentary sequences adjacent to active volcanic zones, such as parts of central Italy, have been identified as promising for magmatically influenced SHGR.[50]

GEOTHERMAL GRADIENTS IN OIL WELLS

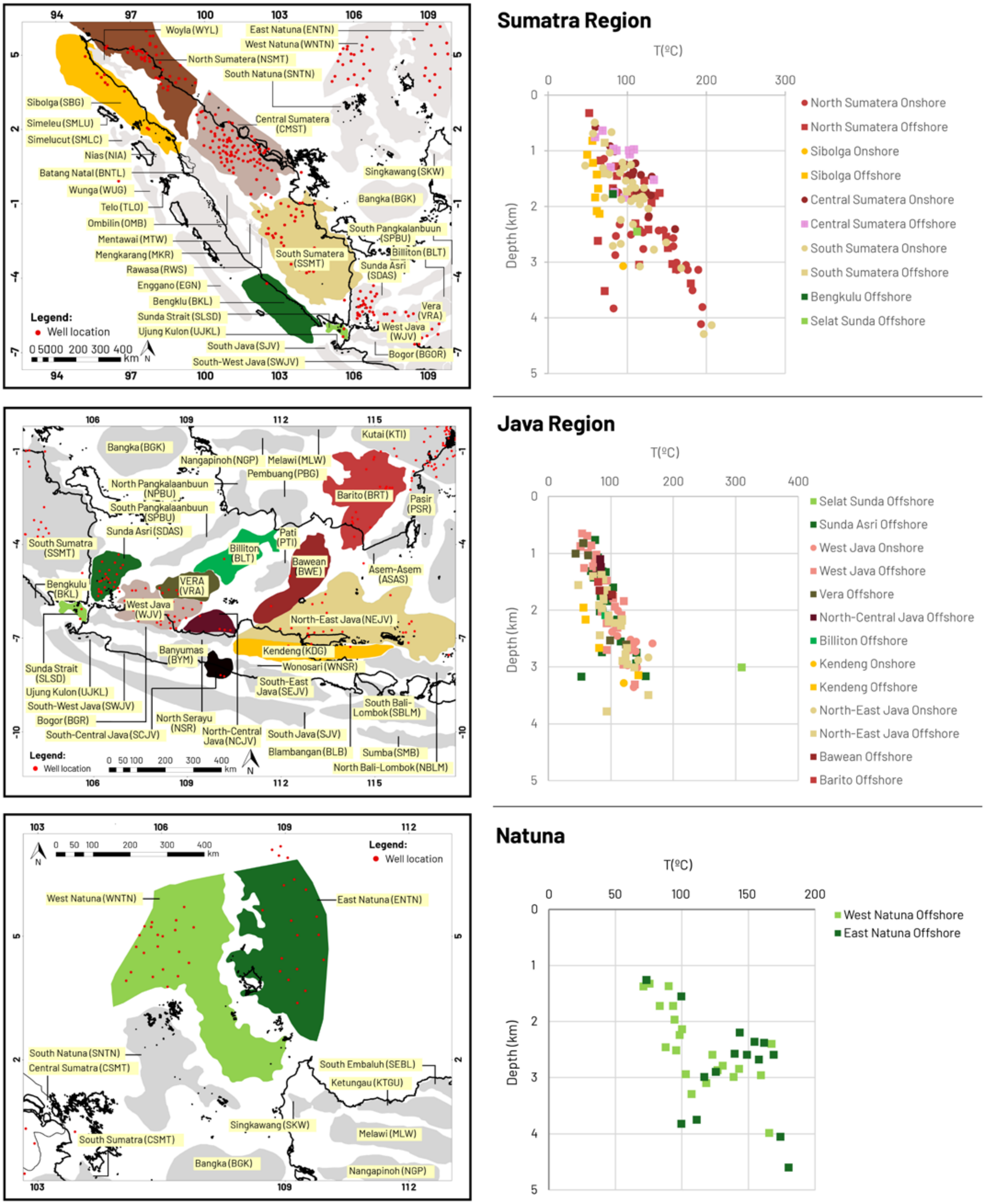


Figure 3.11: Geothermal gradients in selected onshore and offshore oil wells. Source: Compiled from various sources, including Indonesian Petroleum Association. (1981). *Geothermal gradient map of Indonesia* (2nd ed.). AAPG Archives Datapages.

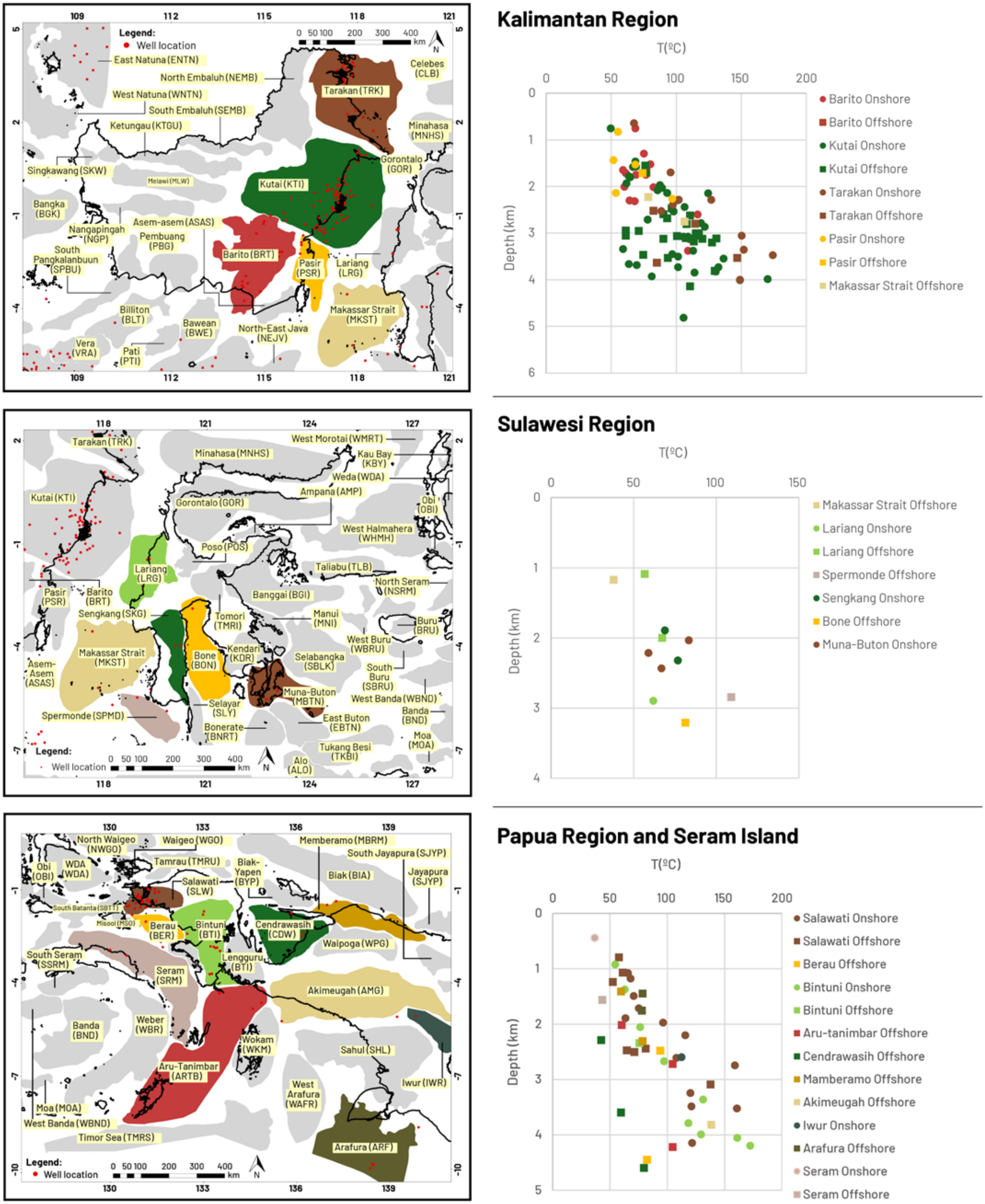


Figure 3.11 continued.

In the Sunda Shelf region, particularly in Sumatra and Java, many major petroleum systems lie in proximity to active magmatic arcs. Surface manifestations have been observed in these areas, although no magmatically influenced SHGR has been formally identified. In northeast Java, the Lusi mud eruption is an example of deep magmatic-sedimentary interaction. Hydrocarbon generation in this region is also linked to intrusion from the Arjuno-Welirang volcanic complex.[51] Seismic evidence from the Kendeng Basin suggests magmatic activity is actively reshaping subsurface structures.[52] While gas composition data would provide more definitive identification, these indicators suggest the presence of magmatically influenced SHGR.

In Sumatra, direct evidence remains limited, but elevated geothermal gradients and well temperature data suggest potential resources (**Figures 3.10** and **3.11**). For instance, while the Sibolga Basin reflects a normal geothermal gradient (<30°C per kilometer), eastern basins such as North and South Sumatra record higher temperatures, with reservoir temperatures reaching up to 200°C, which is strong evidence of magmatic influence, though it may be localized.

In contrast with magmatically influenced SHGR, hot sedimentary aquifer (HSA) systems derive heat primarily from radioactive decay within sediments or from conductive heat transfer from the deep crust or upper mantle.[53,54,55] The latter is related to regional geothermal gradients, which are influenced by crustal thickness and age.[56] Fine-grained sedimentary rocks such as shales and mudrocks are important in HSA systems, not only for their relatively high radiogenic heat production but also for acting as low-conductivity layers that trap heat beneath them (e.g., the Gulf of Mexico Basin in Texas and the Gippsland and Otway basins in Australia).

Sedimentary basins distant from modern volcanic arcs are likely candidates for HSA-type SHGR. For example, the Central Sumatra Basin has been modeled as an HSA resource, with its central zone holding the highest potential.[57] In southern Java, surface manifestations are observed throughout the basin (**Figure 3.10**), but these basins rest on older volcanic deposits and are structurally separated from the active arc by thrust faults,[58] which suggests that residual heat or radiogenic decay is the dominant heat source, pointing to HSA potential.

Other promising HSA prospects are found in Kalimantan (e.g., Tarakan, Kutai, Barito) and Natuna (West and East). These areas lack recent volcanic overprinting and exhibit thick sediment accumulations (>5 kilometers), favoring HSA development. Subsurface data further the potential in these areas, indicating elevated temperature gradients. Surface manifestations have been documented in all three Kalimantan basins. Notably, the Dondang site in the Kutai Basin lies near the core of a pronounced geothermal gradient anomaly and corresponds with the thickest part of the basin (**Figure 3.10**).

In Sulawesi, numerous geothermal manifestations have been identified, especially in the south and southeast. However, available reservoir temperature data suggest that geothermal gradients remain within normal ranges (**Figure 3.11**). Given the manifestation occurrences, basin thickness, and absence of magmatic activity, these regions are theoretically hot sedimentary aquifer candidates, though confirmation will require further study.

In Papua, sedimentary basins are generally thin, and the geothermal gradient is mostly normal, except in the Bird's Head region. Surface manifestations are rare both within and outside sedimentary basins, with the Ransiki–Momi Waren system in the Bintuni Basin being an exception (**Figure 3.10**). Nevertheless, the Bintuni and Salawati basins show subsurface temperatures exceeding 150°C between 3 kilometers and 4 kilometers depth (**Figure 3.11**). The combination of high geothermal gradient and limited surface manifestations suggests the presence of hot sedimentary aquifer potential where permeability, particularly near the surface, may be limited.

Offshore basins such as those in East Sumatra, the Riau Archipelago, the North Java Sea, and the Malacca Strait show deep sedimentation coupled with thermal anomalies, conditions that are favorable for SHGR. Classification as magmatically influenced or hot sedimentary aquifer type can be preliminarily assessed based on reservoir temperature and proximity to

GEOLOGIC FEATURES RELEVANT TO METAMORPHIC GEOTHERMAL POTENTIAL IN INDONESIA

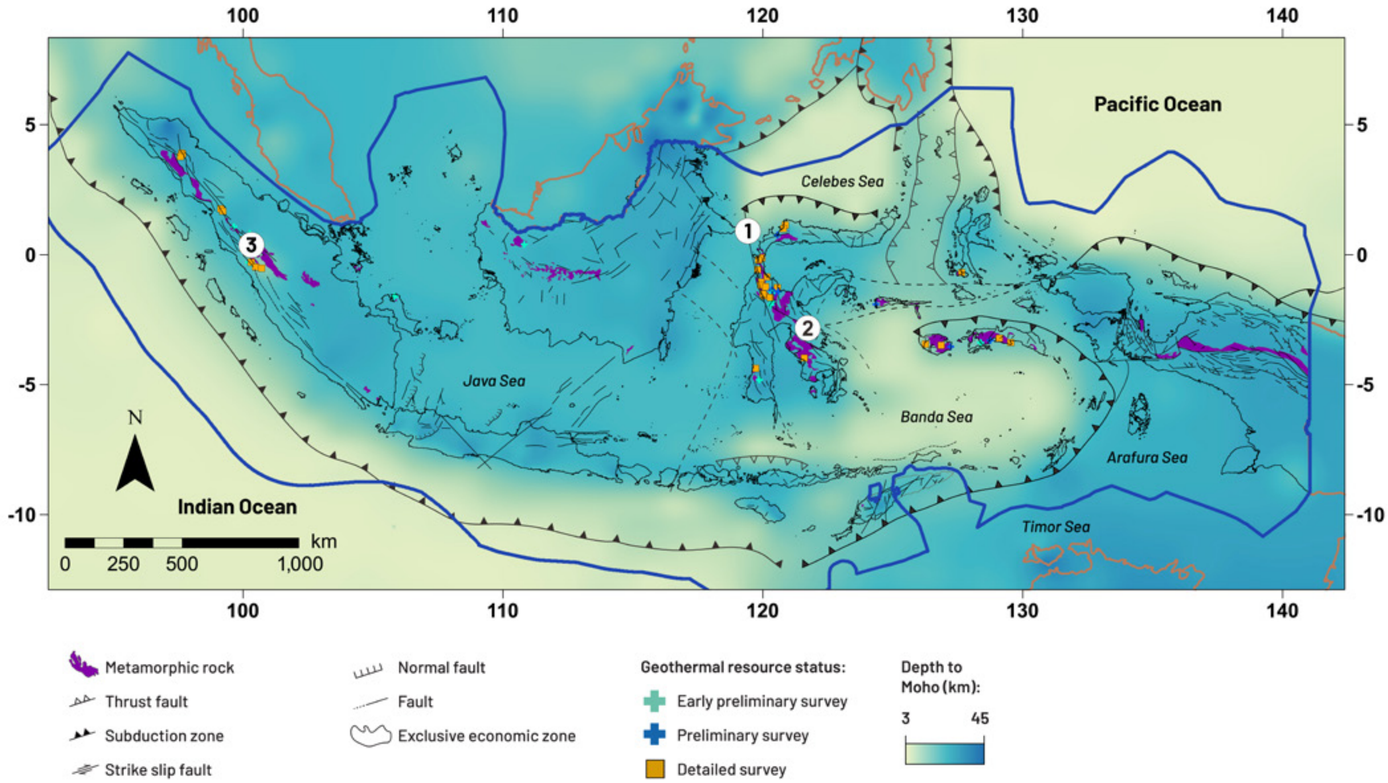


Figure 3.12: Compiled map illustrating the distribution of metamorphic rocks (Setiawan et al., 2012; Sukamto, 2010); geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); locations of known and underexplored metamorphic-hosted geothermal resources (Indonesian Geological Agency, 2023); the Moho depth (Mooney et al., 2024); and the EEZ boundary (Flanders Marine Institute, n.d.). Numbers in circles indicate faults mentioned in the text: 1. Palu-Koro Fault and 2. Matano Fault. See full reference information at the end of this chapter.

volcanic centers. For example, the Sunda Strait Basin exhibits anomalously high temperatures (**Figure 3.11**), likely linked to magmatism from Krakatau, suggesting magmatically influenced SHGR.

Development of SHGRs may benefit from approaches tailored to their distinct thermal and geological characteristics, which differ from those of high-temperature, volcano-hosted systems. Given the typically lower temperature of SHGRs, binary-cycle power plants could serve as a suitable conversion technology. In regions where petroleum production coexists, co-produced geothermal power systems may be considered to harness residual heat from brine or water produced during oil and gas extraction.[59] Furthermore, abandoned petroleum wells could offer promising sites for closed-loop geothermal systems, allowing heat extraction without the need to circulate fluid through the reservoir.[60,61]

Metamorphic Rock-Hosted Geothermal Resources (On Land)

While not yet universally standardized like volcanic- or sedimentary-hosted systems, the term *metamorphic-hosted geothermal resource* (MHGR) is used to describe geothermal systems in which the dominant host rocks are schist, gneiss, or other rocks formed through the metamorphism of sedimentary or igneous protoliths.

Due to their crystalline nature, metamorphic rocks typically have low matrix permeability, making fluid flow highly dependent on fractures and fault systems. Consequently, permeability in MHGRs is often complex, spatially heterogeneous, and temporally variable.[62]

The eastern part of Indonesia—including Sulawesi, Sula, Buru, and Seram—is notable for both the extent of its metamorphic rock exposures and its highly complex structural geology (**Figure 3.11**). Metamorphic units in Sulawesi are closely associated with major fault zones, particularly in the central part of the island.[63,64] These fault–metamorphic interfaces offer favorable conditions for MHGR development by enhancing permeability, enabling deep heat transport, and facilitating fluid circulation. This geothermal potential is further supported by the widespread presence of surface manifestations, especially in proximity to the Palu-Koro and Matano faults (**Figure 3.11**), such as the Bora and Pulu areas.[65] Given that massive granite plutons are present in this region, the primary heat sources for MHGR are most likely the shear heating along faults or radioactive decay from the granite rocks.

Southern Sulawesi may also hold potential for metamorphic-hosted geothermal systems (MHGS), although they are likely less significant than those found in the central region. Evidence of hydrothermal activity within metamorphic rocks has been documented in the Mangolo area, where hot springs and gas emissions emerge from fractures in metamorphic limestones.[66] Similar MHGR potential is observed in Buru, such as in the Wapsalit area[67] and in Seram. In these regions, the heat source is more likely attributed to shear heating, crustal thickening related to active tectonics near the subduction zone, or magmatic activity associated with the subduction process.

In Sumatra, metamorphic rocks occur along the Medial Sumatra Tectonic Zone, with surface exposures mainly in the northern and central regions (**Figure 3.12**). Toward the southeast, the continuity of these units are obscured by thick volcanic and sedimentary cover, although geological evidence supports their subsurface presence.[68,69] Geothermal manifestations in proximity to these metamorphic units suggest active systems. Furthermore, as the Sumatran metamorphic belt intersects the volcanic arc, hybrid geothermal systems may occur, combining magmatic heat sources with metamorphic (and possibly sedimentary) heat reservoirs. Proximity to the Sumatran Fault Zone suggests that these metamorphic rocks may have sufficient permeability for geothermal development.

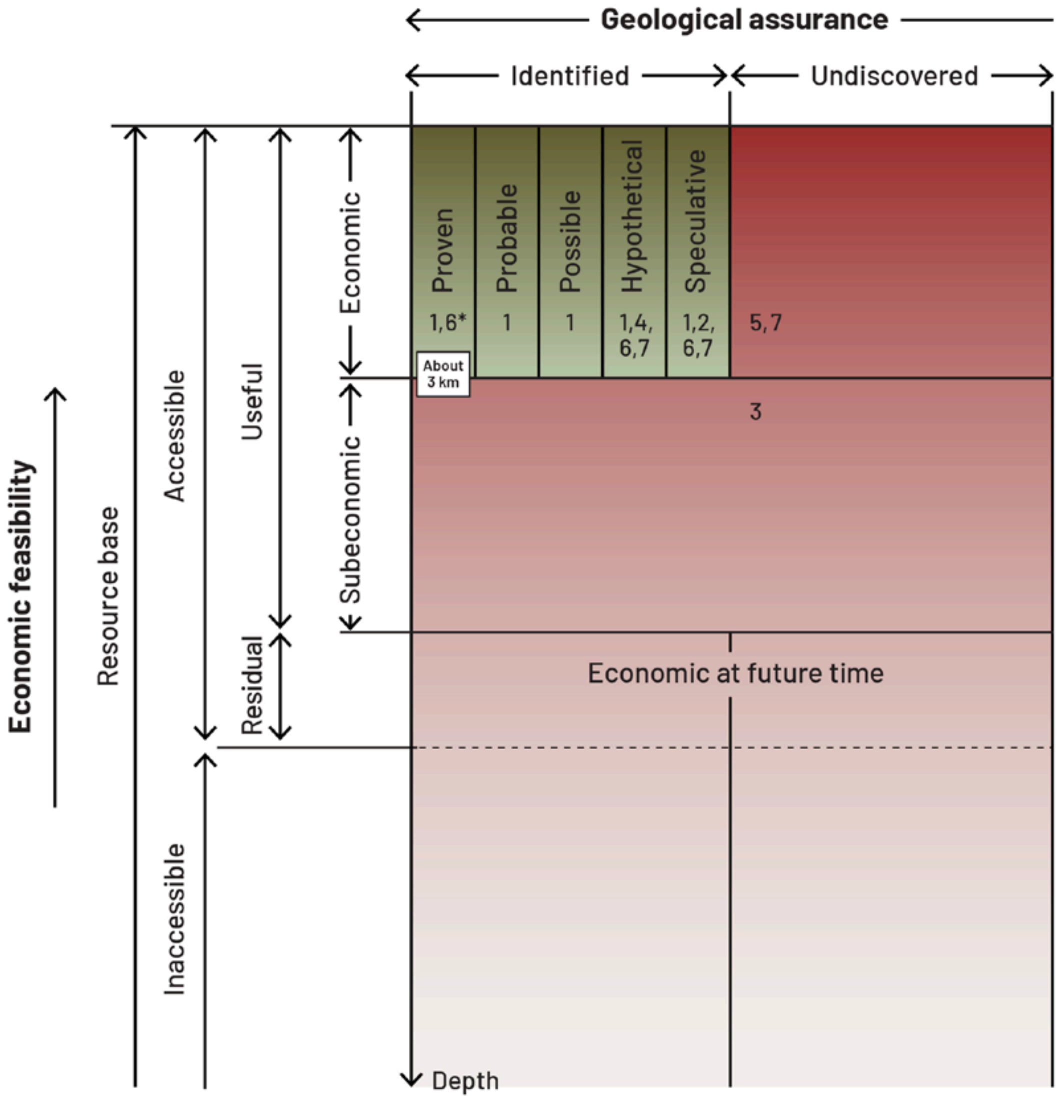
Metamorphic rocks in Kalimantan and Papua may also offer potential for MHGR, despite limited surface manifestations. These regions have undergone intensive faulting, which may enhance permeability in metamorphic formations. In Java, metamorphic rock exposures are localized and too limited in extent for regional mapping. Due to this restricted distribution, they are unlikely to play a significant role in geothermal systems formation. As current mapping is limited to onshore areas, the potential for submarine MHGRs in Indonesia remains largely unexplored.

While intensely fractured, metamorphic rocks can host hydrothermal systems suitable for geothermal production, as demonstrated in Taiwan.[70,71] Moreover, their inherently high thermal conductivity makes them effective heat reservoirs. In areas with limited fracturing, metamorphic rocks present strong potential HDR systems, as demonstrated in the Northwest Geysers project in California in the United States.[72]

However, the development of MHGRs is often constrained by limited knowledge of subsurface system characteristics. Parameters such as temperature, permeability, and fluid chemistry are frequently poorly understood in these settings. Additionally, many metamorphic terranes are associated with mineralization, such as gold deposits in Southeast Sulawesi.[73] These mineral-rich environments often benefit from extensive data sets collected during mining exploration, including geophysical surveys, drill core analyses, and downhole temperature logs. Leveraging these existing data sets can significantly enhance geothermal system characterisation in metamorphic terrains.

This mining-geothermal synergy is demonstrated by the Lihir gold mine in Papua New Guinea. Although Lihir is a volcanic-hosted system rather than MHGR, it demonstrates practical and economic advantages of integrating geothermal energy into mining operations.

GEOTHERMAL RESOURCE ASSURANCE – McKELVEY DIAGRAM



Geothermal resource type:

1. Volcano-hosted hydrothermal (on-land)
2. Volcano-hosted hydrothermal (submarine)
3. Subvolcano supercritical
4. Granite rock-hosted radiogenic hydrothermal
5. Granite rock-hosted radiogenic hot dry rock
6. Sedimentary rock-hosted (* = proven by oil well)
7. Metamorphic rock-hosted

Resource
Energy which could be extracted economically and legally in the near future

Reserve
That part of resources which can be extracted ecnomically and legally at present

Figure 3.13: McKelvey diagram showing the geological assurance levels of various geothermal resources. The division of the "identified" resource follows SNI 6009:2017. Sources: Muffler, P., & Cataldi, R. (1978). Methods for regional assessment of geothermal resources. *Geothermics*, *7*(2-4), 53-89; National Standardization Agency of Indonesia. (2017). *SNI 6009:2017 Classification of geothermal energy resources and reserves in Indonesia (in Bahasa Indonesia)*. Government of Indonesia.

Since 2003, geothermal production at Lihir has reliably supplied electricity, producing 56 megawatts electric as of 2010 to support mine operations and associated infrastructure.[74]

SUMMARY

Indonesia is the second-largest producer of geothermal electricity in the world, yet the existing 2,653 megawatts of electricity produced from conventional resources are only a small fraction of the 23.7 gigawatts of electricity estimated by MEMR. As explored in the next section this number could be significantly higher. Due to Indonesia's diverse geological setting, geothermal resources across the country vary significantly. This variability requires a range of exploration techniques and energy extraction strategies rather than a one-size-fits-all approach. In this chapter, we identified five distinct types of geothermal resources: (1) volcano-hosted hydrothermal, (2) subvolcanic supercritical, (3) granitic rock-hosted radiogenic (hydrothermal and hot dry rock), (4) sedimentary rock-hosted, and (5) metamorphic rock-hosted.

By evaluating the geological assurance levels of these geothermal resource types using the McKelvey diagram (**Figure 3.13**), this chapters shows that resources such as submarine volcano-hosted hydrothermal, radiogenic, and metamorphic rock-hosted systems require additional exploration efforts to elevate their geological assurance classification. Exploration methods should be selected based on their suitability for each geothermal type. Drilling will ultimately prove or disprove a method's technical and economic feasibility. Particularly for the submarine geothermal systems, the study of the environmental baseline must be conducted in a way that mitigates potential negative impacts on the marine ecosystem.

International research advancements in the study of supercritical geothermal should be encouraging for Indonesia—given its numerous volcanoes and high geothermal gradients—to begin systematically exploring the development of such resources. However, significant work remains, particularly in adapting resource identification techniques, establishing development risk mitigation strategies, and ensuring economic feasibility. Supercritical geothermal resources provide a new area of renewable energy development that can produce enormous amounts of energy, yet this resource is the least understood and carries the most development risk due to its extreme temperatures and pressures and its geochemistry. Development requires advanced drilling technologies and strict environmental protections. To overcome these challenges, all stakeholders must have a high level commitment. Above all, the Indonesian government and regulators must provide clear policy frameworks, funding plans, permitting, and special business plans to reduce uncertainty and attract investment.

Chapter 3, Part 2

Expanding the Scope: Next-Generation Geothermal Opportunities

Higinia Torregrosa, Project InnerSpace

Indonesia's unique geological setting offers an exceptional opportunity to advance next-generation geothermal technologies, particularly within its hot sedimentary basins and high-heat-gradient formations that lack the permeability of conventional hydrothermal systems. These resources could support diverse applications, from space cooling and industrial heat to power generation. Using the same methodology that underpinned the IEA's **Future of Geothermal** ***report, Project InnerSpace's national-scale assessment finds Indonesia's geothermal resource base is far larger and more diverse than previously recognized, extending well beyond conventional hydrothermal. We estimate more than 2,000 gigawatts of geothermal technical potential within the first 5 kilometers of the subsurface (excluding protected areas). This amount is two orders of magnitude higher than Indonesia's current conventional geothermal resource potential.***

WHY INDONESIA'S NEXT-GENERATION GEOTHERMAL POTENTIAL MATTERS

As the world's second-largest geothermal power producer, Indonesia already has all of the elements necessary to enter a new phase of geothermal development. While the nation's volcanic arc has long supported conventional hydrothermal projects, these resources represent only a fraction of Indonesia's total geothermal potential. Vast untapped reserves within sedimentary basins and conductive, low-permeability formations—unlockable through technologies pioneered in the oil and gas sector—could enable large-scale deployment of next-generation geothermal systems for heat, cooling, and power across the archipelago.

As discussed in Chapter 1, "Geothermal 101: Overview of Technologies and Applications," next-generation geothermal systems employ technologies originally developed in the oil and gas industry. These technologies include horizontal drilling, improved drill bits, and hydraulic fracturing to access subsurface heat in areas with little or very slow natural fluid circulation (unlike conventional hydrothermal systems).

This chapter expands the scope of Indonesia's geothermal analysis beyond the volcanic arc geological context to include all subsurface heat resources. It outlines the country's total geothermal potential; distinguishes between conventional and next-generation opportunities; and explores how these opportunities can be applied across power, heating, and cooling. The maps in the chapter, made with Project InnerSpace's GeoMap tool,[1] illustrate resource potential, providing a framework for identifying promising regions for development.

Whether for power generation, direct-use industrial heat, or geothermal cooling, this new frontier of geothermal energy can play a transformative role in Indonesia's economy.

As energy and cooling demand accelerates, Indonesia's transition toward sustainable cooling becomes increasingly urgent. Household air-conditioner ownership in Indonesia is expected to increase significantly, from less than 15% today to 50% by 2035 and 85% by 2050,[2] driving a sharp rise in electricity demand and emissions. The projected escalation in cooling demand highlights the need to prioritize geothermal systems as a sustainable pathway for cooling to meet Indonesia's growing thermal energy requirements.

INDONESIA'S TOTAL GEOTHERMAL HEAT-IN-PLACE WITH PROTECTED AREAS

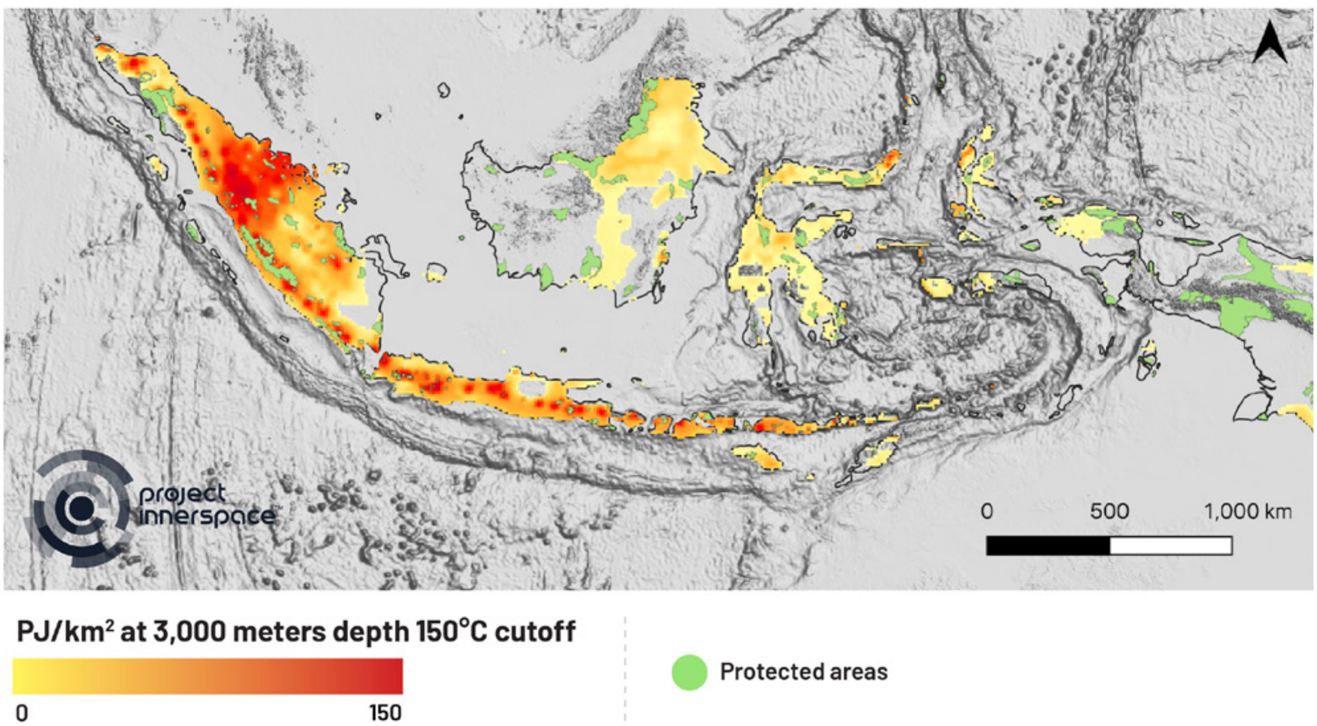


Figure 3.14: Indonesia total geothermal heat-in-place from GeoMap with Indonesia Protected Areas Overlay. The purpose of this map is to highlight the regions with the highest geothermal potential in Indonesia. It represents the cumulative potential up to a depth of 3 kilometers to ensure clear differentiation between areas. Extending the analysis to 5 kilometers would result in almost the entire map appearing red, eliminating meaningful contrasts and insights. Source: Project InnerSpace. (2025). *Heat in Place (PJ/km2) up to 3000 m 150°C cutoff Data Set*. GeoSpace; UNEP-WCMC and IUCN (2025), Protected Planet: [The World Database on Protected Areas (WDPA)][On-line], [October/2025], Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net

Beyond cooling, geothermal heat can play a transformative role in Indonesia's industrial sector. Moderate-temperature resources offer a stable and low-carbon source of process heat for manufacturing, food processing, and other energy-intensive industries. At higher temperatures, engineered geothermal systems developed in low-permeability formations could enable electricity generation in areas previously overlooked. Together, these applications demonstrate the versatility of geothermal energy in meeting Indonesia's growing energy demand while advancing its sustainability and decarbonization goals. (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," for more information.)

TOTAL GEOTHERMAL RESOURCE POTENTIAL

To visualize the spatial distribution of geothermal resources across Indonesia, regardless of resource type, Project InnerSpace produced the map shown in **Figure 3.14**, which highlights onshore areas with the greatest geothermal theoretical potential. Geothermal theoretical potential refers to the physically usable energy supply, or heat-in-place (HiP). The underlying data set was generated using the HiP method, following

INDONESIA'S GEOTHERMAL RESOURCES MAP

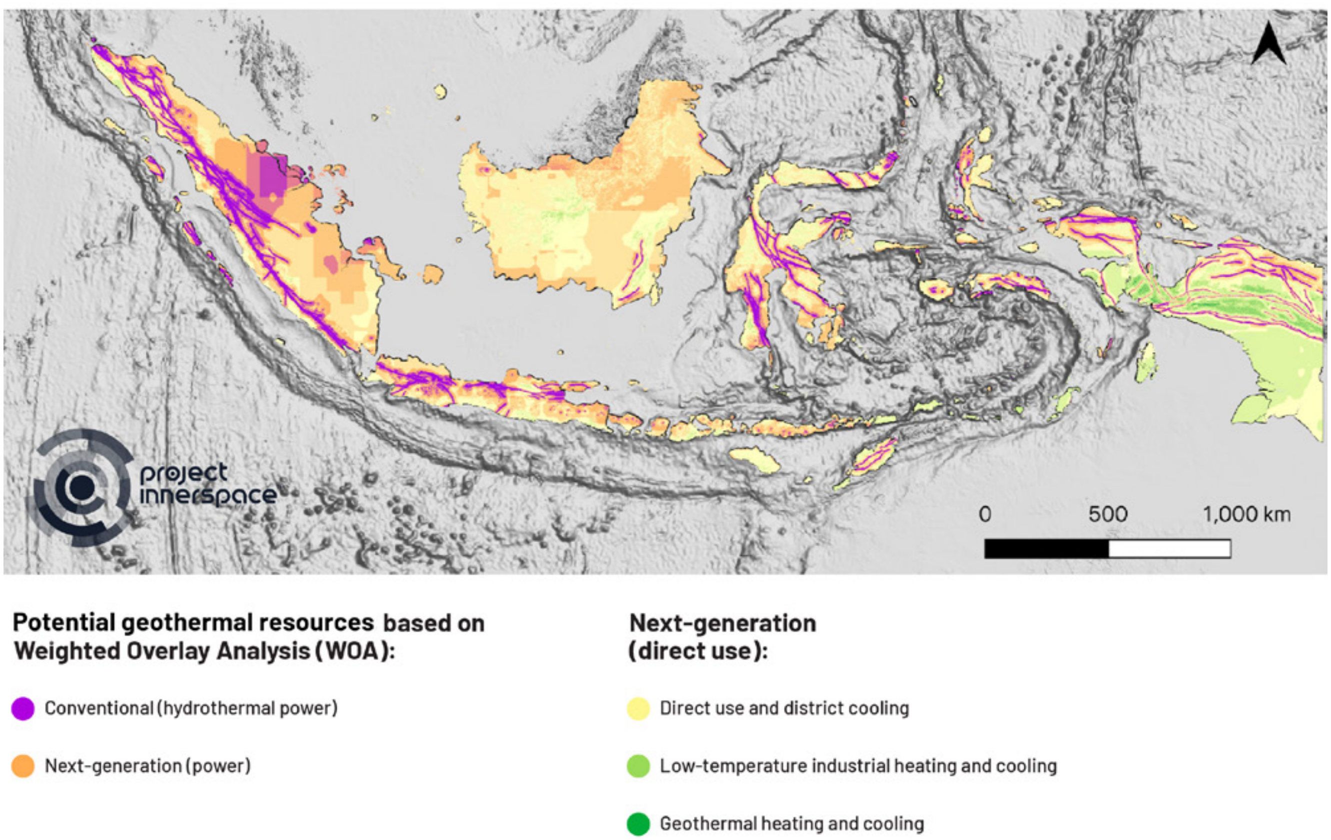


Figure 3.15: Indonesia's geothermal resource map identifying regions best suited for geothermal technologies based on underlying thermal and subsurface characteristics, via the Project InnerSpace Weighted Overlay Analysis, designed to identify and prioritize areas with geothermal potential based on key geological and geophysical factors. Source: Project InnerSpace. (2025). *Indonesia Weighted Overlay Analysis Data Set*.

the approach of Pocasangre and Fujimitsu.[3] This method divides the total subsurface heat into two components: heat stored in the rock matrix and heat contained within the pore fluid. The map presents HiP estimates in petajoules per square kilometer (PJ/km^2) for a 3,000 meter thick interval between 0 meters and 3,000 meters depth, applying a minimum subsurface temperature cutoff of 150°C.

The map in **Figure 3.14** reveals extensive warm zones beyond Indonesia's volcanic arc, with notably high values across the Central and South Sumatra sedimentary basins, as well as regions underlain by granitic and metamorphic basement complexes in Java, Sumatra, and Sulawesi. These areas, characterized by low natural permeability but elevated subsurface temperatures, represent good candidates for next generation geothermal technologies that rely on engineered reservoirs to enhance fluid circulation and heat recovery. Additionally, volcanic and volcanic-sedimentary formations near existing hydrothermal fields offer near-field unconventional targets, where next-generation technologies could expand resource use beyond conventional systems.

In late 2024, the International Energy Agency (IEA) published an analysis of the technical heat energy provided by geothermal resources around the world.[4] The analysis relied on subsurface data calculations from Project InnerSpace's GeoMap tool to estimate the resource potential. The report calculated the recoverable quantities of geothermal energy at various price points given today's technology. For Indonesia, the team calculated the cumulative geothermal technical potential in gigawatts electric (GWe), derived from HiP estimates for a 5000 meters thick isopach interval between 0 meters and 5000 meters depth, using 150 °C as the minimum subsurface temperature cutoff. Using Augustine's methodology,[5] the team converted petajoules into gigawatts, considering a recovery factor (20%), capacity factor (0.9), efficiency (calculated as function of temperature), and plant life (20 years). Project InnerSpace's data show that if Indonesia were to develop all available geothermal resources within the first 5 kilometers of subsurface (excluding protected areas), the country would have a geothermal technical potential of 2,160 gigawatts, or more than 21 times its 2024 total installed power capacity and two orders of magnitude greater than current estimates of conventional geothermal potential. This technical potential is a fraction of the theoretical potential that can be used with current technology.

CONVENTIONAL AND NEXT-GENERATION RESOURCES IN INDONESIA

The map in **Figure 3.15** illustrates the distribution of geothermal potential across Indonesia and helps identify suitable areas for different types of development. It distinguishes among the following potential geothermal resources:

- Conventional (hydrothermal-power)
- Next-generation geothermal (power)
- Next-generation geothermal (direct-use):
    - Direct use and district cooling
    - Low-temperature industrial heating and cooling
    - Geothermal heating and cooling

These categories are derived from GeoMap's weighted overlay analysis,[6,7] a GIS-based method that integrates multiple geological and geophysical data sets, applying relative weights to each factor to pinpoint areas with the greatest geothermal potential. The resulting map highlights the volcanic arc, where potential and proven conventional hydrothermal systems are concentrated, as well as potential near field regions and other hot dry rock regions that offer promising conditions for next-generation geothermal power development. Beyond these areas, extensive sedimentary basins present opportunities for geothermal direct-use applications such as cooling and heating.

Together, these patterns illustrate the range of both established and emerging geothermal opportunities across Indonesia's diverse resource base.

Chapter 1, "Geothermal 101: Overview of Technologies and Applications," details the various types of geothermal applications available today, but each has specific uses in Indonesia.

Conventional Hydrothermal Resources

Indonesia's geothermal industry is predominantly based on volcano-hosted hydrothermal systems located along the Sunda–Banda volcanic arc, which stretches across Sumatra, Java, Bali, Flores, and parts of Sulawesi. These active volcanic zones host the country's most productive geothermal fields, including Gunung Salak (West Java), Sarulla (North Sumatra), Darajat (West Java), Kamojang (West Java), Wayang Windu (West Java), and Ulubelu (South Sumatra).

Most of Indonesia's geothermal power generation relies on high-enthalpy hydrothermal resources, primarily exploited through flash-type power plants. Among these, the Gunung Salak and Sarulla plants, both flash-type plants, stand out not only as Indonesia's largest geothermal facilities but also as two of the top 10 geothermal power plants worldwide. A smaller portion of production comes from dry-steam systems, such as those operating at Kamojang and Darajat in West Java.

Next-Generation Geothermal Power Resources

Next-generation geothermal power systems offer the potential to expand geothermal electricity production beyond Indonesia's volcanic regions. These technologies enable the extraction of heat not only from naturally permeable volcanic rocks but also from adjacent or near-field low-permeability formations and non-volcanic terrains. Next-generation approaches show potential in Indonesia's granitic formations with high radiogenic heat production, metamorphic complexes, and other potential crystalline basement types, including the tin-granite belts of Bangka-Belitung; the South Sumatra basin basement; and the granitic complexes of Kalimantan, Western Papua, and Central Sulawesi.

Next-Generation Geothermal Direct-Use Resources

While conventional and next-generation geothermal systems focus primarily on electricity production from high-temperature resources, new approaches are extending geothermal potential into moderate-temperature environments such as sedimentary basins. This shift moves geothermal energy beyond power generation toward broader direct-use applications, including cooling and heating, that can advance both energy efficiency and decarbonization goals.

In Indonesia's tropical climate, where space heating has limited relevance, geothermal direct-use opportunities are better suited for industrial processes, agricultural activities, district cooling for large commercial or residential developments, and data center operations. Together, these opportunities demonstrate how geothermal energy can provide continuous, low-carbon heating and cooling solutions across diverse environments, complementing power generation and enhancing overall energy resilience. For more information about cooling and heating opportunities in Indonesia see Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential."

Next-Generation Geothermal Cooling

Sedimentary basins across Indonesia offer highly favorable conditions for geothermal cooling, characterized by high porosity, good permeability, and moderate temperatures ranging from 40°C to 150°C. These geological settings provide an excellent foundation for next-generation geothermal cooling systems that use the Earth's natural heat exchange capacity to deliver efficient, low-carbon cooling solutions.

Next-generation geothermal cooling refers to the use of geothermal reservoirs or ground source systems to replace conventional, energy-intensive air-conditioning with more sustainable and energy-efficient alternatives. As Indonesia's cooling demand is projected to rise sharply over the coming decades, geothermal cooling technologies such as ground source heat pumps (GSHPs) and district cooling networks (DCNs) offer scalable pathways to reduce electricity consumption, lower grid stress, and enhance climate resilience. Furthermore, data center cooling applications can leverage geothermal loops or aquifer systems to dissipate waste heat and maintain stable year-round temperatures. See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," for more insights on geothermal and data centers.

Next-Generation Geothermal Industrial Heat

Several sedimentary basins across the country demonstrate strong potential for next-generation geothermal heating, especially where moderate-temperature resources (40°C–150°C) coincide with major industrial corridors and agro-processing hubs. In Central Java's Dieng Basin, geothermal heat is being planned for greenhouse nurseries that support high-value crops such as citrus, avocado, and coffee. In South Sumatra, sedimentary formations could support fish curing and sugarcane processing, while in East Java, similar geothermal gradients align with dairy and textile industries that require steady heat below 150°C. These examples (drawn from Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential") illustrate how sedimentary geothermal systems—due to their permeability, porosity, and broad distribution—can provide reliable, low-carbon process heat to industries and agro-processing hubs, offering a practical pathway to decarbonize Indonesia's manufacturing and agricultural sectors.

CONCLUSION

In Indonesia, while volcanic regions display the highest thermal gradients, vast conductive systems dominate much of the archipelago's subsurface. The nation's sedimentary basins and crystalline regions contain enough thermal energy to support hundreds of gigawatts of clean electricity, direct-use heat, and low-carbon cooling. Using the same methodology that underpinned the IEA's *Future of Geothermal* report, Project InnerSpace's national-scale assessment finds that Indonesia's geothermal resource base is far larger and more diverse than previously recognized, extending well beyond conventional hydrothermal. Project InnerSpace estimates that more than 2,000 gigawatts of geothermal technical potential can be found within the first 5 kilometers depth (excluding protected areas), two orders of magnitude higher than current estimates of hydrothermal potential. By harnessing subsurface heat for power, heating, and cooling, Indonesia can turn its geologic diversity into a foundation for sustainable, low-carbon growth.

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Chapter 4

Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential

Adi Susilo, University of Brawijaya
Daniel W. Adityatama, M. Rizqi Al Asy'ari, and Vincentius A. Brilian, Geoenergis

In 2023, Indonesia's total thermal demand was close to 3 million terajoules. Today, more than 66% of that total demand could be replaced by clean, stable, and secure geothermal at competitive prices. As more projects are built and costs come down, 90% of Indonesia's total thermal demand may be replaceable by geothermal direct-use energy. And that can go a long way toward helping the nation reach its overall 2030 and 2060 climate goals. The best places to start: cooling in Java and process heating in Indonesia's agribusiness sector.

Indonesia is the second-largest producer of geothermal electricity in the world.[1] The country also has a huge untapped opportunity to expand the use of this clean energy beyond electricity and into direct-use heat applications. The International Energy Agency (IEA) estimates that the nation has about 60 terawatts of thermal energy potential. In fact, Indonesia is one of a number of countries where geothermal direct-use output falls well below the country's geothermal potential. This chapter offers an analysis of sectors ripe for a transition to clean geothermal heat—and pathways to create the conditions that will make such an industry viable in the coming years.

Geothermal energy can be broken down into two categories: indirect use and direct use. For indirect use—in other words, power creation—developers require subsurface temperatures generally above

GEOTHERMAL RESOURCE USE

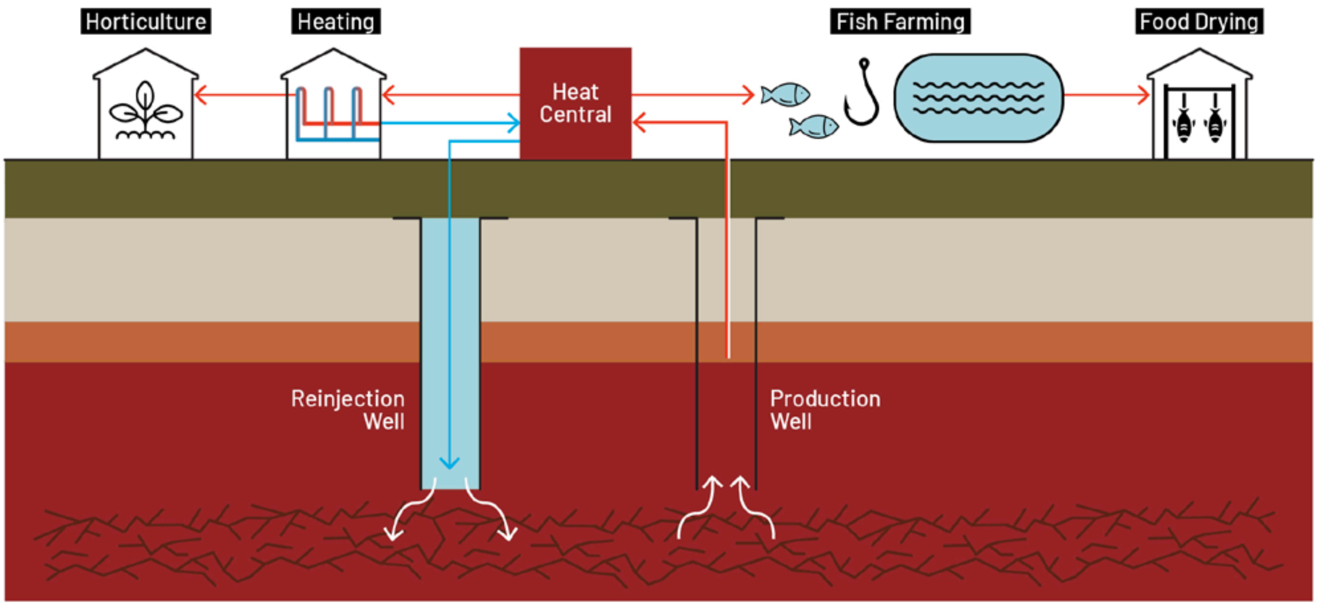


Figure 4.1: Illustration of geothermal resource use, showing the difference between indirect use for electricity generation and direct use of geothermal. Source: Adapted from Al Asy'ari, M. R., Adityatama, D. W., Brilian, V. A., Erichatama, N., & Purba, D. (2024). [Beyond electricity: Geothermal direct use business models and potential applications in Indonesia](). In *Proceedings of the 49th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States; Energy Sector Management Assistance Program. (2022). [Direct utilization of geothermal resources](). World Bank; U.S. Department of Energy. (2019). [GeoVision: Harnessing the heat beneath our feet]().

150°C. For direct-use systems, temperatures between 20°C and 150°C can be used for district cooling, industrial processes, aquaculture, and agricultural applications (see **Figures 4.1 and 4.2**).[2,3,4,5] Any system that uses geothermal resources (fluid or heat from the ground) without first converting them to electricity is considered direct use of geothermal. These direct-use systems can replace the burning of fossil fuels for industrial heating in industries such as food processing, textiles, and chemicals. This shift would support a more sustainable industrial sector and improve energy efficiency in commercial and residential buildings.

A recent analysis of the temperatures at various depths in Indonesia (**Figures 4.25**, **4.26**, and **4.27**) confirms there are many areas in Indonesia with sufficient subsurface heat (30°C–100°C) at shallow to moderate depths of less than 1,000 meters, making Indonesia attractive for many direct-use applications at a cost that makes the use of this technology competitive.

Currently, most geothermal direct-use projects in Indonesia are instigated through corporate social responsibility (CSR) and implemented by developers for community outreach. But there is substantial potential to expand beyond these initiatives as explored in a later section of this chapter, "The Biggest Opportunities: Cooling in Java and Process Heating in Agribusiness," especially as awareness of geothermal energy efficiency and sustainability grows.[6]

DIRECT-USE APPLICATIONS AROUND THE WORLD

Around the world, geothermal direct use is most widely leveraged for heating—particularly in colder climates such as Iceland, Sweden, and Switzerland. Countries such as China, the United States, Turkey, and Japan are expanding direct-use geothermal more broadly for homes, manufacturing, public bathing, and agriculture uses such as greenhouse heating.[7]

GEOTHERMAL APPLICATIONS AND TEMPERATURE REQUIREMENTS

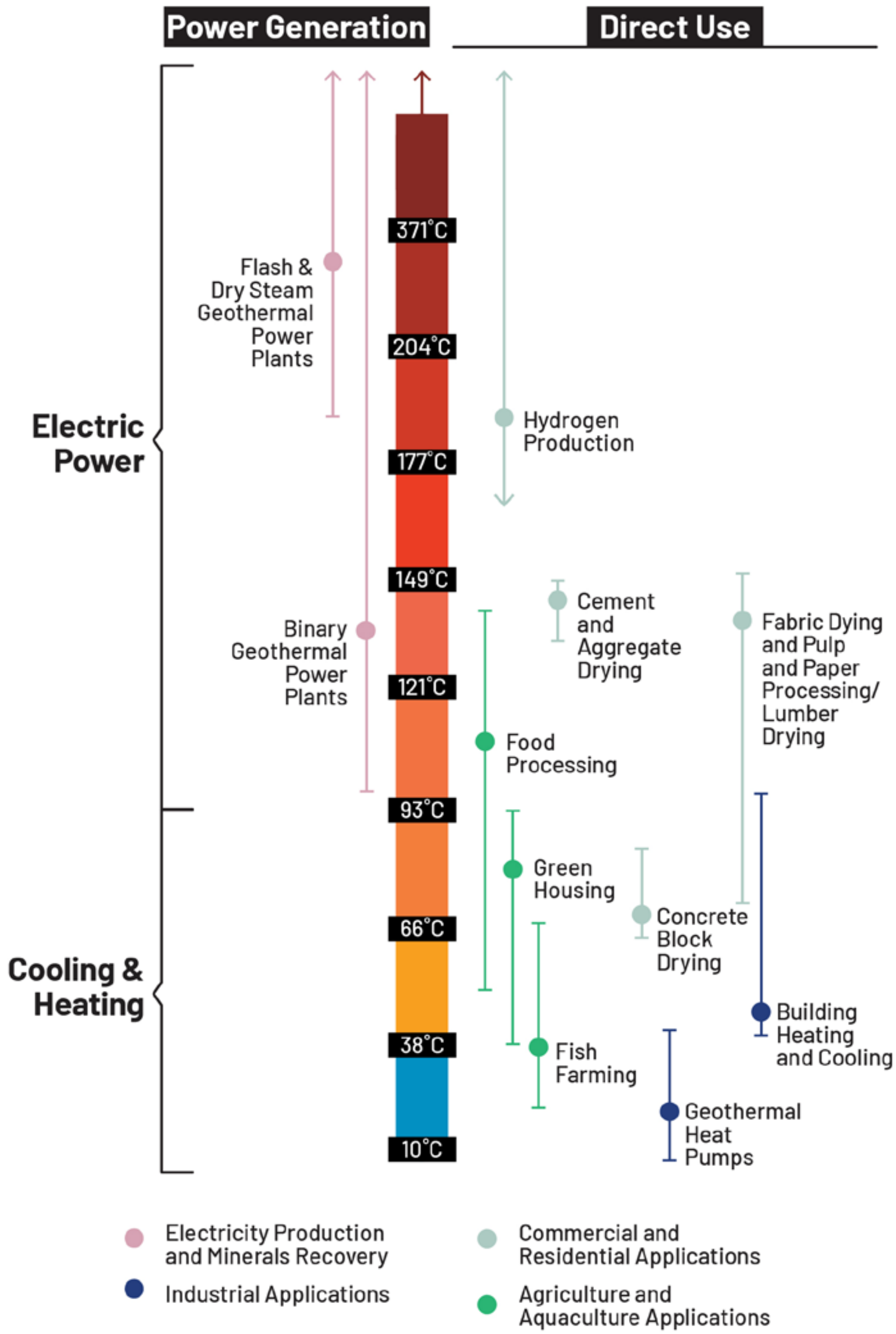


Figure 4.2: This Lindal diagram shows potential applications based on variation of temperature range. Source: Adapted from Porse, S. (2021). *Geothermal energy overview and opportunities for collaboration*. Energy Exchange.

As of 2023, global installed capacity of direct-use geothermal reached about 126,000 megawatts thermal with an annual consumption of 1.28 million terajoules across more than 88 countries.[8] Because it is a mature technology with decades of installed projects globally, ground source heat pumps (GSHPs) that use shallow geothermal temperatures (5°C–30°C for heating and cooling) account for 72% of that installed capacity.[9,10]

Forecasts show there will be significant international growth—an increase of approximately 470,000 terajoules—in the use of direct-use technologies (not including GSHP) by 2030 (see **Figure 4.3**). That is equivalent to an increase of 212%.[11]

HELP FROM THE WORLD BANK

The government of El Salvador has initiated direct-use geothermal projects with funding support from the World Bank. The agency has pledged US$150 million to the country to support government-led geothermal drilling projects for power generation and direct-use applications such as local agribusinesses as part of its sustainable energy transition.[12,13] This commitment underscores the potential of geothermal direct-use projects to not only improve energy and food systems but also attract investment.

THE ROAD AHEAD:
PROPOSALS AND THEIR CHALLENGES

In tropical Indonesia, the smartest applications for direct-use geothermal are in industrial processes, agricultural activities, and district cooling for large commercial or residential buildings. GSHPs can be adapted for cooling and heating needs in commercial and residential buildings.

Despite a long history of geothermal direct-use initiatives, commercialization of this resource has faced delays in various places around the world, particularly due to the absence of regulation in some locations.

In Indonesia, however, the business climate for geothermal direct use is likely to improve. Indonesia currently ranks 74th globally in direct utilization of geothermal, and progress has been limited since

GLOBAL GEOTHERMAL DIRECT-USE GROWTH FORECAST

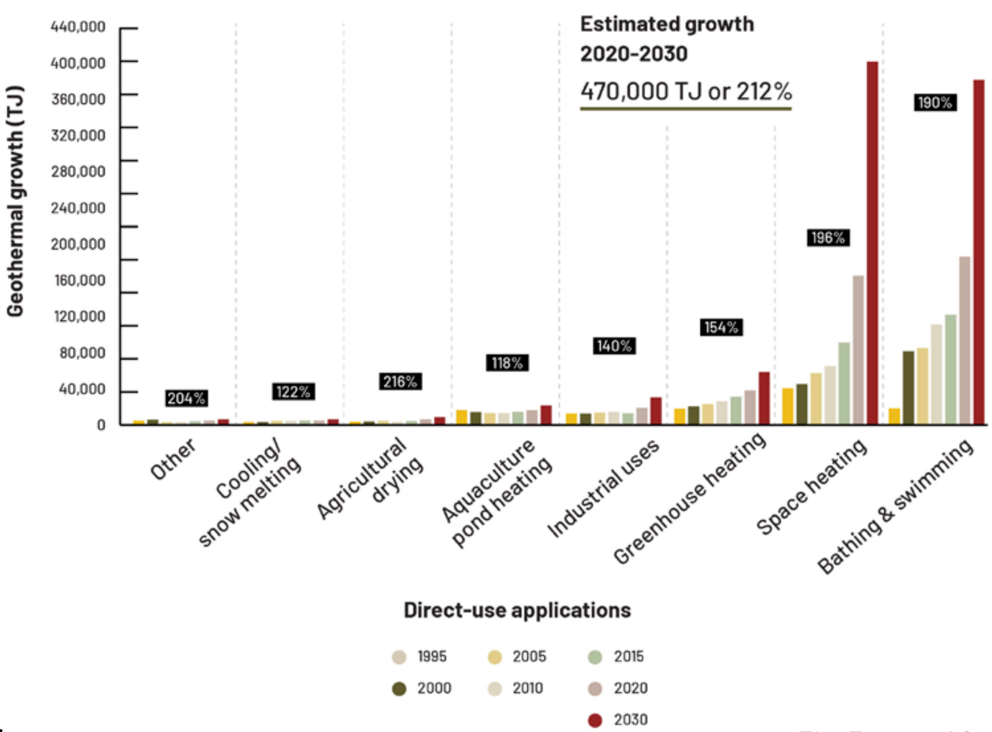


Figure 4.3: Global forecast of geothermal direct use—without heat pumps. Source: Modified from Richter, A. (2023). *Talk #1 - Low enthalpy geothermal: An attempt to positioning* [YouTube video]. SPE Europe Energy GeoHackathon.

GEOTHERMAL DIRECT USE IN INDONESIA

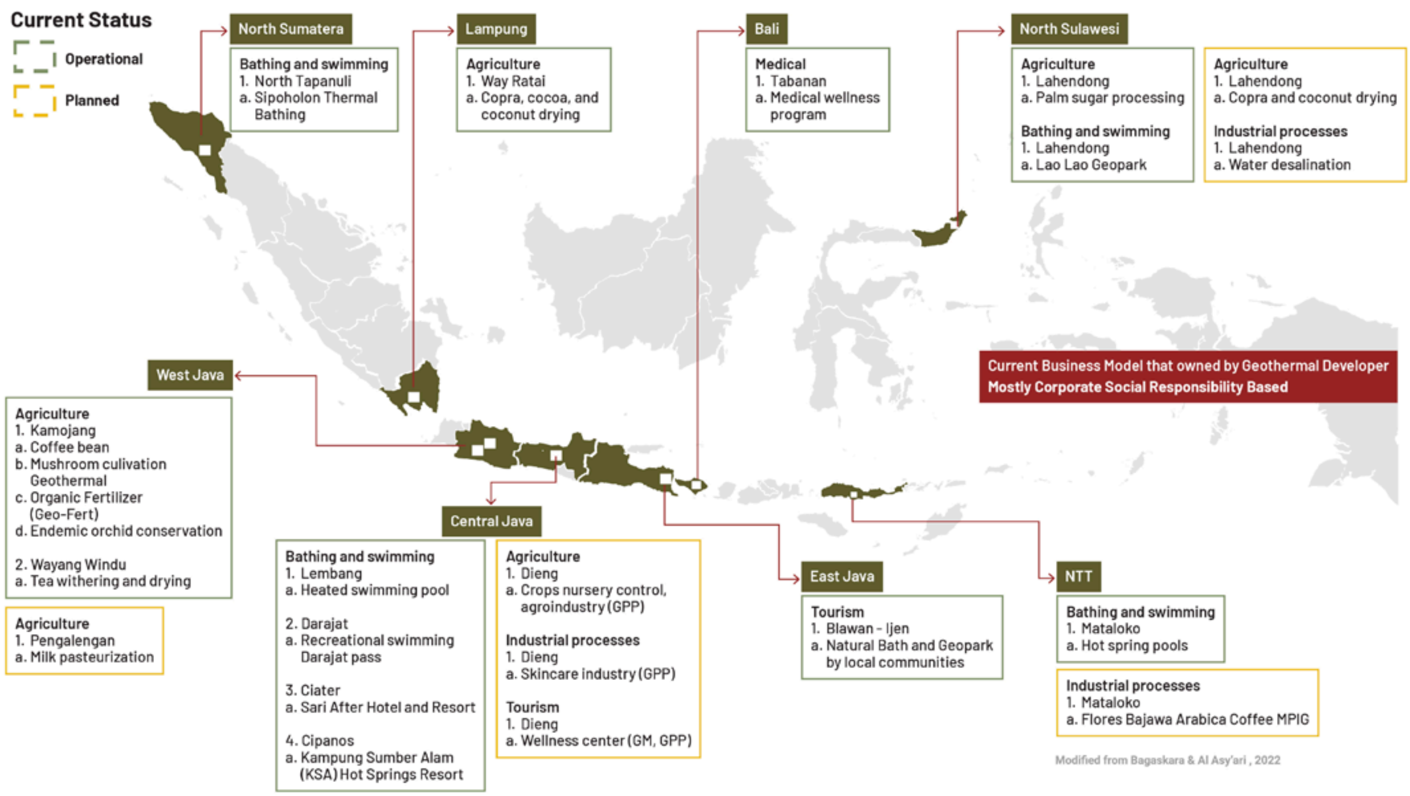


Figure 4.4: Operational and planned geothermal direct-use projects and their current status in Indonesia.Source: Bagaskara, A., Al Asy'ari, R. M., Adityatama, D. W., Purba, D., Ahmad, A. H., Pratama, A. R., & Mukti, A. W. (2023). Exploring new ideas to promote and Improve geothermal direct use in Indonesia. In *Proceedings of the 48th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

2015, due to Indonesia's primary focus on geothermal for power generation and a lack of clear policies enabling direct-use projects.[14] Various stakeholders—including the government, research institutions, and developers—are working to expand the implementation of geothermal heat for practical uses such as agriculture, tourism, and industrial processes.

Another structural barrier is the limited classification of direct-use activities in Indonesia's investment system. The Online Single Submission platform recognizes geothermal direct-use activities under Indonesian Standard Industrial Classification (KBLI) KBLI 06202 (exploration and extraction) and KBLI 35111 (electricity generation); there is currently no dedicated KBLI code for geothermal direct-use applications such as GSHPs (see Appendix 2). Without a specific classification, developers lack a clear pathway to register and license direct-use projects, making it difficult to access investment incentives or financing through Indonesia's formal investment framework. (See Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation.")

To support this expansion, the Ministry of Energy and Mineral Resources (MEMR) issued Regulation No. 5/2021, which outlines licensing standards, project requirements, and personnel competencies.[15] A number of geothermal direct-use projects are already in operation, with additional initiatives under study and slated for future development. Geothermal direct use in Indonesia remains in the early stages, led primarily by state-owned enterprises such as PT Pertamina Geothermal Energy, alongside emerging participation

FINAL ENERGY CONSUMPTION BY TYPE

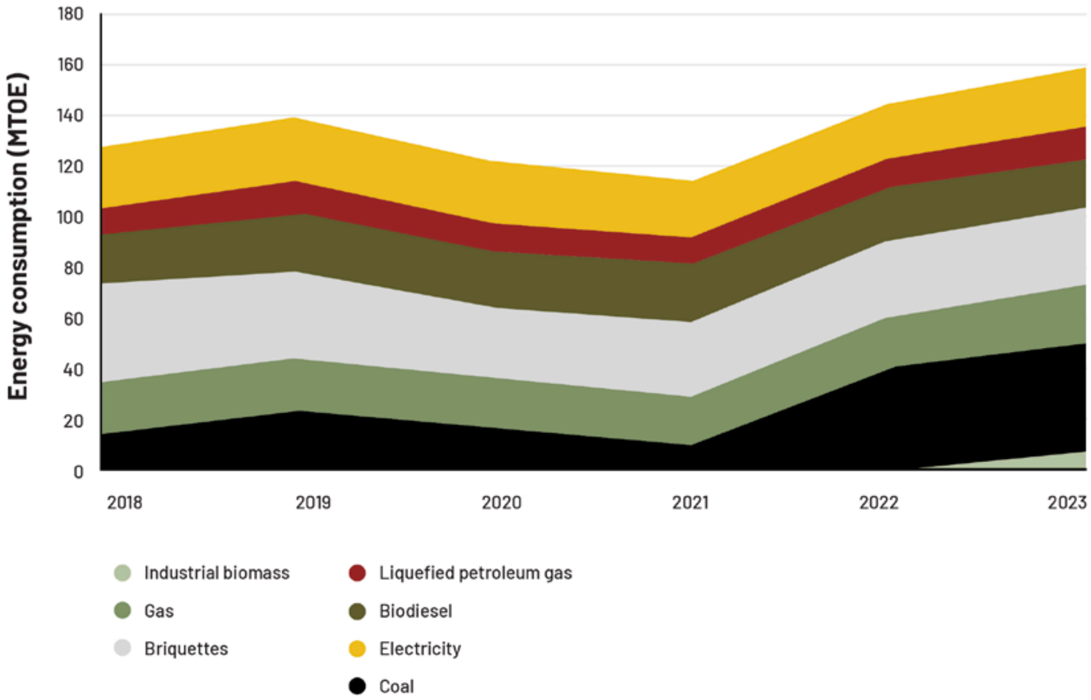


Figure 4.5: Energy consumption in Indonesia by various energy types between 2018 and 2023. Source: National Energy Council. (2024). National energy balance analysis book for 2024. Government of Indonesia.

from private developers under the oversight of the MEMR, whose policies continue to shape and encourage broader adoption. (To help, policymakers should work to foster a deeper understanding of the benefits and potential of geothermal energy. For inspiration, Indonesia could look to New Zealand, where children visit geothermal institutions and sites to learn about the immense energy drawn from the heat of the Earth.[16])

Most of Indonesia's current commercial direct-use projects in operation are in the tourism sector—heating for hot springs and spa resorts. There are also some applications at work in agriculture and industry, via CSR initiatives. These projects have yet to scale to become full commercial ventures. Other geothermal direct-use projects remain in the planning stage.

In Indonesia, the initial studies on geothermal-based heating and cooling projects using GSHP systems in potential locations such as Ciater, Lahendong, Jakarta, and Bali have taken place.[17,18] (See **Figure 4.4** for a list of geothermal direct-use projects in Indonesia and their current status.) To realize these opportunities, several challenges need to be addressed. (See Chapter 7, "Turning Potential Into Power: A Policy Blueprint for Indonesia's Geothermal Transition," for more information on those issues and how to move the industry forward.[19])

QUANTIFYING AND MAPPING INDONESIA'S THERMAL DEMAND

An Overview of the Nation's Energy Demand

Indonesia is one of the world's largest consumers of energy, ranking 10th globally.[20] Across all sectors, most of that energy is produced via coal and oil-based fuels (**Figure 4.5**). In 2023, the industrial sector accounted for the largest share of energy consumption (43%), followed by the transportation sector (38%). The residential and commercial sectors consume less energy but remain significant due to Indonesia's large and urbanizing population (**Figure 4.6**).

To support Indonesia's clean energy transition, it is important to look at replaceable thermal demand—the portion of total heat and cooling needs that can be supplied by geothermal direct use, based on process temperature and available technology. This information is crucial for prioritizing where geothermal solutions can realistically be applied in the near and long term.

Industrial

In the industrial sector, consumption reached 77.9 million tonnes of oil equivalent (MTOE) or 3,261,517.2 terajoules (905.977 TWh). Coal—the biggest energy source—supplied 44.3 MTOE or 1,854,752.4 terajoules (515.209 TWh). This energy is used primarily in industries such as iron and steel, ceramics, cement, and pulp and paper production. The fertilizer and ceramics industries mainly use gas to generate heat; the petrochemical industry generally uses refinery products (see **Figure 4.7**).

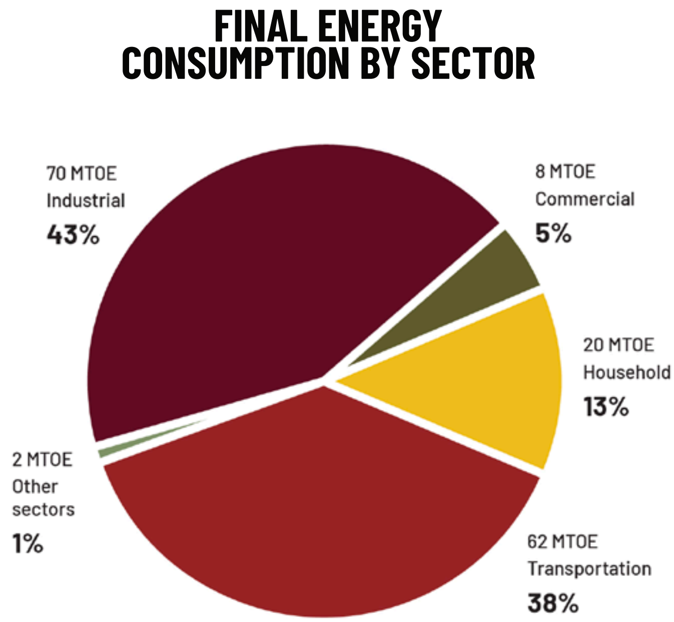


Figure 4.6: Indonesia energy consumption by end-use sector in 2023. MTOE = million tonnes of oil equivalent. Source: National Energy Council. (2024). *National energy balance analysis book for 2024*. Government of Indonesia.

Over the past five years, energy consumption in the industrial sector has increased, for the most part, at an average rate of about 9% each year.[21]

Biomass energy consumption rose significantly in 2023, surpassing 2022 levels by 3 ½ times. Coal consumption also grew by about 26%, paralleling the expansion of the mineral processing industry.[22]

Electricity demand in the industrial sector is also projected to grow at an average rate of 2.1% per year.[23]

Residential

In 2023, energy consumption in Indonesia's residential sector (excluding traditional biomass) reached 21.1 MTOE or 883,440 terajoules (245.4 TWh; see **Figure 4.8**). Half of this consumption was for electricity (about 10.5 MTOE), while liquid petroleum gas (LPG) accounted for 47%.

Most household electricity is used for lighting, air-conditioning, water heating, laundry, and other appliances (**Figure 4.9**).[24] Cooking remains the task requiring the most energy use in homes, and LPG is the most used fuel (kerosene is still used in some remote areas).[25]

Residential energy use rose by about 3.8% per year from 2018 to 2023, a trend the COVID-19 pandemic accelerated as more people worked from home. Looking ahead, household electricity demand is projected to grow at an average rate of 2.4% per year between 2030 and 2060.[26]

Commercial

As shown in **Figure 4.9**, the commercial sector's energy consumption in 2023—including hotels, offices, shopping centers, and similar facilities—reached 7.6 MTOE or 318,196.8 terajoules. Electricity dominated that consumption, using 87%. Electricity demand is expected to continue rising at an estimated rate of 2% per year.[27]

According to 2020 energy use data for the commercial sector, air-cooling systems accounted for the largest portion of electricity consumption.[28] Air-conditioning is essential for maintaining indoor comfort in the tropical environment of Indonesia (see **Figure 4.10**).[29] Other significant uses of electricity include lighting, water supply, and building operations purposes.

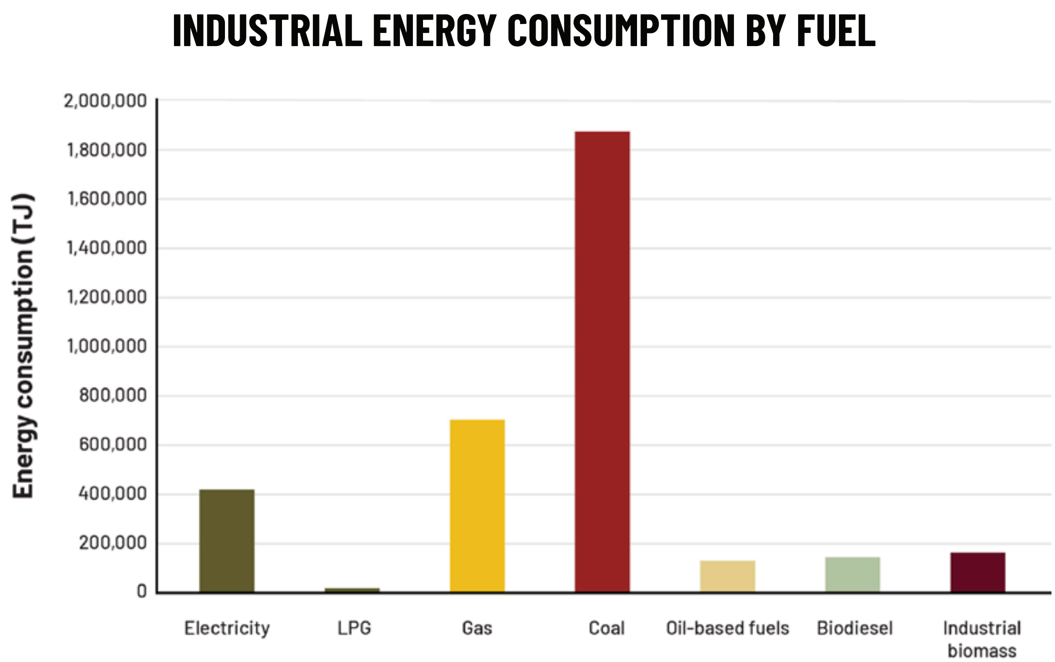


Figure 4.7: Energy consumption by fuel type in the industrial sector in 2023. LPG = liquefied petroleum gas; TJ = terajoules; TWh = terawatt-hour. Source: Modified from Ministry of Energy and Mineral Resources. (2023). *Handbook of energy and economic statistics of Indonesia 2023*. Government of Indonesia.

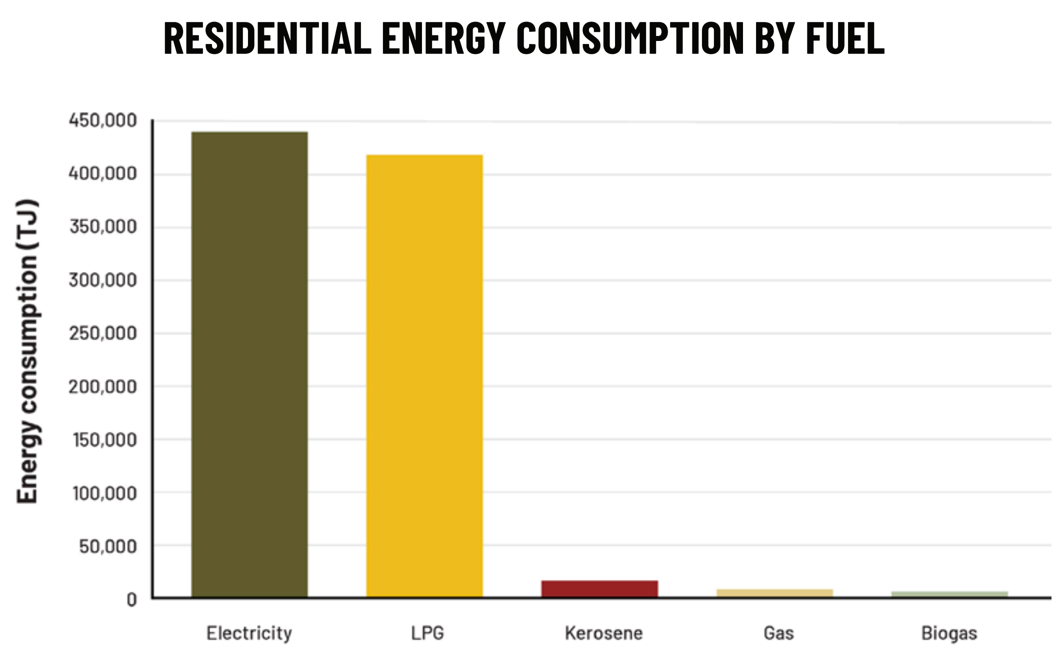


Figure 4.8: Energy consumption by fuel type in the residential sector in 2023. LPG = liquefied petroleum gas; TJ = terajoules; Gas = natural gas (LPG is a pressurized liquid fuel made mainly from propane and butane, produced as a by-product of crude oil refining or natural gas processing, and commonly distributed in cylinders. Natural gas is mostly methane, sourced directly from underground gas reservoirs and delivered primarily through pipelines or as liquefied natural gas). Source: Modified from Ministry of Energy and Mineral Resources. (2023). *Handbook of energy and economic statistics of Indonesia 2023*. Government of Indonesia.

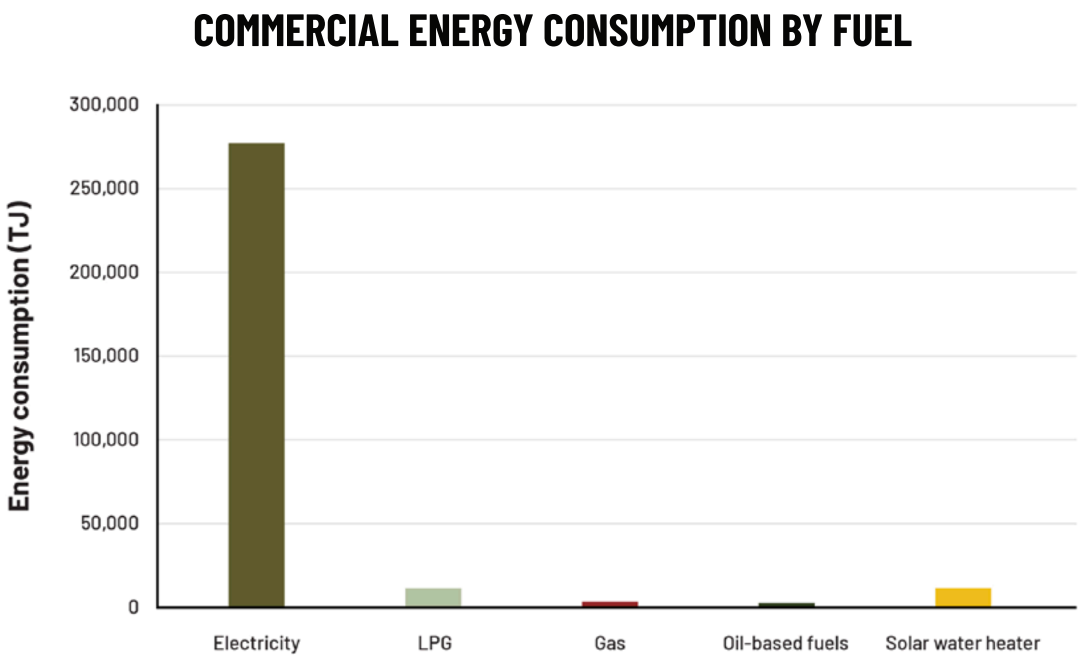


Figure 4.9: Energy consumption by fuel type in the commercial sector in 2023. LPG = liquefied petroleum gas; TJ = terajoules. Source: Modified from Ministry of Energy and Mineral Resources. (2023). *Handbook of energy and economic statistics of Indonesia 2023*. Government of Indonesia.

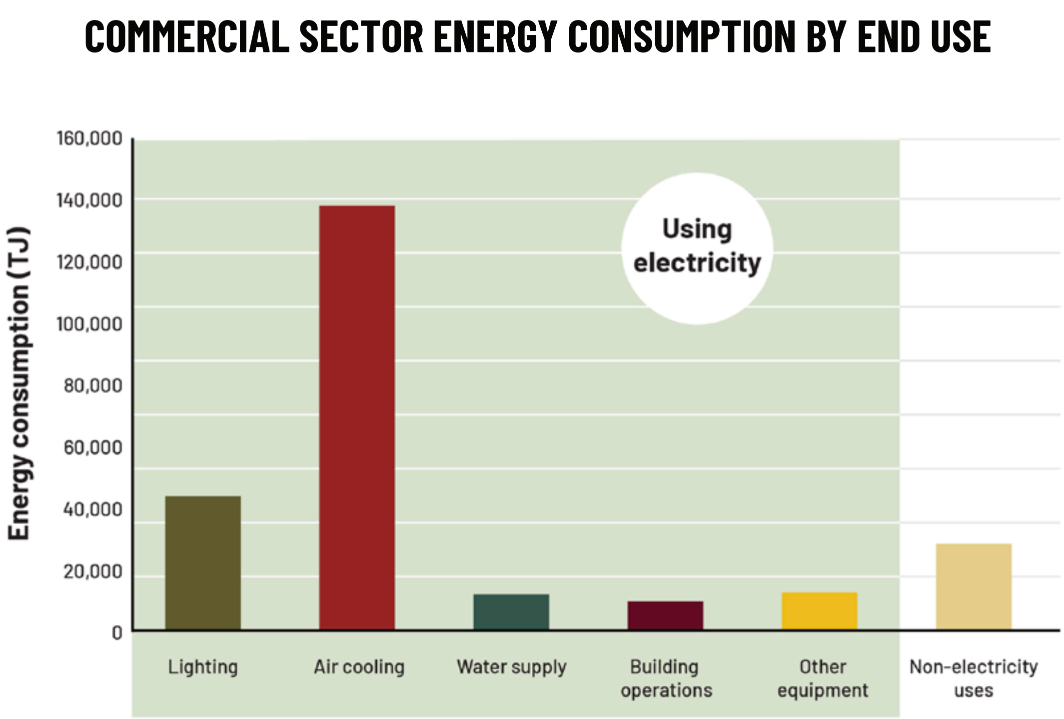


Figure 4.10: Energy usage breakdown in the commercial sector in 2020. The Indonesian government has not yet released an updated breakdown of energy use applications for the residential and commercial sectors. Building operations covers vertical transportation optimization such as elevators and escalators. TJ = terajoules. Source: Palladium. (2023). *Commercial sector NZE calculator 2023*. Mentari.

A COMMERCIAL-SCALE GEOTHERMAL HEAT PUMP PROJECT IN SWITZERLAND

Indonesia has a major opportunity to tap geothermal energy for urban cooling—something cities around the world are already doing at scale. Across Europe, geothermal systems heat and cool entire districts as well as individual buildings, proving the technology is mature and practical in dense urban settings. In Lausanne, Switzerland, for instance, around 150 boreholes—each about 300 meters deep and fitted with double-U heat-exchange probes—now supply the site's full heating and cooling needs. Urban drilling requires only a small surface footprint, and once installed, geothermal systems deliver secure, low-carbon thermal energy for the lifetime of the building.

Figure 4.11: Well services teams prepare to drill a series of shallow geothermal boreholes to provide commercial-scale heating and cooling in the urban area of Lausanne, Switzerland. Photo courtesy of Groupe Grisoni.

How Much Thermal Demand Can Be Replaced?

Thermal applications that use process temperatures up to 200°C are classified as replaceable thermal demand (**Figure 4.13**). This threshold is based on the current output of commercial industrial heat pumps (50°C–150°C) and is projected to reach 200°C as geothermal technology advances.[30]

Today, thermal energy needs in Indonesia range from relatively low temperatures (70°C–100°C) for applications such as agricultural drying to very high temperatures (1,000°C–1,500°C) for metal processing (**Figure 4.12**). Of Indonesia's total thermal demand in 2023 (4,453,153 terajoules), 2,998,058.6 terajoules of that was thermal demand.[31] That number is projected to grow at an average annual rate of 5.1%, reaching 7,142,641.3 terajoules by 2050. So how much of that demand can be replaced over the years?

- In 2023: The replaceable portion was 1,994,144.3 terajoules, with an expected average annual growth rate of 8.2%,
- In 2050: That figure could reach 6,415,222.5 terajoules.

Said another way, 66.5% of the total thermal demand in 2023—and 89.8% in 2050—is considered as having the potential to be replaced by geothermal direct use.

Importantly, Indonesia can meet almost half of its 2030 target and a large portion of its 2060 goal by leveraging its geothermal skill sets and expertise and directing these to other uses such as district cooling.

To put these numbers in perspective, 2,998,058.6 terajoules is equal to about 241 metric tons of carbon dioxide equivalent ($MtCO_2e$) or about one-quarter (23%) of Indonesia's current energy-related missions—a very large, actionable wedge.[32,33] Indonesia's 2030 Enhanced Nationally Determined Contribution (NDC) targets a 365 $MtCO_2e$ reduction in the energy and industrial sectors relative to a "business as usual" scenario; cutting 66.5% of today's thermal demand (approximately 160 $MtCO_2$) would deliver around 44% of that 2030 energy sector reduction on its own.[34]

Not all thermal demand can be replaced at this point by geothermal direct use due to technological limitations. But there are plenty of places in Indonesia where thermal demand currently met with fossil fuels is replaceable—and where it will be replaceable with technological advancements.[35] (Details on the methodology for the findings are outlined in the next section.)

SECTORS AND END USES WITH HIGHEST THERMAL DEMAND

Indonesia Thermal Demand Data

Industrial and Manufacturing Process Heating	
Non-metallic minerals	1. Cement 2. Lime 3. Flat glass
Chemical	1. Ammonia 2. Ethylene 3. Methanol 4. Polyethylene 5. Polypropylene 6. Calcium carbide 7. Acrylic
Pulp and paper	1. Mech. papermaking (recycled fibers) 2. Chem. papermaking (kraft)
Basic metal	1. Steel - blast furnace 2. Steel - electric arc furnace 3. Copper 4. Aluminum 5. Zinc
Textiles	1. Dyeing, printing, and finishing
Petroleum and coal products	1. Oil refining 2. Carbon black
Agriculture and dairy	1. Dairy 2. Sugarcane 3. Tobacco 4. Tea 5. Coffee 6. Timber 7. Palm and brown sugar

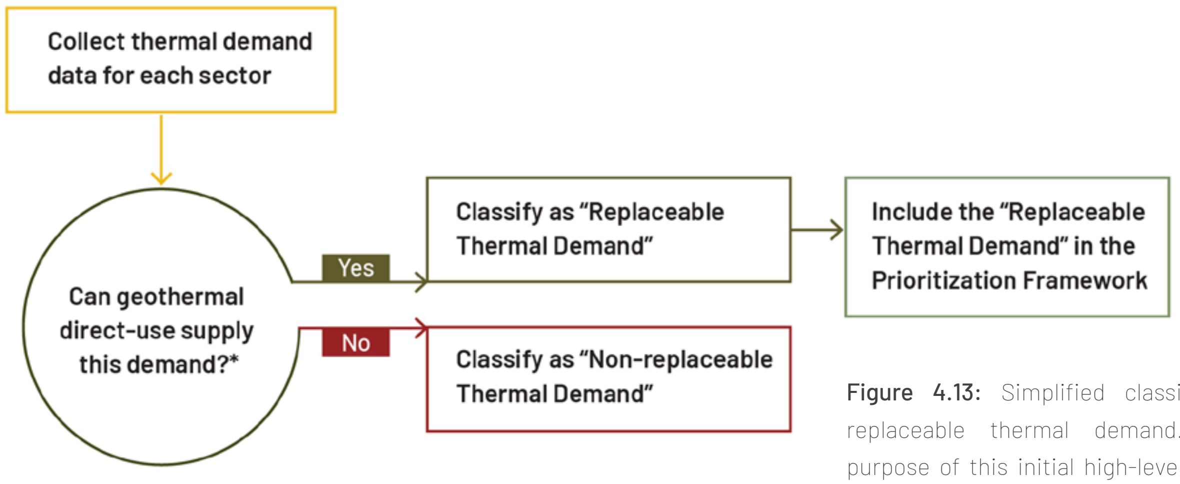
Residential and Commercial Refrigeration and Cold Storage
Commercial refrigeration
Domestic refrigeration
Food and beverages cold storage

Residential and Commercial Heating, Ventilation, and Air-Conditioning (HVAC)
Commercial HVAC
Residential HVAC

Annual Process Heat Demand (TJ)
Annual Production Quality (ton) x Specific Heat Input (TJ/ton)
Annual Refrigeration and Cold Storage Demand (TJ)
Unit Cooling Capacity (TW_{th} per unit) x Annual Equipment Stock (unit) x Utilization Factor (%) x Annual Run Time (hours) x 3600
Annual Residential and Commercial HVAC Demand (TJ)
Unit Cooling Capacity (TW_{th} per unit) x Annual Equipment Stock (unit) x Utilization Factor (%) x Annual Run Time (hours) x 3600

Figure 4.12: End-use sectors and thermal applications considered from the national thermal data collection. Full source list can be found at the end of the chapter.

REPLACEABLE THERMAL DEMAND



*Demand is considered replaceable when the process temperature does not exceed 200°C, based on expected future advances in heat exchanger and heat pump technology.

Figure 4.13: Simplified classification of replaceable thermal demand. For the purpose of this initial high-level screening, replaceability is determined by technical potential based on temperature alone. Further stages of analysis incorporate economic and geographic factors. Source: the authors.

The NDC does not assign an energy-only quota for Indonesia's 2060 net-zero pathway, but decarbonizing 90% of this thermal demand (about 217 $MtCO_2$) would represent a nationally significant emissions cut, showing that geothermal for cooling people and providing industrial heat is a pivotal lever for Indonesia. Importantly, Indonesia can meet almost half of its 2030 target and a large portion of its 2060 goal by leveraging its geothermal skill sets and expertise and directing these to other uses such as district cooling.

Replaceable Demand in Industrial and Manufacturing Process Heating

In 2023, industrial and manufacturing process heating's total thermal demand was 1,178,979.0 terajoules, a figure that is projected to grow by an average of 1% each year.[36,37,38] The replaceable portion of that thermal demand was 175,064.7 terajoules, or 14.8% percent. But here is the important point to keep in mind: That replaceable demand will grow at a rate of 12.8% each year (**Figure 4.14**).[39]

Here is the important point to keep in mind: That replaceable demand will grow at a rate of 12.8% each year.

By the most current figures and as calculated by the authors, almost 62.4% of Indonesia's process heating sector was using fuel-fired heaters that burn diesel and natural gas. Steam boilers burning natural gas made up 35.3%. (Electric heaters made up the last 2.3%.) By 2050, that balance is projected to shift: Steam boiler use will be more than 52%, and fuel-fired heaters at about 44%.

All of these figures point to the fact that in the near future, much of Indonesia's thermal demand could be replaced by clean and secure geothermal direct-use heat, especially for low- to medium-temperature needs (at or below 200°C).[40]

Replaceable Demand and Coming Technology Improvements

Right now, in the textiles and agriculture sectors, more than 70% of the thermal demand is at or below 100°C. (In

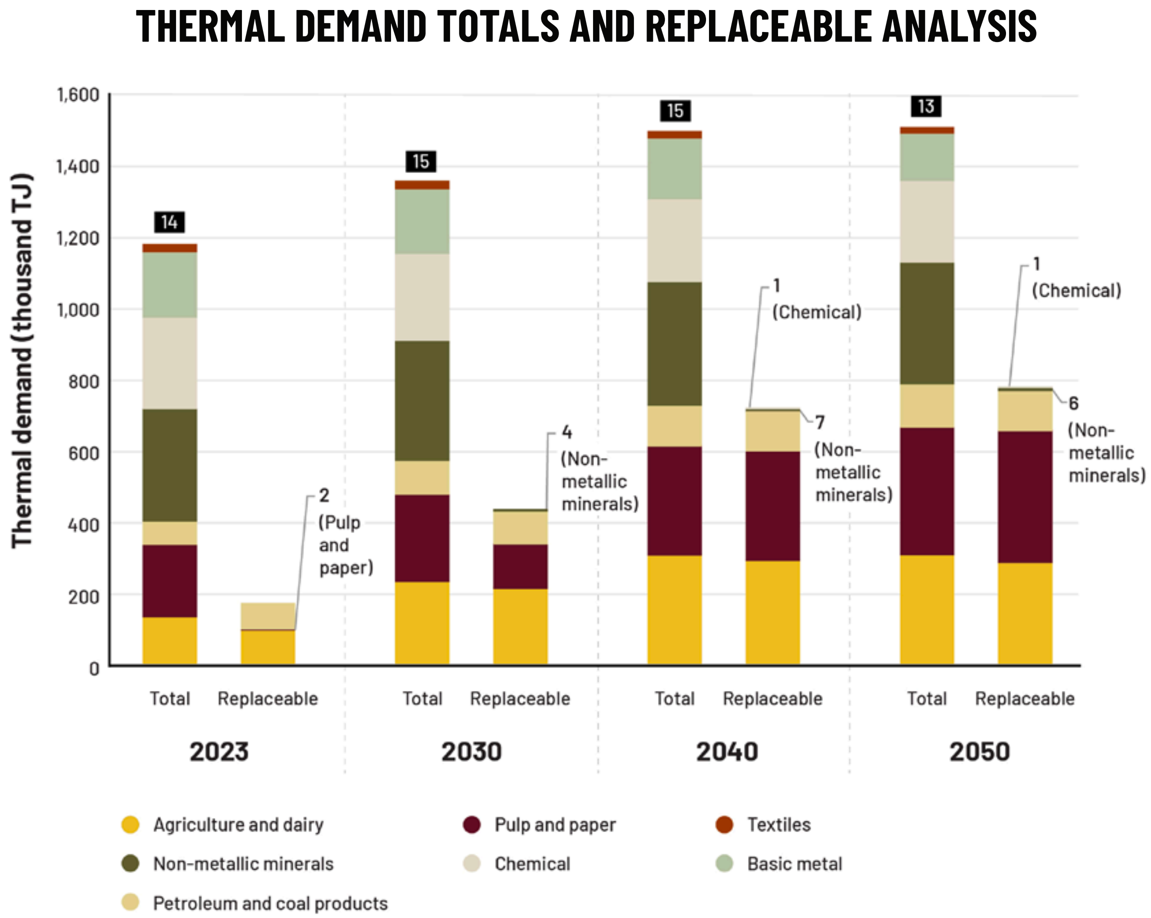


Figure 4.14: Indonesia's industrial and manufacturing projected total and replaceable process heating demand by industry sector, 2023–50. TJ = terajoule. Full source list can be found at the end of the chapter.

fact, in textile manufacturing, all of the industry's process heat needs fall below this temperature; see **Figure 4.15**.) This means that all of the demand in the textile industry today—and a good portion of it in agriculture—can be replaced with geothermal direct use.

In the textiles and agriculture sectors, more than 70% of the thermal demand is at or below 100°C. This means that all of the demand in the textile industry today—and a good portion of it in agriculture—can be replaced with geothermal direct use.

On the other hand, in the production of nonmetallic minerals, chemicals, and pulp and paper—which have the highest total process heating demand across the sector—less than 5% of process heat demand requires lower temperatures, so little of the demand for those processes can be replaced.

The pulp and paper industry uses temperature at or below 200°C for its process heating. (**Figure 4.15**). Looking ahead to 2050, much of this demand could, in principle, be met by geothermal direct use, assuming continued improvements in high-temperature heat pump performance and economic feasibility. In large part, that is because the entire process heating demand from the industry will technically be replaceable by geothermal direct use, based on the future technology advancements in heat pump temperature limitations. In other words, the necessary temperature range will be achievable via the advancement of commercial industrial heat

2023 VERSUS 2050 THERMAL DEMAND FOR INDUSTRIAL AND MANUFACTURING PROCESS HEATING

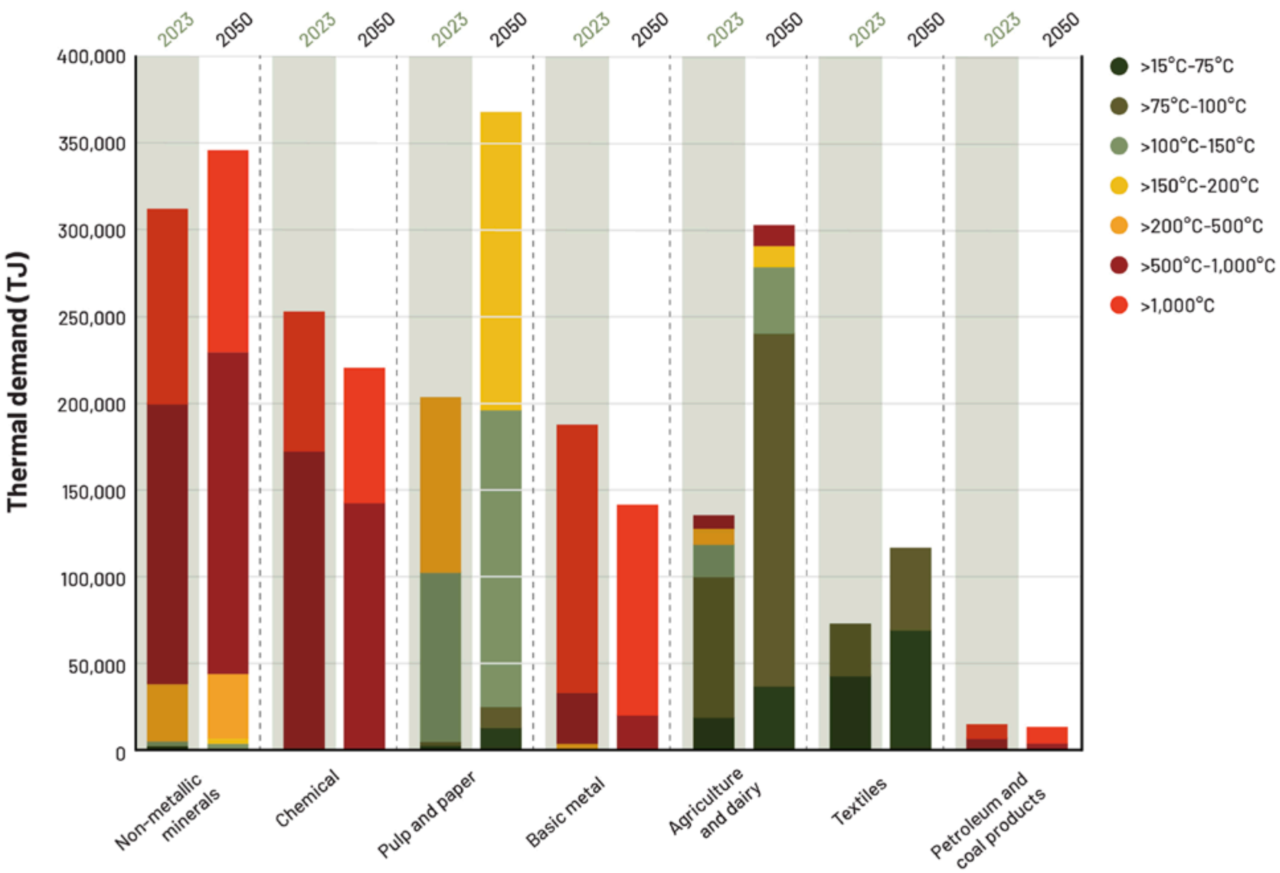


Figure 4.15: Indonesia's industrial and manufacturing total process heating thermal demand by temperature in the 2023 baseline year and the forecast for 2050. TJ = terajoules. Full source list can be found at the end of the chapter.

pumps. (This does not include policy mandates or economic imperatives.)

The term *replaceable* here is the technically replaceable thermal demand merely based on the projected heat pump technology advancement until 2050.

Remarkably, the agriculture and dairy sector, which will rank third in total thermal demand in 2050, will have more than 95% of their demand at or below 200°C.[41]

Refrigeration and Cold Storage

Much of the energy used in Indonesia goes to refrigeration and the storing of food in cold facilities—and that demand is projected to increase substantially. While direct-use geothermal cannot replace a home refrigerator, it can replace commercial food and beverage cold storage.

By the numbers: In 2023, the total demand for cooling for refrigeration and cold storage in Indonesia reached 785,950 terajoules (**Figure 4.16**), with household refrigerators accounting for nearly 91% of the total. By 2050, total demand is projected to rise to 1,002,342 terajoules, but here's the important part: The share of the demand coming from household refrigerators will decrease to 72% as commercial refrigerators and food and beverage cold storage grows to 18% (**Figure 4.16**). And that 18% is key, because while household refrigeration cannot be replaced by geothermal, all commercial and cold storage can be.

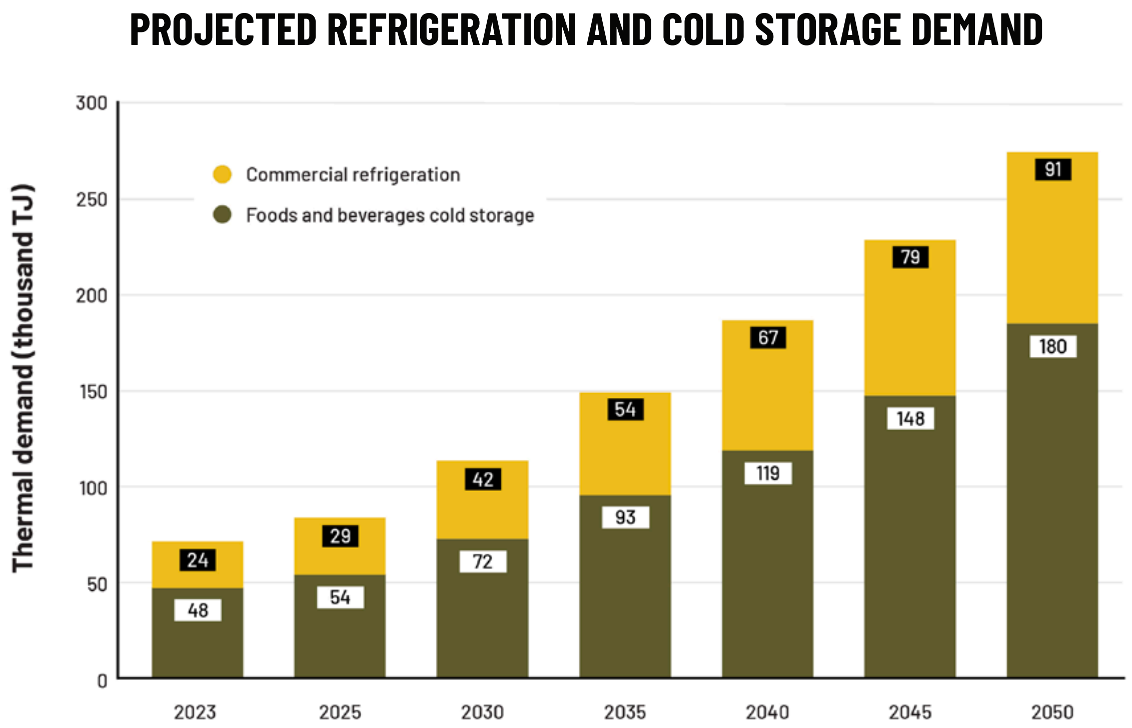


Figure 4.16: Indonesia's commercial refrigeration and cold storage projected thermal demand from 2023 to 2050. TJ = terajoules. Source: authors' calculations; adapted from Ministry of Energy and Mineral Resources. (2024). *Indonesia's National Cooling Action Plan (I-NCAP)*. Government of Indonesia.

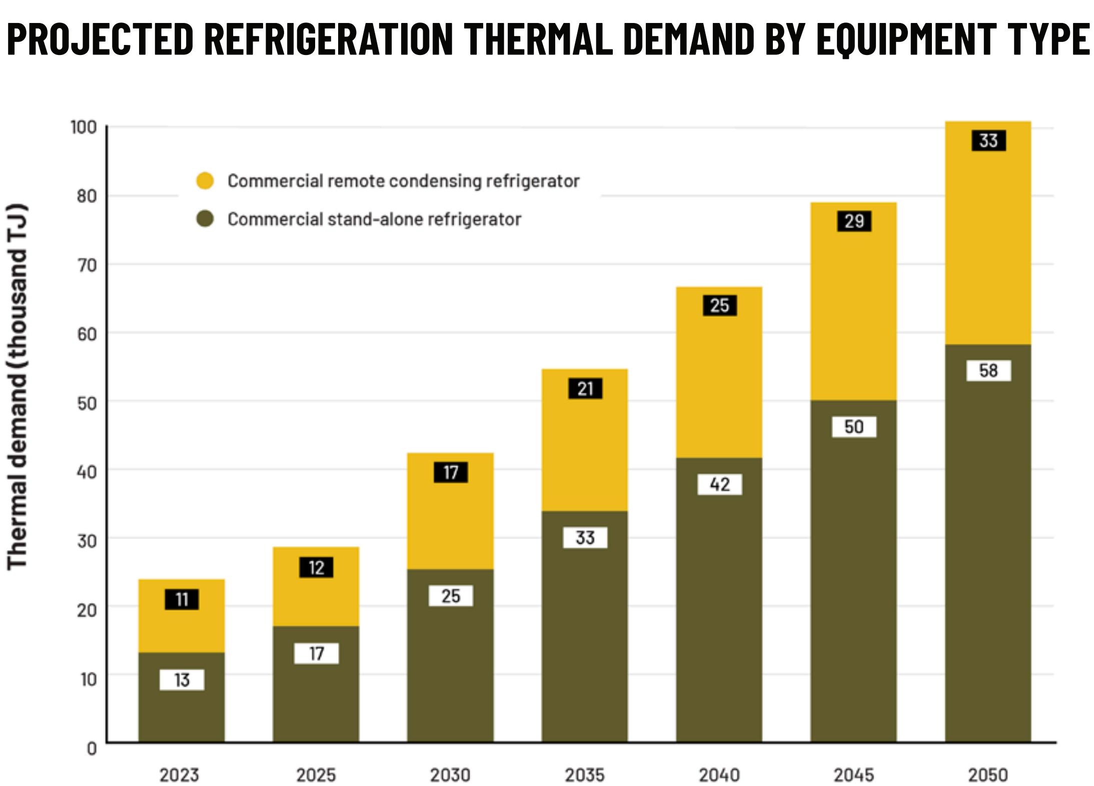


Figure 4.17: Indonesia's commercial refrigeration projected thermal demand by equipment type from 2023 to 2050. The commercial and remote condensing systems are already replaceable today. TJ = terajoules. Source: Ministry of Energy and Mineral Resources. (2024). *Indonesia's National Cooling Action Plan (I-NCAP)*. Government of Indonesia.

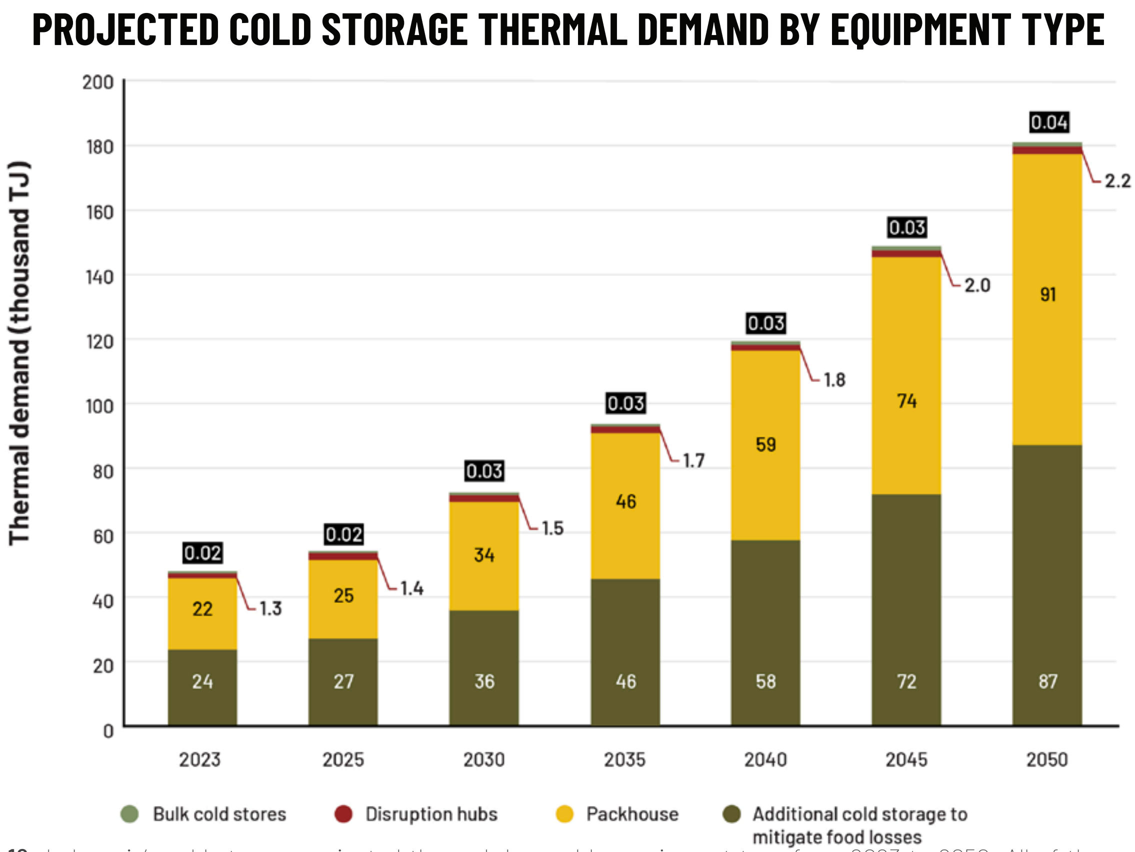


Figure 4.18: Indonesia's cold storage projected thermal demand by equipment type from 2023 to 2050. All of the packhouse, disruption hubs, and bulk cold storage energy demand will be replaceable with geothermal direct use. TJ = terajoules. Source: Ministry of Energy and Mineral Resources. (2024). [Indonesia's National Cooling Action Plan (I-NCAP)](). Government of Indonesia.

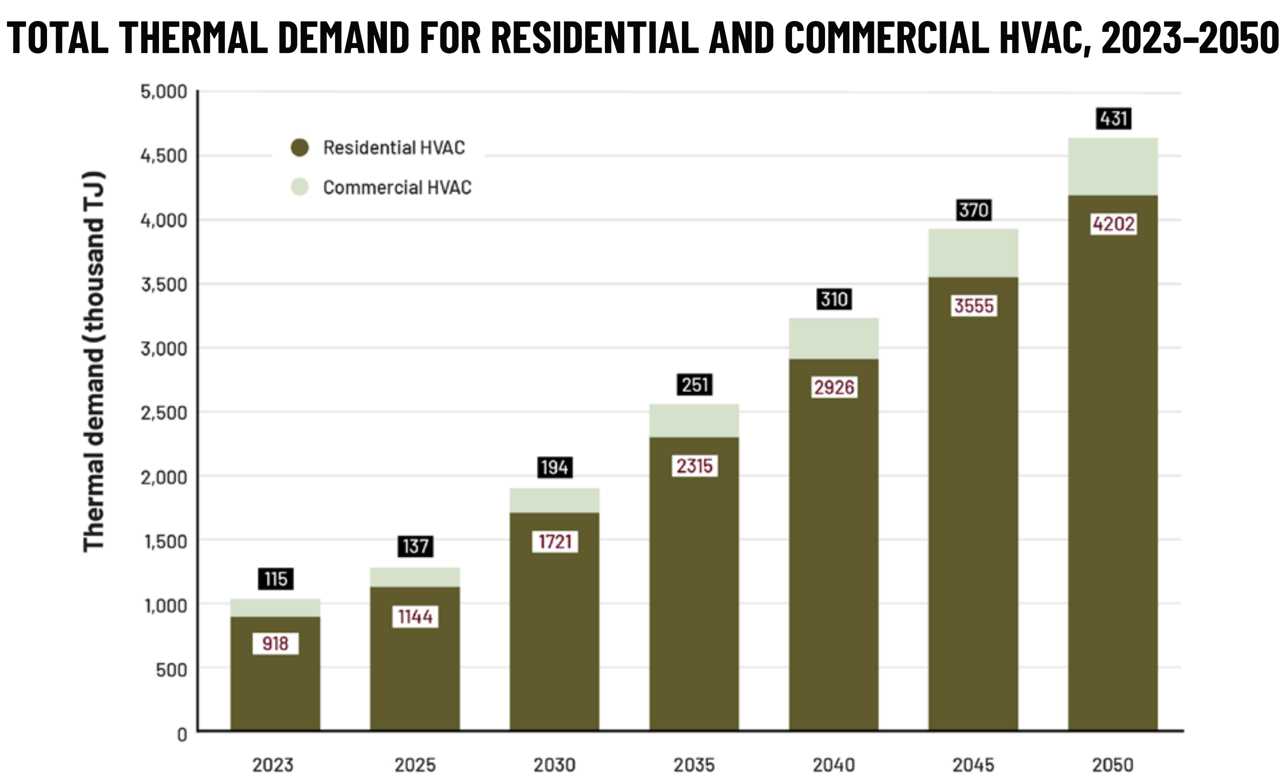


Figure 4.19: Indonesia's residential and commercial HVAC projected thermal demand from 2023 to 2050. TJ = terajoules. Source: Ministry of Energy and Mineral Resources. (2024). [Indonesia's National Cooling Action Plan (I-NCAP)](). Government of Indonesia.

TOTAL THERMAL DEMAND FOR RESIDENTIAL HVAC BY EQUIPMENT TYPE, 2023–2050

Figure 4.20: Indonesia's residential HVAC projected thermal demand by equipment type from 2023 to 2050. TJ = terajoules. Source: Ministry of Energy and Mineral Resources. (2024). *Indonesia's National Cooling Action Plan (I-NCAP)*. Government of Indonesia.

In 2023, with cold storage, most demand came from storage to reduce post-harvest food loss (51%) and market-ready packhouses (46%). By 2050, storage will be at 49%, and packhouses (which are expected to become the largest user of cooling demand in the sector) will subsume 50% of thermal demand (**Figure 4.18**).

A Big Opportunity: Replaceable Demand in Residential and Commercial Cooling

In 2023, Indonesia's total cooling demand for residential and commercial heating, ventilation, and air-conditioning (HVAC) reached 1,033,129 terajoules. By 2050, that demand is expected to more than quadruple—to 4,633,361 terajoules.

A phenomenal 89% of the 2023 total demand came from residential HVAC systems, and that figure is expected to rise as well (see **Figures 4.19 and 4.20**).

In 2023 in commercial settings, HVAC, centrifugal, and screw chillers were the main cooling systems, together making up more than half of commercial demand. These systems are expected to remain dominant in 2050, and many of them could potentially be replaced or supported by cooling derived from geothermal energy (**Figure 4.21**).

SUMMARY: WHAT IS REPLACEABLE NOW, AND WHAT WILL BE REPLACEABLE IN THE NEAR FUTURE

- Indonesia's total thermal demand is projected to grow from 2,998,058.6 terajoules in 2023 to **7,142,641.3 terajoules** by 2050.
- The portion of this demand considered replaceable by geothermal is set to increase from **1,994,144.3 terajoules** in 2023 to **6,415,222.5 terajoules** by 2050.

TOTAL THERMAL DEMAND FOR COMMERCIAL HVAC BY EQUIPMENT TYPE, 2023–2050

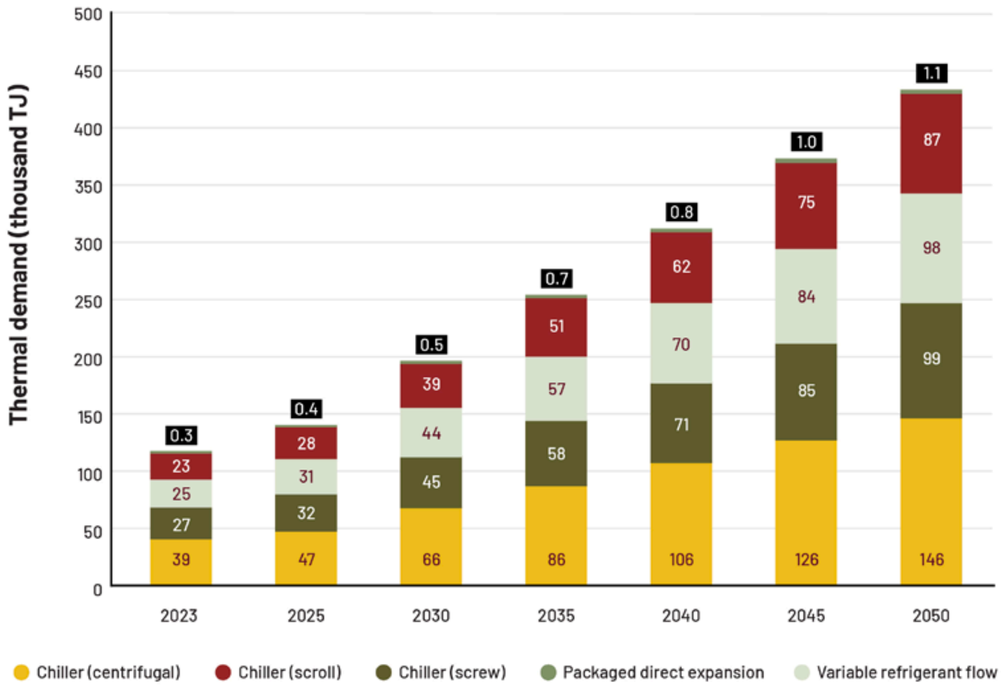


Figure 4.21: Indonesia's commercial HVAC projected thermal demand by equipment type from 2023 to 2050. TJ = terajoules. Source: Ministry of Energy and Mineral Resources. (2024). [Indonesia's National Cooling Action Plan (I-NCAP)](). Government of Indonesia.

PROJECTED TOTAL AND REPLACEABLE THERMAL DEMAND BY END-USE SECTOR, 2023–2050

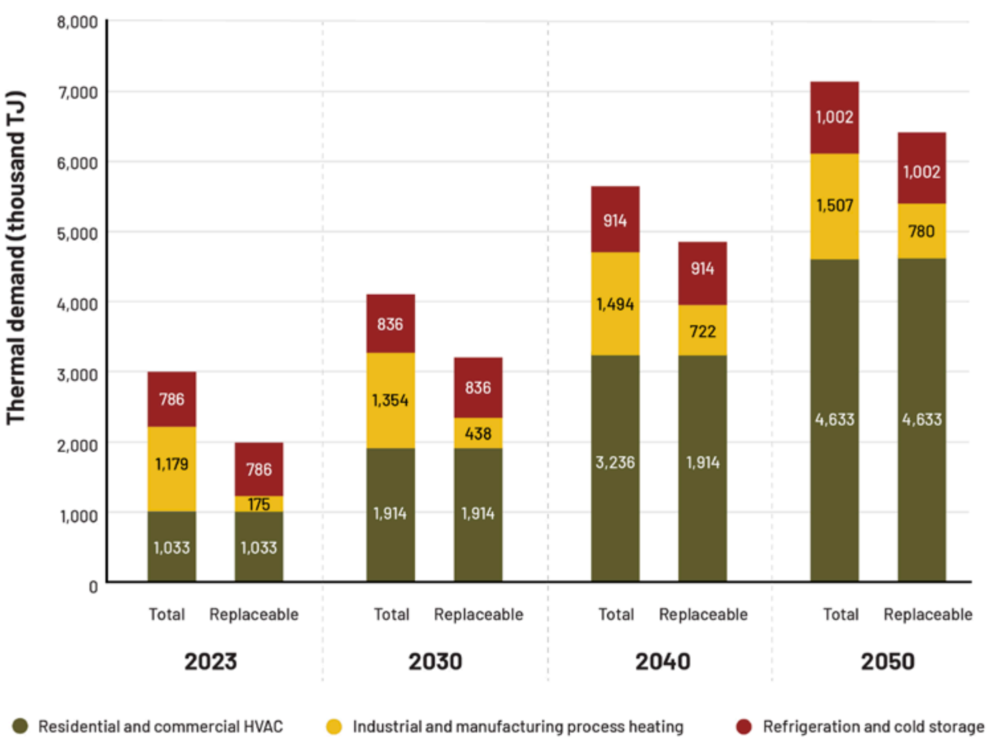


Figure 4.22: Indonesia's projected total and replaceable thermal demand by end-use sector from 2023 to 2050; in other words, 89.9% of thermal demand overall will be replaceable. TJ = terajoules. Source: authors' analysis of the total thermal demand data gathered from official reports of various institutions, academic literature sources, and Indonesian Central Bureau of Statistics (BPS) data. The detailed sources and data used are presented in Appendix 1.

- This means the share of thermal demand that is replaceable is expected to rise from **66.5%** in 2023 to **89.8%** by 2050.

How will this happen? Projected advances in heat pump technology mean it will be able to handle all of the higher residential and commercial HVAC process temperatures.[42]

- In 2023, the industrial and manufacturing sector was the largest consumer of thermal energy, accounting for 39.3% of the total.

- By 2050, the largest consumer of thermal demand is expected to be residential and commercial HVAC, accounting for 64.9% of total demand (see **Figure 4.22**).

- This change will be driven by the rapid annual growth rate projected for the HVAC sector (12.9%) compared with growth in the industrial sector (1.0%).

- The good news: All cooling needs in industrial and residential and commercial HVAC will be technically feasible to be met with direct-use geothermal either through district cooling systems or many individual or networked GSHPs. While this would require significant buildout of the sector and policy support, by 2050, an extraordinary 64.9% of total demand for thermal energy in Indonesia could be supplied by clean, secure geothermal.

ENERGY AND COOLING DEMAND FOR POWER DATA CENTERS IN INDONESIA

While not yet a distinct category in official statistics, Indonesia's data center industry is already expanding rapidly in both scale and importance (as it is across the globe), driven by a booming digital economy and the national imperative for data sovereignty. Indonesia now has the third-largest data center market in Southeast Asia, trailing only Singapore and Malaysia.[43]

Data centers are power-hungry facilities, and a large amount of that energy is dedicated to one critical job: cooling. To keep servers running at their best and prevent them from overheating, data centers depend on powerful cooling systems.

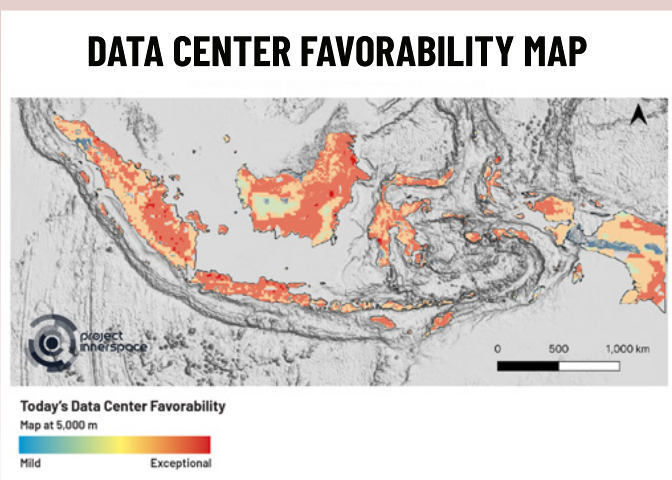


Figure 4.23: Map showing the cumulative geothermal potential (GW) between 0 meters and 5,000 meters around the world, with a 150°C temperature cutoff, representing the minimum threshold for power generation. This map has been combined with a map showing distance to fiber nodes to produce the resultant favorability map. Source: Project InnerSpace. (2025). *Today's global data center favorability Map at 5000 m* [Data Centers Module]. GeoMap.

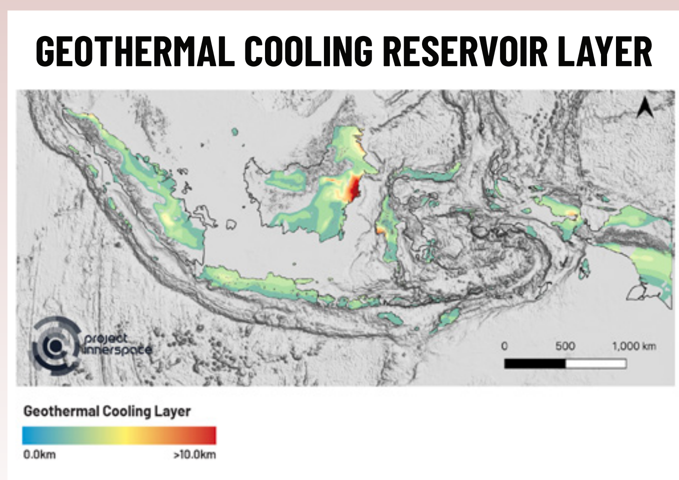


Figure 4.24: Geothermal energy is not just for power—it is also a groundbreaking cooling solution. This map highlights sedimentary aquifers that contain saline/brackish aquifers below the water table—safeguarding viable drinking water—that possess natural porosity and permeability, making them ideal for cooling applications. Source: Project InnerSpace. (2025). *Geothermal cooling layer* [Data Centers Module]. GeoMap.

This breakneck expansion creates a big challenge: surging electricity demand, estimated to reach 1,400 megawatts of information technology load and 700 megawatts of cooling load in Indonesia by 2030.[44]

At the moment, data centers are concentrated in the economic hub of greater Jakarta. The city of Batam, across the strait from Singapore, is fast becoming a secondary hub to capture spillover demand from that city-state.[45] That is good news: Both regions have strong geothermal cooling potential, as shown in **Figure 4.23**.

Next-generation geothermal presents a strategic opportunity for data centers in Indonesia via two primary pathways:

- **Behind-the-meter power:** Co-locating data centers with geothermal resources offers a direct source of firm, clean, and on-site power. Recent analysis focused on the United States shows that this approach can reduce the levelized cost of electricity by between 31% and 45% compared with a traditional, grid-dependent model. This analysis also shows that geothermal can cost-effectively meet two-thirds of the projected data center energy demand.[46] Specific savings in Indonesia will depend on local factors such as grid tariffs and geothermal drilling costs, but the U.S. data are instructive for Indonesia. Initiatives are already emerging: There are plans to build data centers next to major geothermal plants in West Java[47] and for new geothermal-powered facilities in Jakarta, Bandung, and Sumatra via a Renewable Energy Certificate scheme from PLN.
- **Geothermal direct cooling:** By replacing conventional cooling systems, geothermal direct-use cooling technology can offset up to 40% of a data center's total energy consumption.[48] Using these systems would vastly reduce the overall electrical load on the nation's power grids, particularly in high-demand areas. To create the most impact, developers should prioritize assessing the use of geothermal direct cooling in data center projects in greater Jakarta and Batam.

Indonesia is a world leader in geothermal. Companies are scrambling to find clean, firm energy to power their data centers. Few, if any, countries have more potential for geothermal data centers than Indonesia.

To expand and grow this sector, targeted policies and technical support are essential (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for more). Key priorities include the following:

- Clearer regulations for behind-the-meter power generation systems
- Established geothermal resource rights specifically for direct-use cooling applications
- Improved subsurface data to support the development of enhanced and advanced geothermal systems, enabling data centers to have more locations

For more information on the energy and cooling landscape for data centers in Indonesia, see **Figures 4.23** and **4.24**.

Projection for 2030

- ~1400 megawatts of IT load capacity
- ~700 megawatts of cooling load, assuming PUE (power usage effectiveness) of 1.5 (more efficient cooling technology)
- ~6,132 gigawatt-hours of energy required for cooling per year

Source: Morridor Intelligence. (2025). *Indonesia data center cooling market size and share analysis—growth trends & forecasts (2025–2031)*.

Data Center Location Distribution

- 150 data centers from 25 markets in Indonesia
- **Greater Jakarta:** The primary hub, benefiting from dense fiber networks and proximity to major businesses and government entities
- **Batam:** The emerging hub alternative, a key landing point for new international subsea cables that offers a reliable grid and strategic proximity to Singapore

Source: Project InnerSpace, 2025; Data Center Map. (n.d.). *Indonesia data centers*.

Spatial Mapping of Geothermal Direct-Use Resource Potential

The key to finding the best places to install direct-use geothermal is to look at where the demand corresponds to the most suitable subsurface temperatures.

To assess subsurface conditions, we used 2024 data from the Directorate of Data and Computation ambient temperatures[49] and various other subsurface temperature data sets.[50,51] Data quality varies by region, but the best data available were for Java, North Sumatra, and Riau because of prior geothermal and oil and gas exploration.

As mentioned, direct-use applications can typically be developed without the need to reach the deep, high-temperature resources often pursued for electricity generation. In fact, low- to medium-temperature resources at shallower depths can be more economical than higher-temperature resources in significantly deeper depths. (The depth at which usable temperatures are found influences the technology used and the viability of a project.)

Some existing direct-use facilities rely on excess steam from power plants or surface manifestations. In areas without these features, shallow thermal anomalies offer viable targets for near-surface drilling, enabling geothermal use without the cost of deep wells. This study emphasizes the potential of shallow drilling in areas without such features.

Easily Accessible Heat

Temperature-at-depth analyses (**Figures 4.25**, **4.26**, and **4.27**) confirm that Indonesia has many areas with subsurface heat between 30°C and 50°C at shallow to moderate depths of less than 1,000 meters, making these areas suitable for various direct-use applications at a competitive cost. This can include industrial heating and bathing.

Shallow Ground Temperatures Suitable for GSHPs

Shallow ground temperature data (at 2 meters deep) is used to assess and identify areas suitable for shallow GSHP applications.[52] By comparing shallow ground and ambient air temperatures, we can identify areas with efficient heat exchange potential where cooler ground supports cooling and hotter ground supports heating. The greater the temperature difference, the higher the GSHP efficiency. **Figure 4.28** shows the spatial distribution to help with site selection for GSHP deployment in Indonesia. See the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities," for further insights on next-generation geothermal potential.

Limitations and the Future

Thermal demand and subsurface temperature mapping indicate that many areas in Indonesia, especially Java and parts of Sumatra, have potential for direct-use geothermal. However, suitability ultimately depends on factors such as permeability and the technology needed.

Areas that are geologically controlled by primary permeability, such as graben-fill sedimentary environments, can be evaluated through detailed lithological mapping and assessment. Meanwhile, areas with tectonically active regimes may host faults and structures that act as secondary permeability zones. Therefore, regions characterized by secondary permeability can be identified through surface manifestations and geophysics-derived structural assessments. Conceptually, areas with high permeability are more suitable for fluid flow and heat transfer. (See Chapter 3, "Beneath the Archipelago: Indonesia's Geothermal Systems," for more.)

While some applications (e.g., heat pumps) work with lower temperatures and minimal subsurface requirements, others need higher temperatures and better permeability (e.g., absorption chillers). Matching technology with local conditions and conducting sector-specific assessments are essential steps. And given that each industry has distinct resource requirements, a more refined and targeted evaluation is essential for determining actual suitability on a case-by-case basis.

These findings show a realistic opportunity for Indonesia to use its natural geothermal heat to cover a large part of its future heating and cooling needs—and a clear path to support the country's goals for shifting to cleaner

TEMPERATURE AT 100 METERS DEPTH

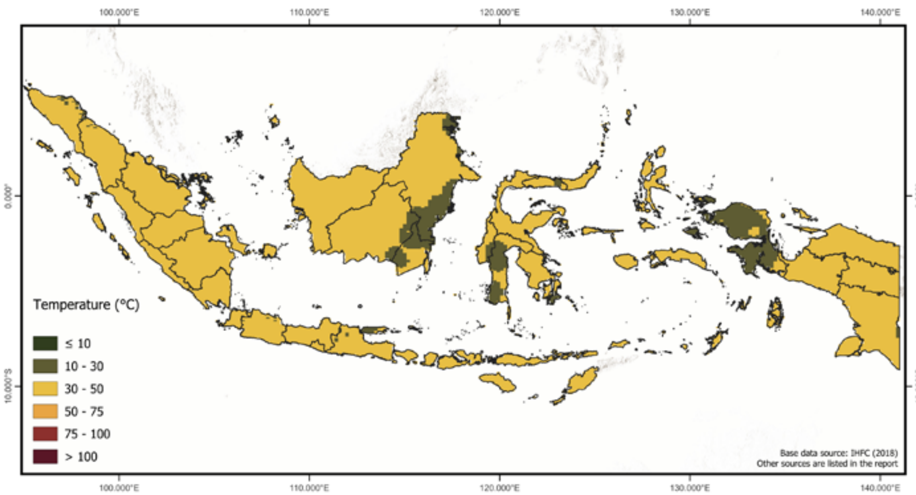


Figure 4.25: Distribution of temperature at 100 meters depth based on available geothermal well data and temperature calculation from heat flow, temperature gradient, and average conductivity. Source: International Heat Flow Commission (IHFC). (n.d.). *The global heat flow database*.

TEMPERATURE AT 500 METERS DEPTH

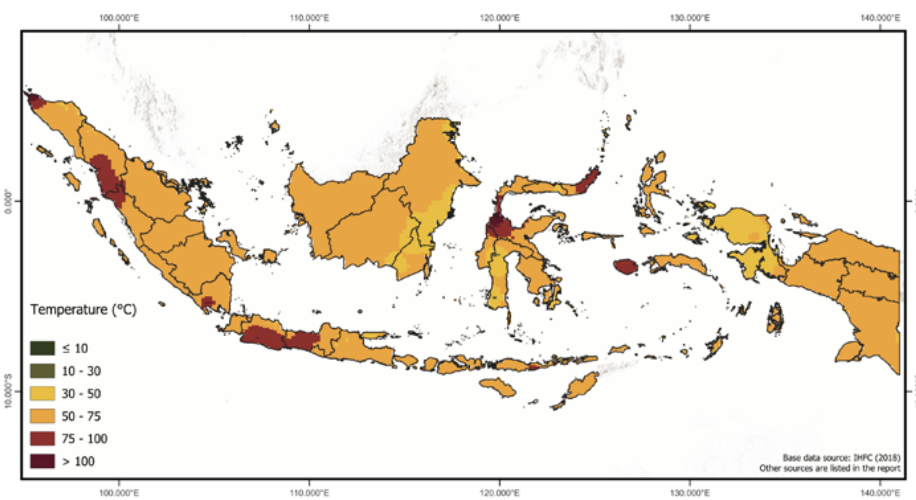


Figure 4.26: Distribution of temperature at 500 meters depth based on available geothermal well data and temperature calculations from heat flow, temperature gradient, and average conductivity. Source: International Heat Flow Commission (IHFC). (n.d.). *The global heat flow database*.

TEMPERATURE AT 1,000 METERS DEPTH

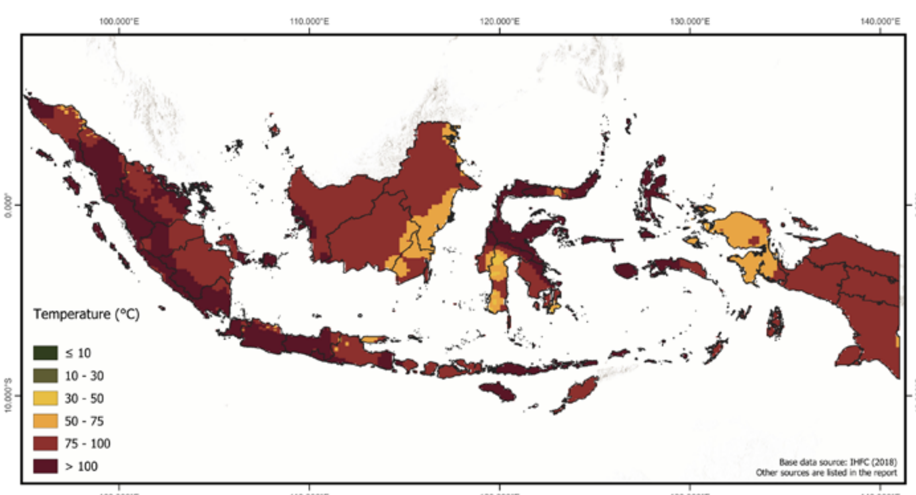


Figure 4.27: Distribution of temperature at 1,000 meters depth based on available geothermal well data and temperature calculations from heat flow, temperature gradient, and average conductivity. Source: International Heat Flow Commission (IHFC). (n.d.). *The global heat flow database*.

SHALLOW GROUND TEMPERATURE DISTRIBUTION

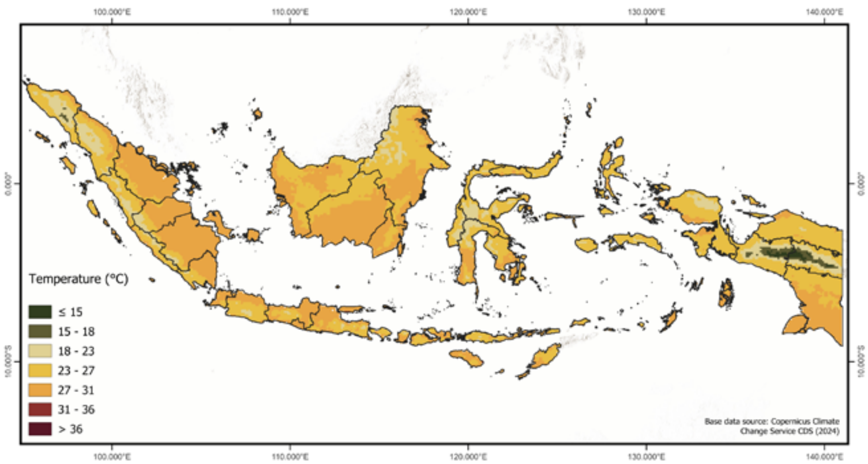
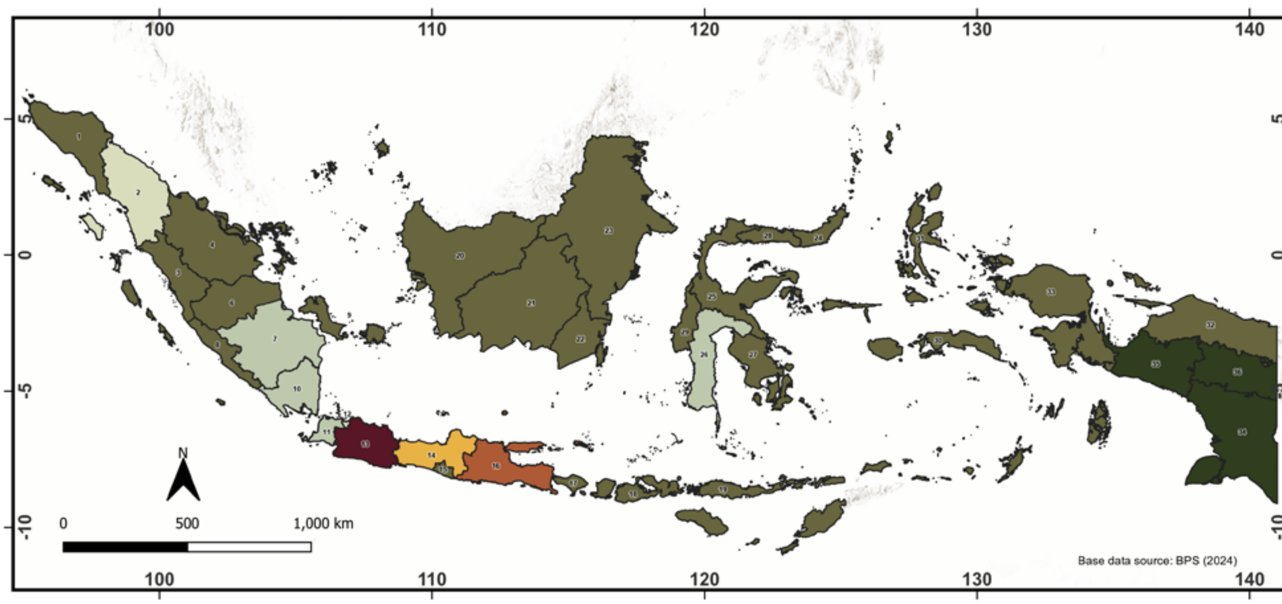


Figure 4.28: 2024 annual average shallow ground temperature distribution at 2 meters depth. The khaki and orange areas have the best GSHP efficiency. The data are generated through physics-based land surface modeling using actual meteorological inputs such as air temperature, precipitation, solar radiation, and soil moisture. Source: Copernicus Climate Change Service (C3S). (2025). [Thermal comfort indices derived from ERA5 reanalysis] [Data set]. Climate Data Store (CDS).

COOLING DEMAND FOR RESIDENTIAL SECTOR, BY PROVINCE IN INDONESIA



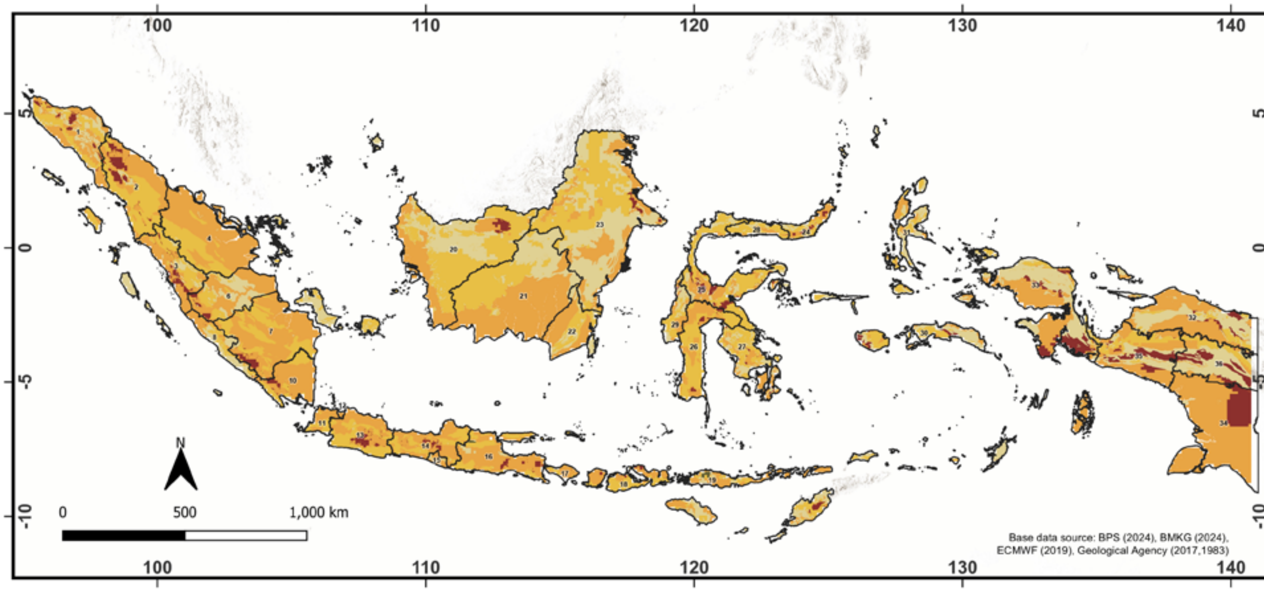
Thermal Demand for HVAC Residential (TJ)

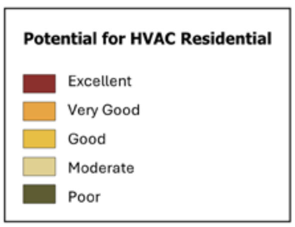
- 0 - 3,000
- 3,000 - 25,000
- 25,000 - 45,000
- 45,000 - 75,000
- 75,000 - 100,000
- 100,000 - 125,000
- 125,000 - 150,000
- > 150,000

NO	PROVINCE	THERMAL DEMAND (TJ)
1	Aceh	16,610
2	North Sumatra	47,261
3	West Sumatra	16,282
4	Riau	22,634
5	Riau Islands	3,338
6	Jambi	12,078
7	South Sumatra	27,120
8	Bengkulu	6,920
9	Bangka Belitung Islands	5,607
10	Lampung	27,485
11	Banten	41,007
12	DKI Jakarta	54,136
13	West Java	174,264
14	Central Java	121,043
15	DI Yogyakarta	15,072
16	East Java	138,799
17	Bali	15,630
18	West Nusa Tenggara	20,326
19	East Nusa Tenggara	13,753
20	West Kalimantan	16,754
21	Central Kalimantan	8,983
22	South Kalimantan	15,143
23	East Kalimantan and North Kalimantan	15,823
24	North Sulawesi	8,536
25	Central Sulawesi	10,110
26	South Sulawesi	29,197
27	Southeast Sulawesi	8,419
28	Gorontalo	3,703
29	West Sulawesi	3,911
30	Maluku	3,592
31	North Maluku	5,142
32	Papua	6,162
33	West Papua and Southwest Papua	3,394
34	South Papua	0
35	Central Papua	0
36	Highland Papua	0

Figure 4.29: Mapping of baseline 2023 cooling demand for residential sector by province in Indonesia. TJ = terajoules. Source: Adapted from PLN. (2024). Statistics 2023; BPS-Statistics Indonesia. (2024). Riau Province in figures 2024; BPS-Statistics Indonesia. (2024). Jawa Tengah Province in figures 2024; BPS-Statistics Indonesia. (2024). Sumatera Selatan Province in figures 2024; BPS-Statistics Indonesia. (2024). Jambi Province in figures 2024; BPS-Statistics Indonesia. (2024). East Java Province in figures 2024; BPS-Statistics Indonesia. (2024). West Java Province in figures 2024.

SUITABILITY MAP FOR RESIDENTIAL HVAC DEMAND, 2023





NO	PROVINCE	NO	PROVINCE	NO	PROVINCE	NO	PROVINCE
1	Aceh	10	Lampung	19	East Nusa Tenggara	28	Gorontalo
2	North Sumatra	11	Banten	20	West Kalimantan	29	West Sulawesi
3	West Sumatra	12	DKI Jakarta	21	Central Kalimantan	30	Maluku
4	Riau	13	West Java	22	South Kalimantan	31	North Maluku
5	Riau Islands	14	Central Java	23	East Kalimantan and North Kalimantan	32	Papua
6	Jambi	15	DI Yogyakarta	24	North Sulawesi	33	West Papua and Southwest Papua
7	South Sumatra	16	East Java	25	Central Sulawesi	34	South Papua
8	Bengkulu	17	Bali	26	South Sulawesi	35	Central Papua
9	Bangka Belitung Islands	18	West Nusa Tenggara	27	Southeast Sulawesi	36	Highland Papua

Figure 4.30: Suitability mapping for residential HVAC based on the baseline 2023 thermal demand, ambient and ground temperature differences, and qualitative thermal conductivity of shallow formation. Source: Adapted from PLN. (2024). *Statistics 2023*; BPS-Statistics Indonesia. (2024). *Riau Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jawa Tengah Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Sumatera Selatan Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jambi Province in figures 2024*; BPS-Statistics Indonesia. (2024). *East Java Province in figures 2024*; BPS-Statistics Indonesia. (2024). *West Java Province in figures 2024*.

energy. This possibility is especially true for reducing carbon emissions via GSHP for cooling homes and direct-use systems for cooling commercial buildings, where the need for thermal energy is expected to grow the fastest.

THE BIGGEST OPPORTUNITIES: COOLING IN JAVA AND PROCESS HEATING IN AGRIBUSINESS

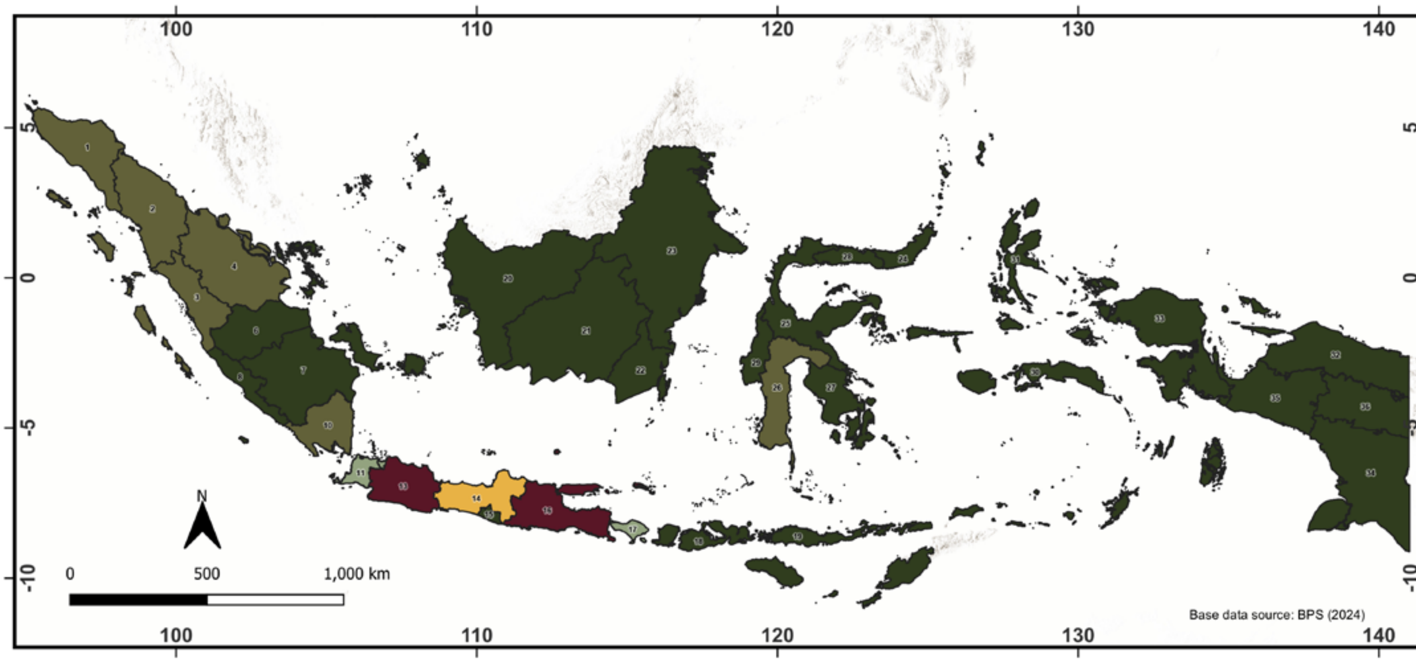
Cooling Java's Urban Centers

Java's populous, economically vital provinces have the highest demand and excellent geological suitability. Deploying geothermal cooling technologies across West, Central, and East Java can greatly cut electricity use, reducing peak demand, strengthening reliability, and avoiding expensive capacity expansions. The highest priority for direct use in these regions is providing cooling for buildings, starting with large commercial or public buildings like hospitals. **Figures 4.29** and **4.30** map the cooling-demand distribution and suitability, respectively, for residential cooling in Indonesia. For commercial cooling, **Figures 4.31** and **4.32** show the demand and the suitability of the available geothermal resources.

GEOTHERMAL DISTRICT COOLING FOR COMMERCIAL AND RESIDENTIAL BUILDINGS

With an average ambient temperature of about 27°C, cooling isn't just a seasonal need—it's a year-round necessity. Indonesia faces a critical need for efficient and sustainable building cooling.

BASELINE THERMAL DEMAND FOR COMMERCIAL HVAC, BY PROVINCE IN INDONESIA

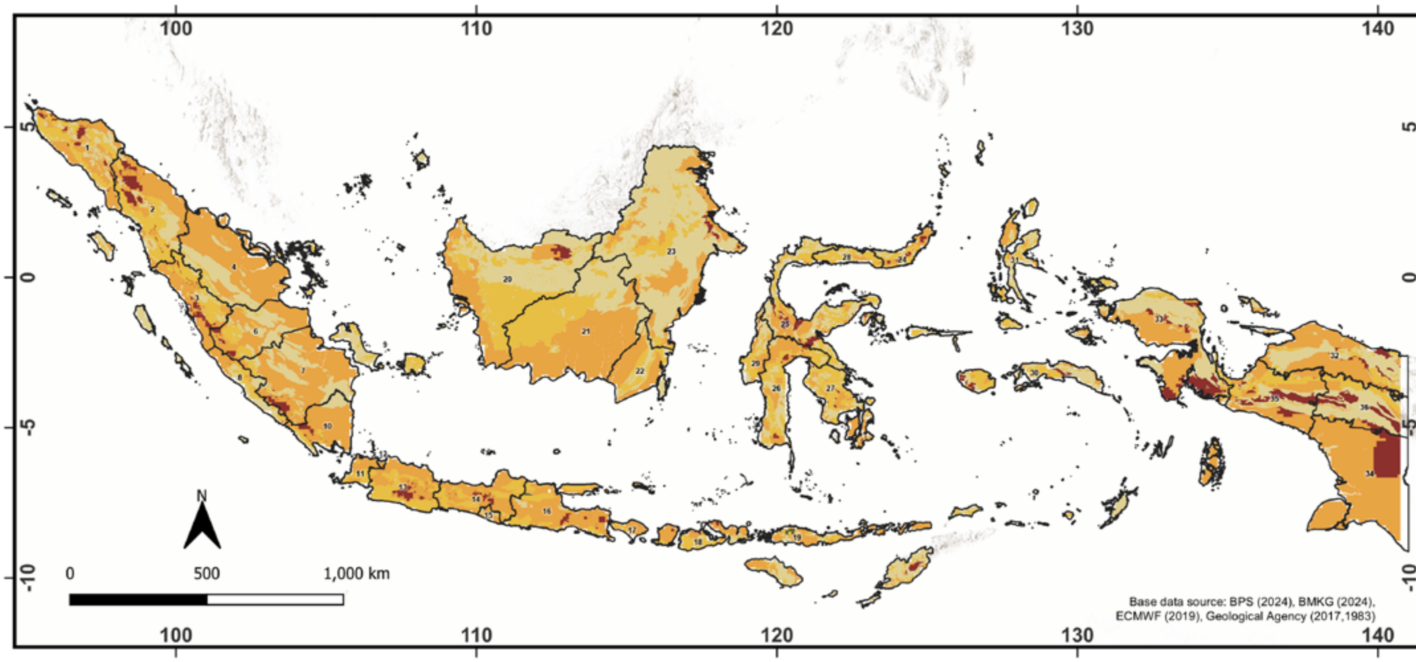


NO	PROVINCE	THERMAL DEMAND (TJ)
1	Aceh	4,002
2	North Sumatra	3,865
3	West Sumatra	4,654
4	Riau	4,267
5	Riau Islands	742
6	Jambi	1,368
7	South Sumatra	1,584
8	Bengkulu	510
9	Bangka Belitung Islands	976
10	Lampung	2,633
11	Banten	5,720
12	DKI Jakarta	7,412
13	West Java	20,350
14	Central Java	14,014
15	DI Yogyakarta	1,769
16	East Java	18,047
17	Bali	5,959
18	West Nusa Tenggara	1,018
19	East Nusa Tenggara	885
20	West Kalimantan	2,026
21	Central Kalimantan	1,722
22	South Kalimantan	1,828
23	East Kalimantan and North Kalimantan	2,283
24	North Sulawesi	699
25	Central Sulawesi	681
26	South Sulawesi	2,746
27	Southeast Sulawesi	734
28	Gorontalo	255
29	West Sulawesi	307
30	Maluku	277
31	North Maluku	348
32	Papua	808
33	West Papua and Southwest Papua	409
34	South Papua	0
35	Central Papua	0
36	Highland Papua	0

Thermal Demand (TJ)
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 7,500
- 7,500 - 10,000
- 10,000 - 12,500
- 12,500 - 15,000
- 15,000 - 17,500
- > 17,500

Figure 4.31: Mapping of baseline 2023 thermal demand for commercial HVAC by province in Indonesia. TJ= terajoules. Source: Adapted from PLN. (2024). *Statistics 2023*; BPS-Statistics Indonesia. (2024). *Riau Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jawa Tengah Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Sumatera Selatan Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jambi Province in figures 2024*; BPS-Statistics Indonesia. (2024). *East Java Province in figures 2024*; BPS-Statistics Indonesia. (2024). *West Java Province in figures 2024*.

SUITABILITY MAP FOR COMMERCIAL COOLING



NO	PROVINCE	NO	PROVINCE	NO	PROVINCE	NO	PROVINCE
1	Aceh	10	Lampung	19	East Nusa Tenggara	28	Gorontalo
2	North Sumatra	11	Banten	20	West Kalimantan	29	West Sulawesi
3	West Sumatra	12	DKI Jakarta	21	Central Kalimantan	30	Maluku
4	Riau	13	West Java	22	South Kalimantan	31	North Maluku
5	Riau Islands	14	Central Java	23	East Kalimantan and North Kalimantan	32	Papua
6	Jambi	15	DI Yogyakarta	24	North Sulawesi	33	West Papua and Southwest Papua
7	South Sumatra	16	East Java	25	Central Sulawesi	34	South Papua
8	Bengkulu	17	Bali	26	South Sulawesi	35	Central Papua
9	Bangka Belitung Islands	18	West Nusa Tenggara	27	Southeast Sulawesi	36	Highland Papua

Potential for HVAC Commercial

- Excellent
- Very Good
- Good
- Moderate
- Poor

Figure 4.32: Suitability map for commercial HVAC, highlighting the high potential (dark red) concentrated in Java and parts of Sumatra. Source: Adapted from PLN. (2024). Statistics 2023; BPS-Statistics Indonesia. (2024). Riau Province in figures 2024; BPS-Statistics Indonesia. (2024). Jawa Tengah Province in figures 2024; BPS-Statistics Indonesia. (2024). Sumatera Selatan Province in figures 2024; BPS-Statistics Indonesia. (2024). Jambi Province in figures 2024; BPS-Statistics Indonesia. (2024). East Java Province in figures 2024; BPS-Statistics Indonesia. (2024). West Java Province in figures 2024.

Geothermal energy is the most efficient form of cooling available, offering a path to energy security, economic resilience, and a sustainable future.

Target Zones: Where Demand and Geothermal Resources Align

- Indonesia's greatest potential for cooling is concentrated in several key regions. The largest is in **West Java**, **Central Java**, and **East Java**. These highly populated areas serve as Indonesia's main economic hubs and manufacturing centers.
- The **Greater Jakarta** area, the country's central business and government hub, also has significant cooling potential.
- **North Sumatra**, especially in Medan and Jambi, has good potential for residential cooling because of high population density.
- The cities of Balikpapan, Banjarmasin, and Samarinda on the island of Borneo are also early candidates for district-scale geothermal cooling projects.

GEOTHERMAL COOLING AND HEATING NETWORK

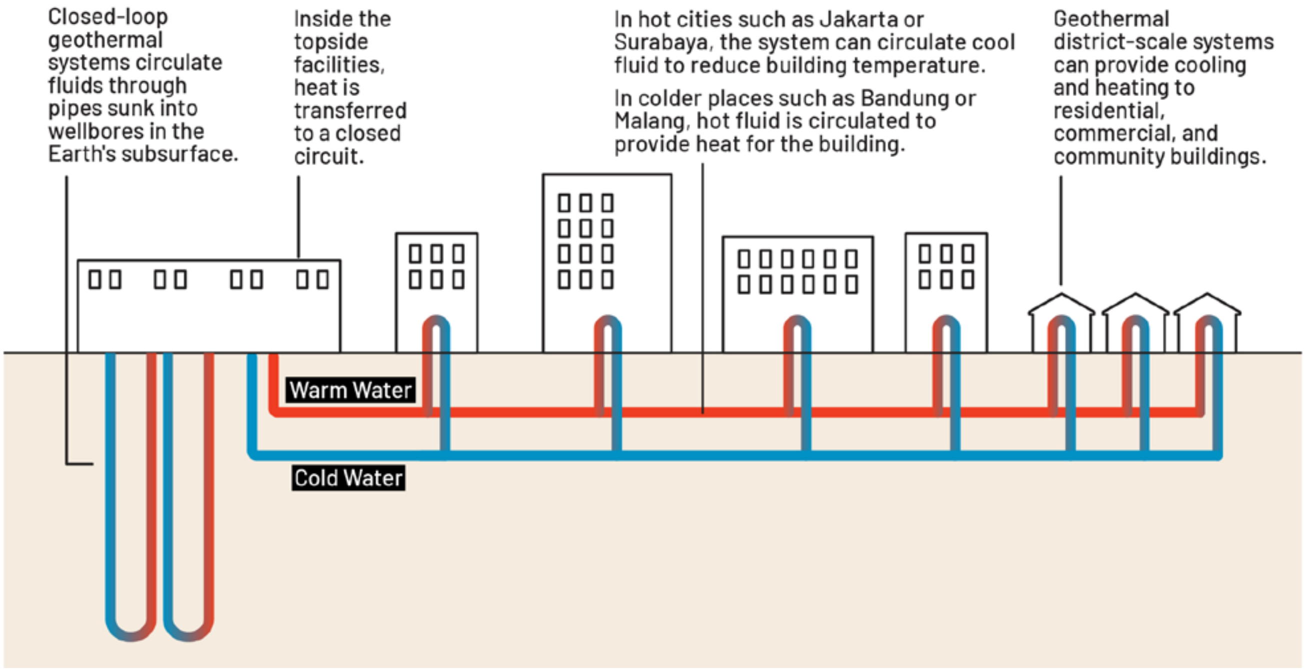


Figure 4.33: District cooling system fluid is typically brought to the surface at a target temperature of around 21°C. That fluid is then passed through a heat pump to provide cold water in the summer for cooling and hot water in the winter for heating. This style of cooling and heating can be more than twice as efficient as traditional HVAC systems as the thermal load is shared between buildings. Source: Adapted from U.S. Department of Energy. *Geothermal district heating & cooling*.

INDONESIA'S SPATIAL COOLING POTENTIAL

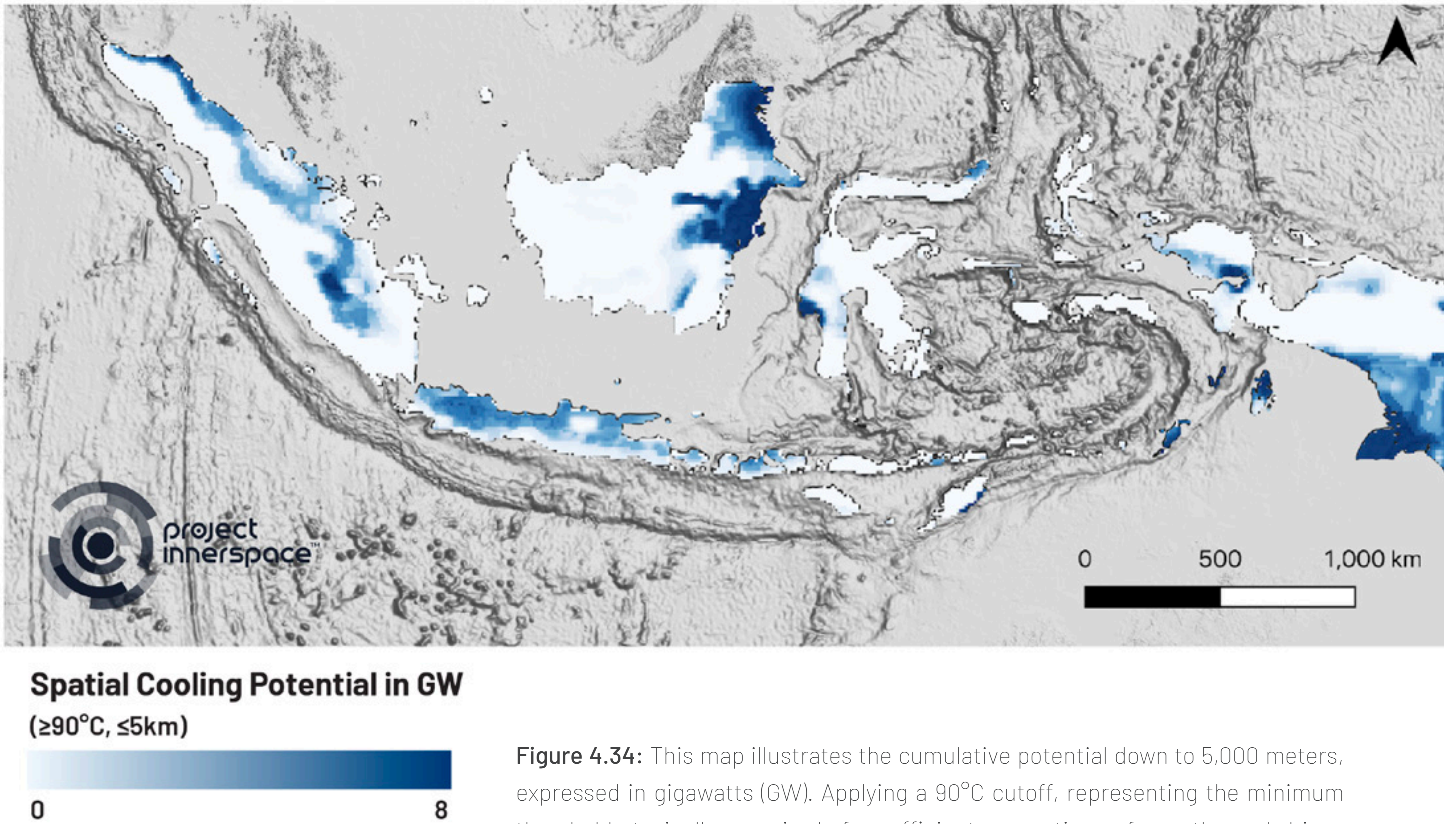


Figure 4.34: This map illustrates the cumulative potential down to 5,000 meters, expressed in gigawatts (GW). Applying a 90°C cutoff, representing the minimum threshold typically required for efficient operation of geothermal-driven absorption chillers used in district cooling, we estimate district-level geothermal energy reserves in GW in sedimentary aquifers. Sedimentary basins are uniquely poised for a geothermal revolution due to their geological characteristics. These basins feature sedimentary aquifers often with high porosity and permeability, allowing them to store and transmit geothermal fluids efficiently. Source: Project InnerSpace. (2025). GeoMap.

BY THE NUMBERS

- **365 days per year:** How often cooling is needed due to Indonesia's equatorial climate[53]
- **338 million:** The estimated population of Indonesia by 2050, based on projections from Indonesia's Central Bureau of Statistic and urbanization cooling demand utilities[54]
- **1°C –1.5°C:** The projected temperature rise by 2050[55]

DIRECT USE FOR AGRO-INDUSTRIES PROCESS HEATING

Current Projects

Today, direct-use geothermal applications in agriculture and industry are largely developed through CSR initiatives, and most of them are small-scale projects such as greenhouse heating or drying, often in partnership with local communities.

Several pilot projects in the agriculture industry have begun demonstrating how geothermal direct use can harness low- to medium-temperature resources, especially in highland regions where subsurface resources and agricultural activities intersect. The Kamojang geothermal field is a prime example: To support the surrounding communities, PT Pertamina Geothermal Energy (PGE) uses excess steam captured from the geothermal electricity generation plant steam traps for processes such as sterilizing mushrooms and processing organic waste into compost (**Figure 4.35**).

Several direct-use applications implemented by PGE provide tangible demonstrations of geothermal utilization for agricultural purposes. Although these initiatives currently operate on a small and local scale, they illustrate the technical feasibility and socio-economic value of direct-use projects, laying the groundwork for future investment. Such examples can also strengthen geothermal developers' social license to operate across Indonesia by delivering visible community benefits (see Chapter 6, "Common Ground: Building Trust and Transparency in Indonesia's Energy Transition"). Moreover, agro-industrial development has been identified as one of the supporting activities within PGE's geothermal operations. If geothermal regulations are more clearly defined and supportive of non-power applications, these initiatives can be replicated and scaled up, offering an additional revenue stream for developers and advancing Indonesia's broader geothermal sector (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation").

At Canaya Coffee, farmers use a geothermal-powered dryhouse instead of relying on the fickle weather. This dryhouse has reduced bean-drying times from two weeks to three or four days. This saved time helps farmers maintain product quality, secure a more reliable income, and reduce energy uncertainty (**Figure 4.36**).

This model empowers local farmers to manage day-to-day operations, while PGE ensures the sustainable provision of geothermal steam. This partnership benefits both the community and the environment.

USING EXCESS GEOTHERMAL STEAM IN AGRICULTURE

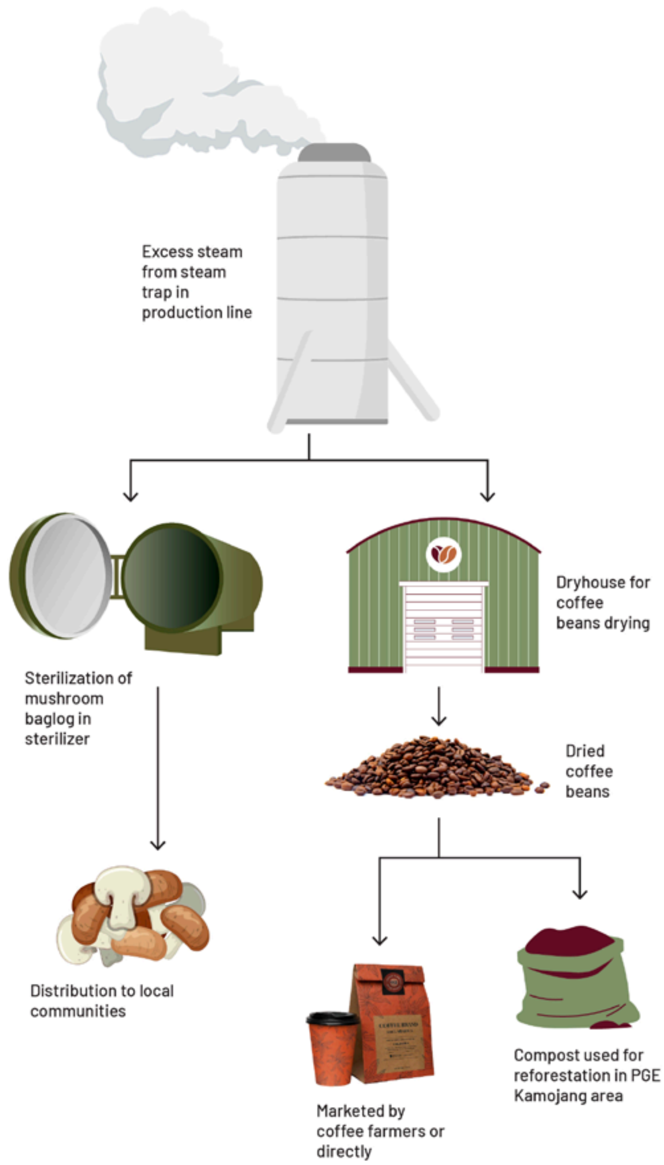


Figure 4.35: Use of excess geothermal steam as direct-use heat at the Kamojang geothermal field. Source: authors.

PROCESS HEAT FLOW FOR DIRECT-USE COFFEE DRYING

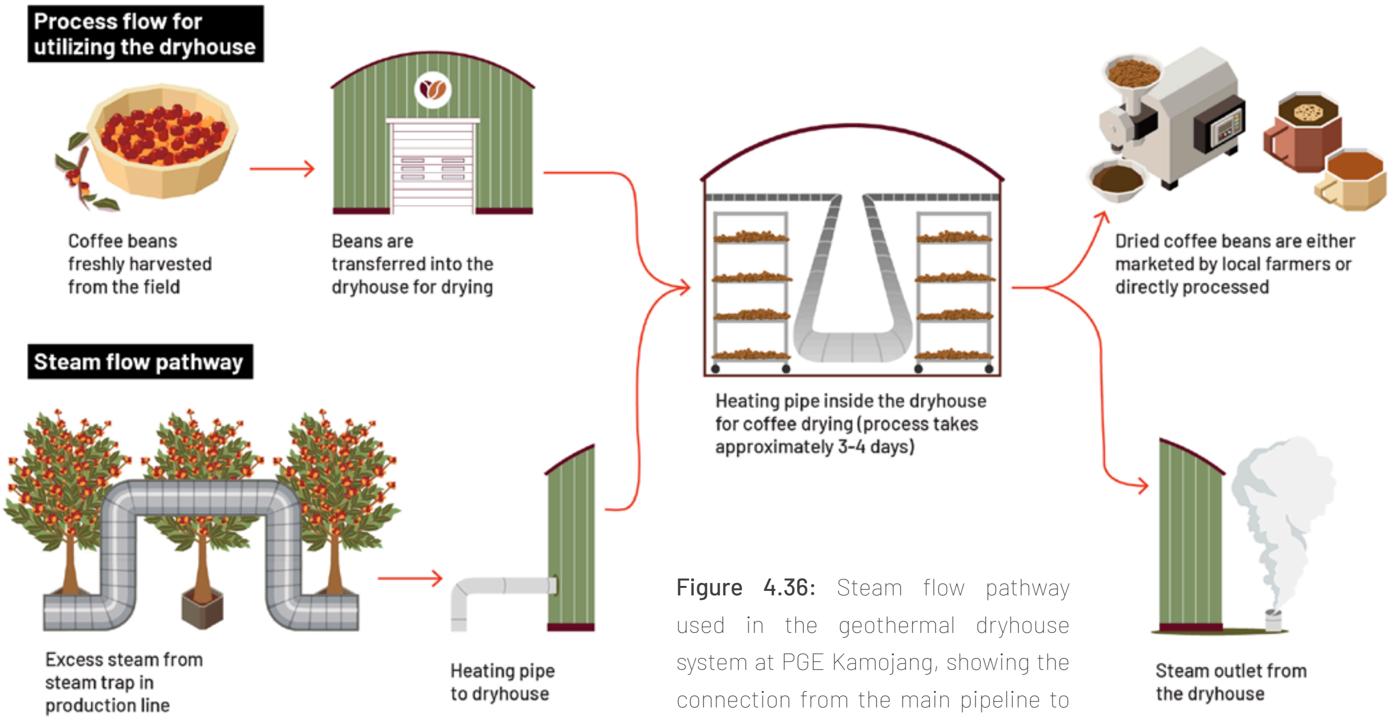


Figure 4.36: Steam flow pathway used in the geothermal dryhouse system at PGE Kamojang, showing the connection from the main pipeline to the dryhouse. Source: authors.

This dryhouse has reduced bean-drying times from two weeks to three or four days. This saved time helps farmers maintain product quality, secure a more reliable income, and reduce energy uncertainty.

As demand for Canaya Coffee continues to grow, PGE's investment reinforces a broader commitment to sustainable rural development and resilient, community-driven energy solutions.[56]

Deploying Direct Use for Agribusiness in the Future

There is growing interest in expanding geothermal direct-use for agriculture through various proposed and exploratory projects. One planned project by PT Geo Dipa Energi in the Dieng geothermal area aims to use geothermal heat in a greenhouse designed to produce high-quality agroforestry seedlings for distribution throughout the area.

Geothermal heat would be used for sterilizing the plantation media, made from coco peat and husk charcoal. The seeds will be sown in the plantation media, then transplanted to the cultivation area. Geothermal heat is also distributed in the greenhouse to control the temperature and humidity, maintaining an optimal growing environment for the crops. The plan is to grow long-term crops such as citrus, avocado, and coffee and short-term crops such as Carica and citronella to ensure both sustained and immediate economic returns while supporting agroforestry and local livelihoods in the region.

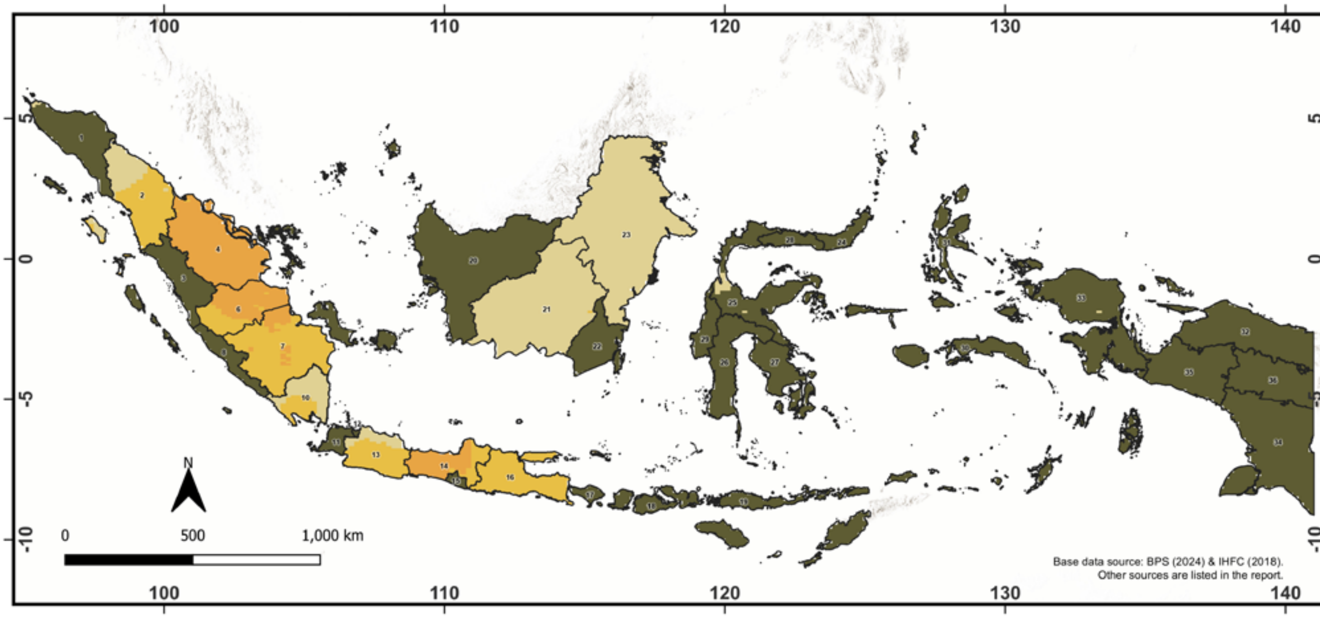
A High Priority

Based on 2023 production capacity in the nation's provinces, the highest baseline thermal demand for process heating (**Figure 4.37**), and the location of quality geothermal resources, agricultural applications such as timber drying, fruit and vegetable preservation, food dehydrating, and sugarcane and potato processing have been identified as early targets for piloting direct-use technologies. Deploying geothermal for process heating in agriculture and dairy offers a lot of potential to support local economies and national commodity production. The following six provinces are the most suitable because of the combination of solid demand and shallow geothermal resources (**Figures 4.28** and **4.37**):[57]

- **Riau:** timber drying, fruit and vegetable preservation, fish curing and drying
- **Central Java:** fruit and vegetable preservation, dairy processing
- **Jambi:** timber drying
- **South Sumatra:** fish curing and drying
- **East Java:** dairy processing
- **West Java:** fish curing and drying

The necessary and logical next step is to conduct detailed feasibility studies for these commodity processes in their respective provinces.

SUITABILITY FOR AGRICULTURE AND DAIRY PROCESS HEATING ACROSS INDONESIA



Potential for Agriculture and Dairy

- Excellent
- Very Good
- Good
- Poor
- Very Poor

NO	PROVINCE	POTENTIAL	NO	PROVINCE	POTENTIAL	NO	PROVINCE	POTENTIAL	NO	PROVINCE	POTENTIAL
1	Aceh	Very Poor	10	Lampung	Poor	19	East Nusa Tenggara	Very Poor	28	Gorontalo	Very Poor
2	North Sumatra	Good	11	Banten	Very Poor	20	West Kalimantan	Very Poor	29	West Sulawesi	Very Poor
3	West Sumatra	Very Poor	12	DKI Jakarta	Very Poor	21	Central Kalimantan	Poor	30	Maluku	Very Poor
4	Riau	Very Good	13	West Java	Good	22	South Kalimantan	Very Poor	31	North Maluku	Very Poor
5	Riau Islands	Very Poor	14	Central Java	Very Good	23	East Kalimantan and North Kalimantan	Poor	32	Papua	Very Poor
6	Jambi	Very Good	15	DI Yogyakarta	Very Poor	24	North Sulawesi	Very Poor	33	West Papua and Southwest Papua	Very Poor
7	South Sumatra	Good	16	East Java	Good	25	Central Sulawesi	Very Poor	34	South Papua	Very Poor
8	Bengkulu	Very Poor	17	Bali	Very Poor	26	South Sulawesi	Very Poor	35	Central Papua	Very Poor
9	Bangka Belitung Islands	Very Poor	18	West Nusa Tenggara	Very Poor	27	Southeast Sulawesi	Very Poor	36	Highland Papua	Very Poor

Figure 4.37: Suitability mapping of each province in Indonesia for agriculture and dairy process heating using geothermal direct use based on the baseline 2023 thermal demand and required depth to reach a subsurface temperature of 50°C. Source: authors' analysis of BPS-Statistics Indonesia data on all provinces; Copernicus Climate Change Service (C3S). (2025). *Thermal comfort indices derived from ERA5 reanalysis* [Data set]. Climate Data Store (CDS); International Heat Flow Commission (IHFC). (n.d.). *The global heat flow database*.

CONCLUSION: KEY PRIORITIES AND IMPLEMENTATION ROADMAP

As this chapter makes clear, there are significant opportunities for geothermal direct-use applications to meet Indonesia's growing thermal energy needs. A clear, phased approach can unlock this potential, focusing on the most promising sectors and locations first.

Key Opportunities

- Residential and commercial cooling is the top priority. Residential and commercial cooling demand is projected to quadruple by 2050 and can be met with mature residential and industrial heat pump technology. The best areas for development are in West Java, East Java, and Central Java.

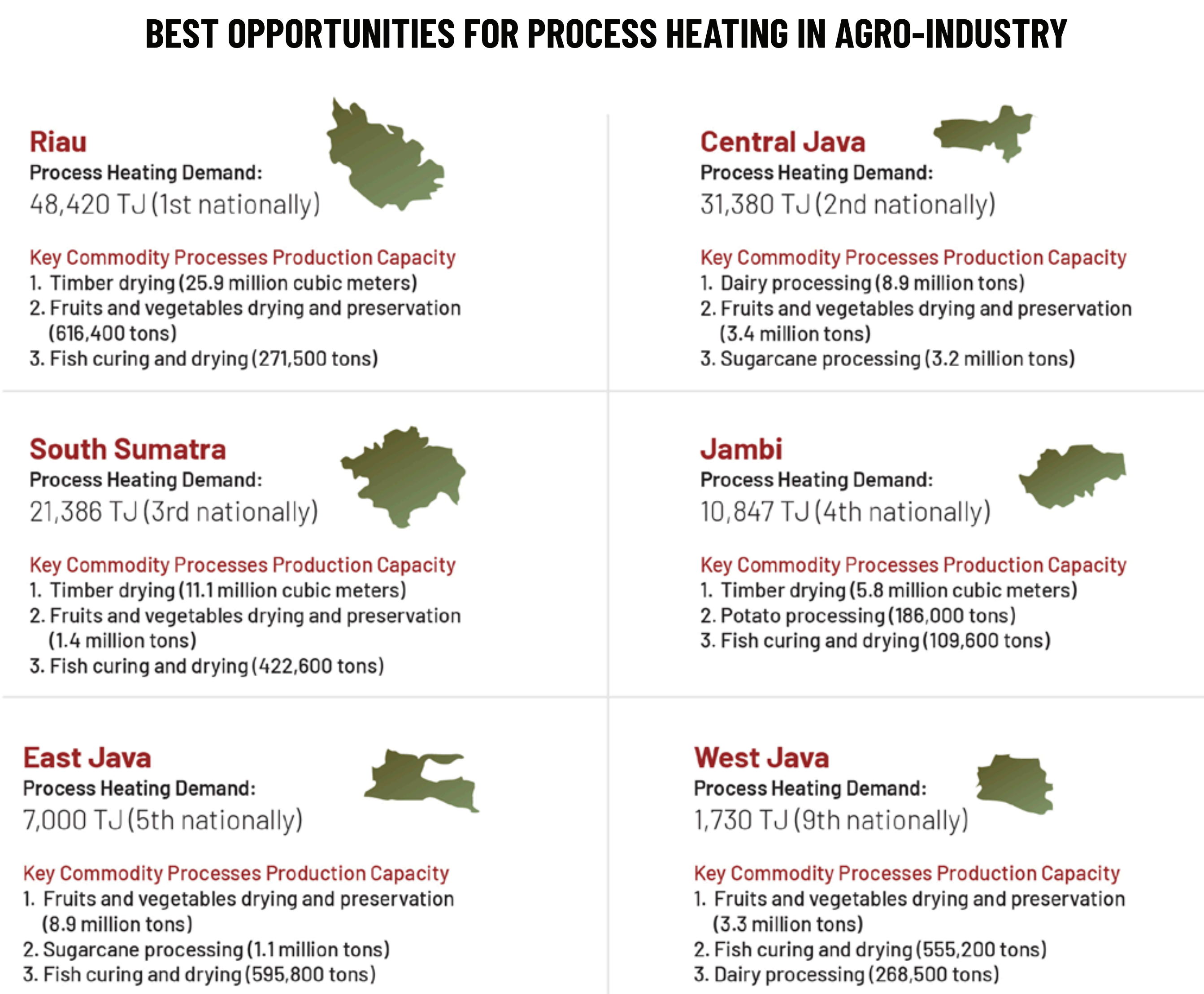


Figure 4.38: High-impact opportunities to implement direct use in agro-industry and dairy operations across six geothermal-rich provinces. Source: BPS-Statistics Indonesia. (2024). *Riau Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jawa Tengah Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Sumatera Selatan Province in figures 2024*; BPS-Statistics Indonesia. (2024). *Jambi Province in figures 2024*; BPS-Statistics Indonesia. (2024). *East Java Province in figures 2024*; BPS-Statistics Indonesia. (2024). *West Java Province in figures 2024*.

PHASED IMPLEMENTATION ROADMAP

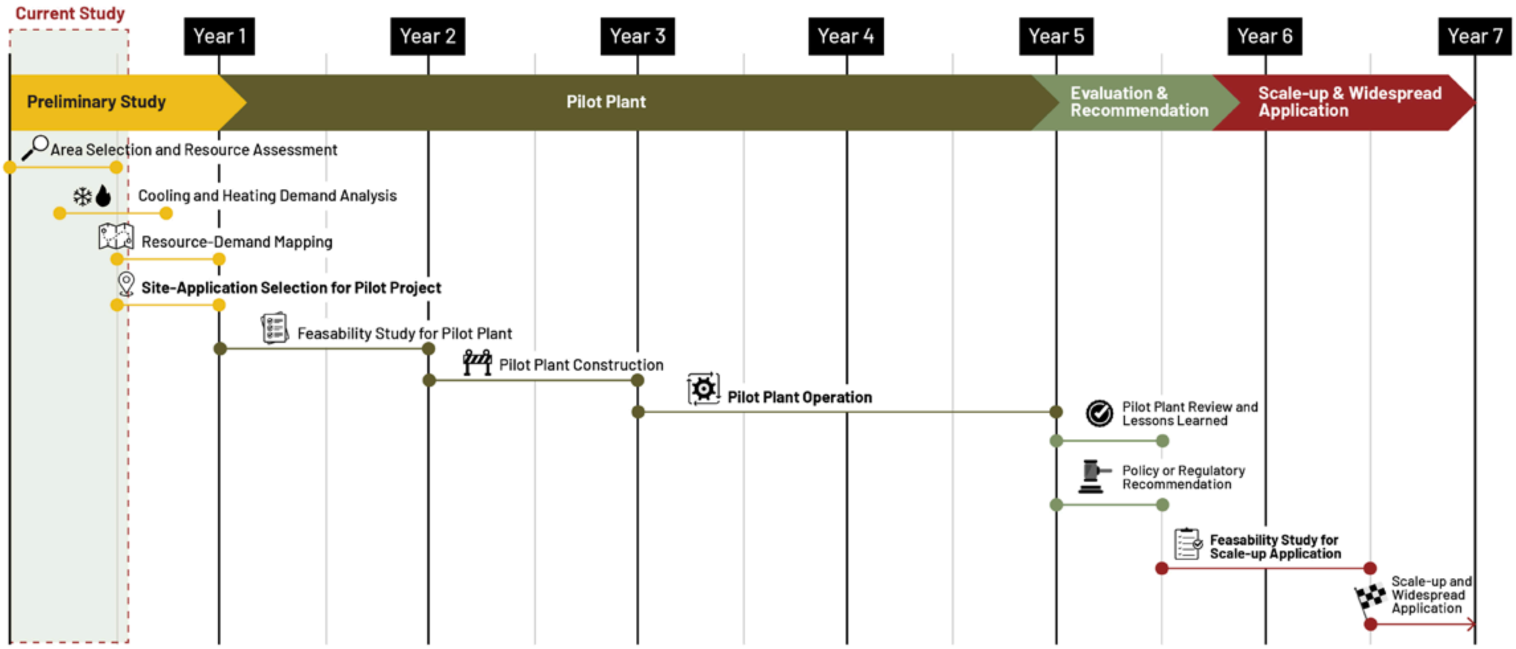


Figure 4.39: Proposed implementation roadmap for geothermal direct use in Indonesia. Source: the authors.

- Agro-industry is a strong second priority. The agriculture and dairy industries have heating needs (up to 150°C) that are well within the range of current industrial heat pump technologies. The most promising provinces for installation include Riau, Central Java, Jambi, South Sumatra, and East Java.

- A proven path to commercialization in agriculture exists. Successful corporate social responsibility projects—such as coffee processing in Kamojang and palm-sugar processing in Lahendong—have demonstrated the potential to transition into full commercial ventures, which is a viable model for initiating new agricultural geothermal projects.

A Phased Implementation Roadmap

To translate these opportunities into reality, the goal is to start with targeted projects, prove their viability, and then scale up nationally. The entire process is estimated to take approximately seven years (see **Figure 4.39**).

Phase 1: Pilot Projects

Establishing pilot plants in the highest-priority locations will test technical and economic feasibility under real-world conditions. This phase involves detailed site studies, construction, and between one and three years of operation to gather critical data on performance, cost, and reliability. A key focus should be on demonstrating the use of heat pump systems for district cooling (see **Figure 4.40** for an example of preliminary screening for pilot projects) and exploring the use of waste heat from existing geothermal power plants through cascaded systems.

Phase 2: Evaluation and Policy Enablement

Following the pilot phase, results must be thoroughly evaluated so that government leadership, the utility company, geothermal operators, and local communities and stakeholders understand the benefits, challenges, and lessons learned. These insights can then be used in the development of recommendations for policies and regulations that will enable wider adoption and streamline future projects.

Phase 3: National Scale-Up

With successful pilots completed and enabling policies in place, the final phase involves widespread application. The knowledge gained from the pilot projects should be used to conduct feasibility studies for new sites and sectors, driving the national scale-up of geothermal direct-use.

COMPARISON OF THREE HIGH-PRIORITY GEOTHERMAL COOLING SITES

Parameter	Unit	Jakarta, DKI Jakarta	Bekasi, West Java	Yogyakarta, DI Yogyakarta
Population*	People	10,672,100	3,172,833	4,073,907
Area*	km^2	660.98	213.12	3,185.80
Population density*	People/km^2	16,145.87	14,887.54	1,278.77
Average ambient temperature*	°C	27.2	26.5	26.2
Average humidity*	%	74.4	80.2	80
Land use*				
• Industrial area	km^2	6.8	69	2.5
• Hotel	Unit	549	19	1,924
• Tower building	Unit	149	24	127
Cooling demand		Dominant for tower building needs	Dominant for the industrial area needs	Dominant for hospitality facility needs

Figure 4.40: Example of preliminary screening results, summarizing demographic aspects, average temperature, average air humidity, and cooling demand for three high-priority geothermal cooling pilot sites where different types of pilot projects could be implemented. * = The demographic, average temperature, and humidity levels data are annual figures for the year 2023 sourced from the respective BPS (Badan Pusat Statistik)'s websites of each area. Source: BPS. (2024). *DKI Jakarta Province in figures 2024*; BPS. (2024). *Bekasi City in figures 2024*; BPS. (2024). *Yogyakarta City in figures 2024*.

ADDITIONAL SOURCE INFORMATION

Figures 4.12, 4.14, and 4.15 sources: BPS-Statistics Indonesia. (2025). *Estates production by crops, Indonesia (thousand tons), 2024*. Hongyou, L., de la Rue du Can, S., Letschert, V. E., Wong, H. LC, Zhou, N., Wijaya, F., Hidayati, F., & Husodo, D. C. (2024). *Industry decarbonization roadmaps for Indonesia: Opportunities and challenges to net-zero emissions*. Energy Technologies Area, Berkeley Lab; PT Emdeki Utama Tbk. (2023). *Annual report and sustainability report 2023*; Rehfeldt, M., Fleiter, T., & Toro, F. (2018). A bottom-up estimation of the heating and cooling demand in European industry. *Energy Efficiency*, *11*, 1057–1082.

Figure 4.22

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APPENDIX 1

Detailed Methodology for Thermal Demand Data Collection and Analysis

This report used a process-based approach to analyze differences in the thermal energy required per unit of product, known as *process heating energy intensity*, when the same commodity is produced using different technologies. Meanwhile, the thermal applications under the refrigeration, cold storage, and HVAC end-use sectors are further divided based on equipment type. In total, 15 equipment types are considered across these end-use sectors.[58]

The national thermal demand is quantified in terajoules (TJ) based on the fundamental concept of multiplying thermal energy intensity (for heating or cooling) by the quantity of product or equipment (Equation 1). Additionally, quantifying Indonesia's thermal demand requires certain data and assumptions that must be collected and analyzed, as summarized in the Indonesia National Cooling Action Plan. Equation 2 shows the calculation for annual national refrigeration, cold storage, and HVAC cooling demand.

Equation 1

Annual process heating demand (TJ)
= annual production quantity (ton) × unit heat input (TJ/ton)

Equation 2

Annual refrigeration,cold storage,and HVAC cooling demand (TJ)
= unit capacity (TW_th per unit) × annual equipment stock (unit)
× utilization factor (%) × annual runtime (hours) × 3600

This study estimates the portion of Indonesia's thermal demand that can be technically replaced by geothermal direct use—specifically, heat currently supplied by fuel-fired heaters or boilers at temperatures achievable through commercial geothermal technologies (**Figure 4.42**). The methodology is outlined in **Figure 4.41**. Present-day commercial heat pumps can deliver temperatures up to 150°C, with projections reaching 200°C by 2050,[59] suggesting that even high-temperature industrial processes may be decarbonized via geothermal in the future. However, actual implementation depends on feasibility factors beyond temperature—such as cost, site access, and energy system integration.

While geothermal steam, reinjection brine, or idle wells can deliver heat up to 200°C,[60] such sources are site specific and limited to areas with existing geothermal fields. Therefore, this analysis focuses on heat pump applications, which expand geothermal direct use potential beyond traditional systems. Heat pumps can operate with subsurface temperatures as low as 20°C–25°C to provide process heat up to 75°C[61] or to support residential and commercial HVAC systems with cooling temperatures of 15°C–25°C.[62] Higher heat demands (e.g., 150°C) may require subsurface temperatures around 70°C, which is achievable at depths of approximately 1.5 kilometers in

HOW TO CALCULATE TECHNICALLY REPLACEABLE THERMAL DEMAND BY GEOTHERMAL

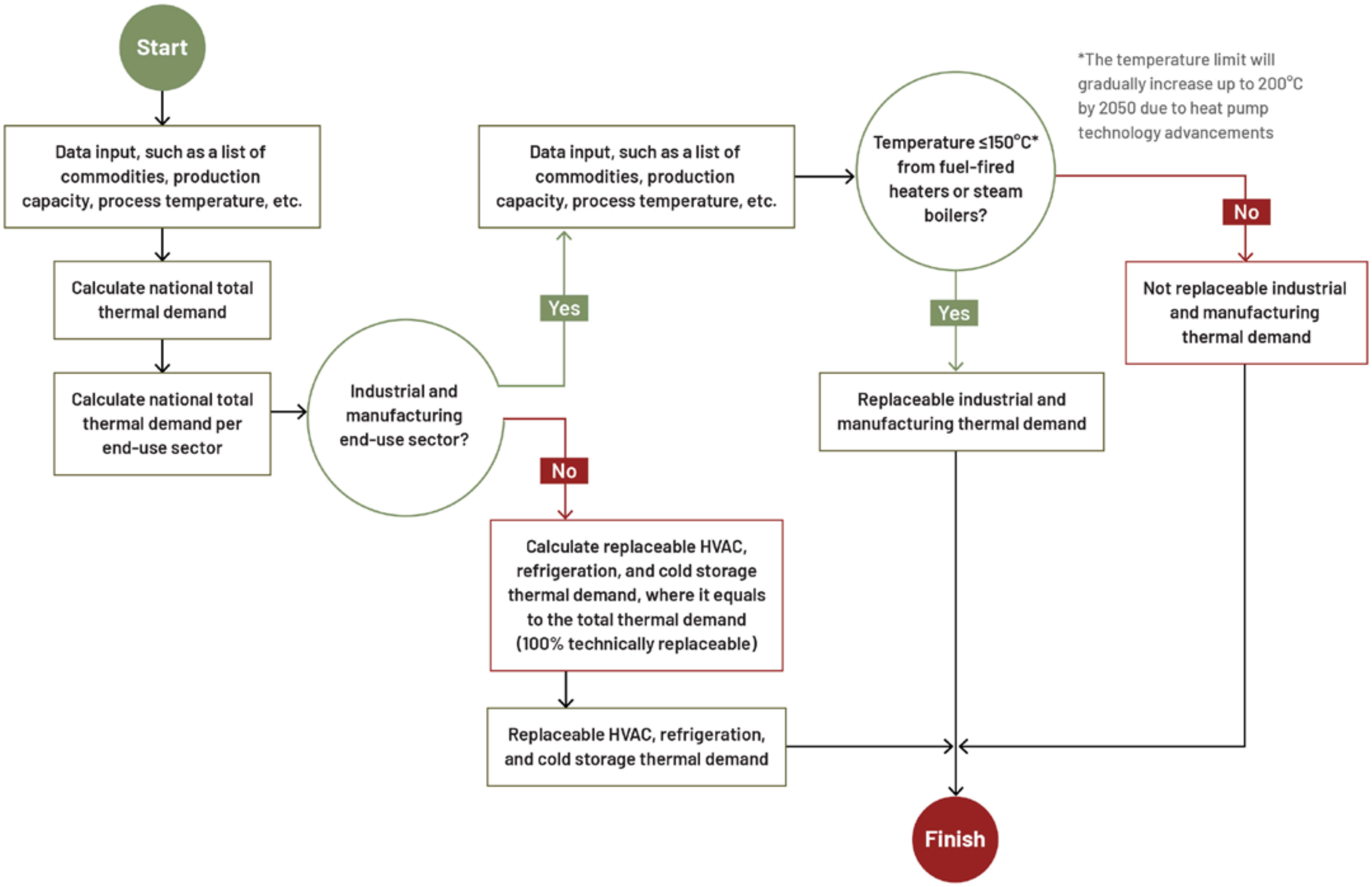

Figure 4.41: Simplified workflow used to calculate technically replaceable thermal demand by geothermal direct use. Source: the authors; International Energy Agency (IEA). (2022). *The future of heat pumps*.

GEOTHERMAL-DRIVEN TECHNOLOGIES FOR REPLACING THERMAL DEMAND

End-Use Sector	Required Output Temperature	Thermal Demand Replacement Technology	Output Temperature Capability for Commercial Technologies	Required Minimum Heat Source/Sink Temperature	Source
Industrial and manufacturing process heating	15°C to higher than 1,000°C	Industrial heat pumps driven by closed-loop geothermal	Current: up to 100°C 2030: up to 150°C 2040: up to 200°C	Heat source: 25°C for output ≤ 100°C 70°C for output > 100°C–150°C 150°C for output > 200°C	IEA, 2022
Refrigeration and cold storage	From 15°C down to freezing levels	Ammonia/water mixture-based absorption coolers driven by closed-loop geothermal	-60°C to 25°C	Heat source: 80°C	Office of Energy Efficiency and Renewable Energy, 2024
Residential and commercial HVAC	15°C–25°C	Heat pumps driven by closed-loop geothermal (ground source heat pump)	15°C to 25°C	Heat sink: 25°C	Paul & Kumar, 2025

Figure 4.42: Assumed suitable geothermal-driven technologies for replacing thermal demand with geothermal direct use. Sources: International Energy Agency (IEA). (2022). *The future of heat pumps*. IEA; Office of Energy Efficiency and Renewable Energy. (2024). *CHP technologies: Absorption chillers* [Combined Heat and Power Technology Fact Sheet series]. U.S. Department of Energy; Paul, S. D., & Kumar, K. R. (2025). *Advancements in adsorption bed for cooling applications: A comprehensive review of configurations and operating parameters*. *Renewable and Sustainable Energy Reviews, 211*, 115301.

regions with strong geothermal gradients,[63] typical of what is found throughout Indonesia, meaning that heat pumps offer a viable, scalable pathway to broaden geothermal direct use across the archipelago.

For refrigeration, cold storage, and HVAC, the replaceable thermal demand is considered to equal the entire cooling demand. This assumes that the full range of cooling temperatures can be met by various commercially available cooling technologies, such as ground source heat pumps for air-conditioning output temperatures between 15°C and 25°C and ammonia/water mixture-based absorption chillers for cooling output temperatures ranging from 10°C down to freezing levels.[64] Equations 3 and 4 show how to calculate replaceable thermal demand.

Equation 3

Replaceable process heating demand (TJ) = heat input from fuel combustion or steam (TJ) × proportion of heat input within the process temperatures achievable by commercial industrial heat pumps (%)

Equation 4

Replaceable refrigeration, cold storage, and HVAC cooling demand (TJ) = refrigeration, cold storage, and HVAC cooling demand (TJ)

INDUSTRIAL AND MANUFACTURING PROCESS HEATING DATA AND ASSUMPTIONS

Baseline 2023 Process Heating Parameters

Target Industry	Process	Industry Production		Process Heat Demand by Heater Type						Portion of Process Heat Demand by Temperature							
		Quantity (ton)	Reference	Fuel-Fired[a] (TJ/ton)	Steam[a] (TJ/ton)	Gross Electricity[a] (TJ/ton)	Portion of Electricity for Process Heating	Net Electricity[b] (TJ/ton)	Reference	>15°C to 75°C	>75°C to 100°C	>100°C to 150°C	>150°C to 200°C	>200°C to 500 °C	>500 to 1000°C	>1000°C	Reference
Non-metallic minerals	Cement manufacturing—dry clinker calcination	62,000,000	Lu et al., 2024	3.6	-	0.14	0%	0.00	Lu et al., 2024; Rehfeldt et al., 2017	-	-	-	-	10%	60%	30%	Su et al., 2021; Rehfeldt et al., 2017
Non-metallic minerals	Lime manufacturing	17,822 329	BPS, 2025c	3.7	-	0.14	0%	0.00	Korczak et al., 2022; Rehfeldt et al., 2017	-	-	-	-	-	40%	60%	Su et al., 2021; Rehfeldt et al., 2017
Non-metallic minerals	Flat glass manufacturing	1,261 463	Asahimas Flat Glass, 2024	19.2	-	3.32	0%	0.00	Korczak et al., 2022; Rehfeldt et al., 2017	-	2%	11%	11%	43%	12%	22%	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Ammonia manufacturing—Synthesis gas	5,800 000	USGS, 2024; Lu et al., 2024	37.0	-	0.48	0%	0.00	Lu et al., 2024; Rehfeldt et al., 2017	-	-	-	-	-	67%	33%	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Ethylene manufacturing	743,000	Chandra Asri, 2024	35.9	-	0.00	0%	0.00	Thiel & Stark, 2021; Rehfeldt et al., 2017	-	-	-	-	-	100%	-	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Methanol manufacturing—Synthesis gas	660,000	HUMI, 2024	7.5	7.5	0.49	0%	0.00	Thiel & Stark, 2021; Rehfeldt et al., 2017	-	-	-	-	-	22%	78%	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Polyethylene manufacturing	650,000	Chandra Asri, 2024	-	0.6	2.04	0%	0.00	Thiel & Stark, 2021; Rehfeldt et al., 2017	-	-	50%	50%	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Polypropylene manufacturing	517,000	Chandra Asri, 2024	-	0.8	1.15	0%	0.00	Thiel & Stark, 2021; Rehfeldt et al., 2017	-	-	50%	50%	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Chemical	Acrylic manufacturing	110,231	ICN, 2023	-	0.0 0418	-	-	-	Turton, 2018	-	-	-	50%	50%	-	-	Turton, 2018)
Chemical	Calcium carbide manufacturing	20,647	MDQ Karbit, 2024	6.1	-	8.32	95%	7.90	Thiel & Stark, 2021; Rehfeldt et al., 2017	-	-	-	-	-	-	100%	Su et al., 2021; Rehfeldt et al., 2017

Target Industry	Process	Industry Production		Process Heat Demand by Heater Type						Portion of Process Heat Demand by Temperature							
		Quantity (ton)	Reference	Fuel-Fired[a] (TJ/ton)	Steam[a] (TJ/ton)	Gross Electricity[a] (TJ/ton)	Portion of Electricity for Process Heating	Net Electricity[b] (TJ/ton)	Reference	>15°C to 75°C	>75°C to 100°C	>100°C to 150°C	>150°C to 200°C	>200°C to 500 °C	>500 to 1000°C	>1000°C	Reference
Pulp and paper	Paper-making—Mechanical	1,765,755	FAO, 2025; Lu et al., 2024	-	1.2	7.92	1%	0.08	Lu et al., 2024; Rehfeldt et al., 2017	50%	50%	-	-	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Pulp and paper	Paper-making—Chemical	15,891,794	FAO, 2025; Lu et al., 2024	-	12.7	2.30	1%	0.02	Lu et al., 2024; Rehfeldt et al., 2017	-	-	50%	50%	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Basic metal	Iron and steel-making—Blast furnace	6,460,000	World Steel Association, 2025; Lu et al., 2024	20.0	-	0.60	0%	0.00	Lu et al., 2024; Rehfeldt et al., 2017	-	-	-	-	3%	20%	77%	Su et al., 2021; Rehfeldt et al., 2017
Basic metal	Iron and steel-making—Electric arc furnace	10,540,000	World Steel Association, 2025; Lu et al., 2024	-	-	2.28	95%	2.17	Lu et al., 2024; Rehfeldt et al., 2017	-	-	-	-	-	10%	90%	Su et al., 2021; Rehfeldt et al., 2017
Basic metal	Copper manufacturing	3,999,565	BPS, 2025b	8.0	-	2.79	20%	0.56	Dutta et al., 2022; Rehfeldt et al., 2017	-	-	-	-	-	-	100%	Su et al., 2021; Rehfeldt et al., 2017
Basic metal	Aluminum manufacturing	215,000	BN Nasional, 2024	5.2	-	53.64	5%	2.68	Dutta et al., 2022; Rehfeldt et al., 2017	-	-	-	-	-	100%	-	Su et al., 2021; Rehfeldt et al., 2017
Basic metal	Zinc manufacturing	18	The Global Economy.com, 2025	1.0	-	1.59	10%	0.16	Dutta et al., 2022; Rehfeldt et al., 2017	-	-	-	-	-	-	100%	Su et al., 2021; Rehfeldt et al., 2017
Textiles	Textile dyeing, printing, and finishing	1,837,760	DPR RI, 2024	-	39.4	4.38	1%	0.04	Farhana et al., 2022; Lu et al., 2024	60%	40%	-	-	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Petroleum and coal products	Oil refining	34,935,150	MEMR, 2024b	0.2	-	-	-	-	Su et al., 2021; Rehfeldt et al., 2017	-	-	-	-	-	100%	-	Su et al., 2021; Rehfeldt et al., 2017

Target Industry	Process	Industry Production		Process Heat Demand by Heater Type						Portion of Process Heat Demand by Temperature							
		Quantity (ton)	Reference	Fuel-Fired[a] (TJ/ton)	Steam[a] (TJ/ton)	Gross Electricity[a] (TJ/ton)	Portion of Electricity for Process Heating	Net Electricity[b] (TJ/ton)	Reference	>15°C to 75°C	>75°C to 100°C	>100°C to 150°C	>150°C to 200°C	>200°C to 500 °C	>500 to 1000°C	>1000°C	Reference
Petroleum and coal products	Carbon black manufacturing	130,000	Ardyansa, 2022	64.8	-	-	-	-	Su et al., 2021; Rehfeldt et al., 2017	-	-	-	-	-	-	100%	Su et al., 2021; Rehfeldt et al., 2017
Agriculture and dairy	Dairy processing	2,743,200	Foreign Agricultural Service, 2024	-	1.6	0.53	5%	0.03	Su et al., 2021; Rehfeldt et al., 2017	45%	45%	7%	3%	-	-	-	Su et al., 2021; Rehfeldt et al., 2017
Agriculture and dairy	Sugarcane processing	869,030	BPS, 2025a	-	4.5	-	-	-	Su et al., 2021; Rehfeldt et al., 2017	5%	5%	30%	30%	0%	30%	-	Su et al., 2021; Rehfeldt et al., 2017
Agriculture and dairy	Coffee processing	758,730	BPS, 2024a	-	0.0039	0.0004	100%	0.0004		90%	10%	-	-	-	-	-	(BPS, 2024a)
Agriculture and dairy	Tobacco processing	272,175	BPS, 2025a; DPR RI, 2016	-	2.8	3.65	5%	0.18	Wismilak, 2024; Rehfeldt et al., 2017	-	-	40%	40%	20%	-	-	Cozzani, et al., 2020
Agriculture and dairy	Tea processing	116,510	BPS, 2024b	-	0.0 0126	0.0036	50%	0.0018		90%	10%	-	-	-	-	-	BPS, 2024b
Agriculture and dairy	Timber Processing	49,406,100	BPS, 2024c	-	0.0 0187	-	-	-	Meng et al., 2019; Carey, 2018	-	10%	80%	10%	-	-	-	Meng et al., 2019; Carey, 2018)
Agriculture and dairy	Palm and brown sugar processing	156,124	BPS, 2025a	-	0.00 015	-	-	-	Kurniawan et al., 2024	90%	10%	-	-	-	-	-	Kurniawan et al., 2024

Notes:
a. It is assumed that 100% is used for process heating and does not include heat generated from cogeneration facilities.
b. This includes electricity demand for purposes other than process heating, such as auxiliary process equipment and buildings.
c. This includes electricity demand for process heating only.
- = 0%, meaning that the commodity requires 0% process heat within the temperature range with the dash.

Figure 4.43: Industrial and manufacturing process heating data and assumptions.

FORECAST 2050 PROCESS HEATING PARAMETERS

Target Industry	Process	Annual Production Quantity Linear Growth Rate	Annual Heat Input Linear Reduction Rate (Efficiency Improvement)	Reference	Remarks
Non-metallic minerals	Cement manufacturing—Dry clinker calcination	1.8%	0.7%	Lu et al., 2024	-
Non-metallic minerals	Lime manufacturing	2.6%	2.1%	BPS, 2025c; IEA, n.d.	-
Non-metallic minerals	Flat glass manufacturing	5.5%	2.1%	Asahimas Flat Glass, 2024; IEA, n.d.	-
Chemical	Ammonia manufacturing—Synthesis gas	0.6%	0.8%	USGS, 2024; Lu et al., 2024	-
Chemical	Ethylene manufacturing	-1.7%	1.7%	Chandra Asri, 2024; CEIC, n.d.	The historical production quantity from 2020 to 2023 showed a declining trend.
Chemical	Methanol manufacturing—Synthesis gas	6.4%	1.7%	HUMI, 2024; CEIC, n.d.	
Chemical	Polyethylene manufacturing	-1.2%	1.7%	Chandra Asri, 2024; CEIC, n.d.	The historical production quantity from 2020 to 2023 showed a declining trend.
Chemical	Polypropylene manufacturing	-0.8%	1.7%	Chandra Asri, 2024; CEIC, n.d.	The historical production quantity from 2020 to 2023 showed a declining trend.
Chemical	Acrylic manufacturing	2.9%	1.7%	ICN, 2023; CEIC, n.d.	
Chemical	Calcium carbide manufacturing	1.2%	1.7%	MDQ Karbit, 2024; CEIC, n.d.	
Pulp and paper	Papermaking—mechanical	24.8%	1.8%	FAO, 2025; Lu et al., 2024	
Pulp and paper	Papermaking—chemical	1.4%	0.9%	FAO, 2025; Lu et al., 2024	It is predicted that the total share of chemical papermaking will decline in the future, in contrast to mechanical papermaking.
Basic metal	Iron and steel-making—Blast furnace	-1.75%	0.5%	World Steel Association, 2025; Lu et al., 2024	It is predicted that the total share of steel produced using blast furnaces will decline in the future, in contrast to steel produced using electric furnaces.

Target Industry	Process	Annual Production Quantity Linear Growth Rate	Annual Heat Input Linear Reduction Rate (Efficiency Improvement)	Reference	Remarks
Basic metal	Iron and steel-making—Electric arc furnace	6.2%	1.0%	World Steel Association, 2025; Lu et al., 2024	
Basic metal	Copper manufacturing	5.3%	2.1%	BPS, 2025b; IEA, n.d.	
Basic metal	Aluminum manufacturing	3.0%	2.1%	BN Nasional, 2024; IEA, n.d.	
Basic metal	Zinc manufacturing	-1.4%	2.1%	The Global Economy.com, 2025; IEA, n.d.	The historical production quantity from 2020 to 2023 showed a declining trend.
Textiles	Textile dyeing, printing, and finishing	6.7%	1.6%	DPR RI, 2024; IEA, n.d.	
Petroleum and coal products	Oil refining	1.2%	2.1%	MEMR, 2024b; IEA, n.d.	
Petroleum and coal products	Carbon black manufacturing	6.3%	2.1%	Ardyansa, 2022; IEA, n.d.	
Agriculture and dairy	Dairy processing	9.7%	2.1%	Foreign Agricultural Service, 2024; IEA, n.d.	
Agriculture and dairy	Sugarcane processing	9.4%	2.1%	BPS, 2025a; IEA, n.d.	
Agriculture and dairy	Coffee processing	1.0%	2.1%	BPS, 2024a; IEA, n.d.	
Agriculture and dairy	Tobacco processing	2.8%	2.1%	BPS, 2025a; DPR RI, 2016	
Agriculture and dairy	Tea processing	0.4%	2.1%	BPS, 2024b; IEA, n.d.	
Agriculture and dairy	Timber processing	18.3%	2.1%	BPS, 2024c; IEA, n.d.	
Agriculture and dairy	Palm and brown sugar processing	3.6%	2.1%	BPS, 2025a; IEA, n.d.	

Figure 4.44: Forecast 2050 process heating parameters.

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APPENDIX 2

Eligible Indonesian Business Classification (KBLI) Codes to Obtain Direct-Use Business Permits

KBLI Code	KBLI Title	KBLI Description
01640	Selection of Plant Seeds for Development	Includes all post-harvest activities aimed at improving the development of seed quality through sifting of non-seed material, seeds that are too small, mechanically damaged seeds or damage to seeds due to insects and immature seeds, as well as keeping seed moisture to a safe condition. storage of seeds. This activity includes drying, cleaning, sorting and so on until the seeds are marketed. The maintenance of modified seeds is also included here.
10211	Fish Salt / Drying Industry	Includes the business of processing and preserving fish (finned / pisces) through the salting / drying process, such as salted tembang fish, salted anchovies and dried fresh fish.
10291	Other Biota Water Salting / Drying Industry	Includes the business of processing and preserving crustaceans, molluscs, echinoderms and other aquatic biota through salting / drying processes, such as salted shrimp, salted squid, dried shrimps, salted jellyfish, salted cuttlefish, dried sea cucumbers, dried cuttlefish, and others.
10313	Fruit and Vegetable Drying Industry	Includes the preservation of fruits and vegetables by drying, whether in packaged form or not, such as raisins (grapes), shallots, garlic, dried chilies, dried bamboo shoots and dried mushrooms. Including the fruit and vegetable chips industry.
10510	Fresh and Cream Milk Processing Industry	Includes the fresh liquid milk processing industry, pasteurized, sterilized, homogenized and / or ultra-heating (UHT) milk and the cream processing industry from fresh liquid milk, pasteurization, sterilization and homogenization, in liquid or semi-liquid form and other similar products.
10722	Brown Sugar Industry	Includes the business of making brown sugar in the form of mold, powder / granule or liquid, which is pure from sap as raw material, both from sugar cane and palm trees (sugar palm, coconut and the like).
10733	Manufacture of Sweet Fruits and Dry Vegetables	Includes the preservation of fruits and vegetables, both fruits, nuts, fruit skins and other parts of plants by sweetening and drying processes, whether in packaged form or not, such as candied nutmeg and dried mango, vegetables and other dried fruits.
10761	Coffee Processing Industry	Includes the business of roasting, grinding and extracting (processing) coffee into various types of powder or liquid, such as roasted coffee, ground coffee, instant coffee, coffee extract and essence.
10763	Tea Processing Industry	Includes the business of processing tea leaves into tea. Including activities of blending tea and mat, extraction and processing industry based on tea and mat.
12091	Drying and Tobacco Processing Industry	Includes the tobacco leaf drying business by smoking or by other means including the tobacco leaf chopping business.

KBLI Code	KBLI Title	KBLI Description
15111	Skin Preservation Industry	Includes the preservation of skins originating from large animals, small animals, reptiles, fish and other animals, whether done by drying, salting or acidifying, such as large animal skins (cow, buffalo), small animal skins (sheep, goats), reptile skins (crocodiles, snakes, monitor lizards), fish skins (stingrays, sharks, snappers, eels) and other animal skins.
16102	Wood Preservation Industry	Includes wood preservation by drying wood, chemical processing and soaking wood with preservatives or other materials.
17011	Paper Industry (Pulp)	Includes businesses making pulp from wood or other fibers and / or used paper. Its activities include the bleached, partially bleached or unbleached pulp industry either through mechanical, chemical (dissolving or non-dissolving), or semi-chemical processes, the cotton-linters pulp industry and the removal of ink and the pulp industry from used paper.
20294	Essential Oil Industry	Includes businesses in the manufacture of essential oils, such as ginger oil, keningar oil, coriander oil, clove oil, kapol oil, nutmeg oil, jasmine oil, cananga oil, rose oil, vetiver oil, lemongrass oil, patchouli oil, sandalwood oil, oil eucalyptus oil, candy oil, spice oil, castor oil and oil from grasses / shrubs, leaves and wood which are not included in any group.
93221	Natural Bath / Hot Spring / Waterfall	Includes a business that provides a place and facilities for bathing using hot water and / or a waterfall as a main business and can be complemented by the provision of food and drink services and accommodation.
93231	Agrotourism	Includes an effort to manage tourist attractions by utilizing agricultural areas which include food crops and horticulture, plantations, fisheries and livestock as the main business and can be equipped with the provision of various types of facilities including food and drink services and accommodation. The types of activities include production, collection, conservation, processing, and cultural activities of the community.

Source: BPS. (n.d.). *Indonesian Standard Classification of Business Fields (KBLI) 2020*.

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57 The priorities presented in this report were determined using the Analytical Hierarchy Process (AHP), a structured framework for decision-making. This established method allowed for a systematic evaluation of potential geothermal applications by comparing both qualitative and quantitative factors. The AHP model incorporated six main criteria to ensure a comprehensive assessment: suitable industry (thermal demand), geothermal resource availability, economic considerations (savings/cost), environmental and social safeguards, technology risk, and regulations and incentives.

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Chapter 5

Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions

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Purnomo Yusgiantoro Center

Nearly all of the existing strengths of Indonesia's oil and gas operations can be adapted to suit geothermal development needs. This is a huge asset for Indonesia, as reaching the goals outlined in this report could yield more than 650,000 jobs, many of which could come from the oil and gas workforce.

Indonesia's energy sector is currently undergoing a significant transformation as the country aims to reduce its reliance on fossil fuels. A key component of this transformation is the expansion of renewable energy, particularly geothermal power. The nation's geothermal resources offer abundant opportunities for expanded conventional power generation, next-generation systems, direct-use industrial heat, and geothermal-based cooling.

In fact, Indonesia has some of the best geothermal potential in the world, estimated at approximately 23.7 gigawatts of conventional resources[1] and 2,160 gigawatts of next-generation geothermal potential. (See Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities"). This potential places the nation in a uniquely favorable position to develop geothermal energy on a large scale. As of September 2025, the installed capacity of geothermal electricity was 2,744 megawatts, meaning only 11.5% has been utilized from the country's conventional resources. Indeed, Indonesia could reach a goal of 15 gigawatts of geothermal electricity and 15 gigawatts thermal of geothermal heat by 2035—and 25 gigawatts of electricity and 35 gigawatts thermal use by 2045 (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," Recommendation #2). And reaching these goals could lead to more than 650,000 new jobs in Indonesia.

Resource availability, however, is only part of the story: The significant overlap in skills, technology, and infrastructure with Indonesia's historic oil, gas, and mining industries—and the existing geothermal skill set from the nation's conventional geothermal industry—sets the expansion of geothermal apart from other renewable technologies.

INDONESIA'S CURRENT OIL AND GAS WORKFORCE AND POTENTIAL GEOTHERMAL JOBS

Indonesia has been active in the oil and gas sector since the 1800s. This long-standing commitment has helped build a strong foundation of knowledge, experience, and

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

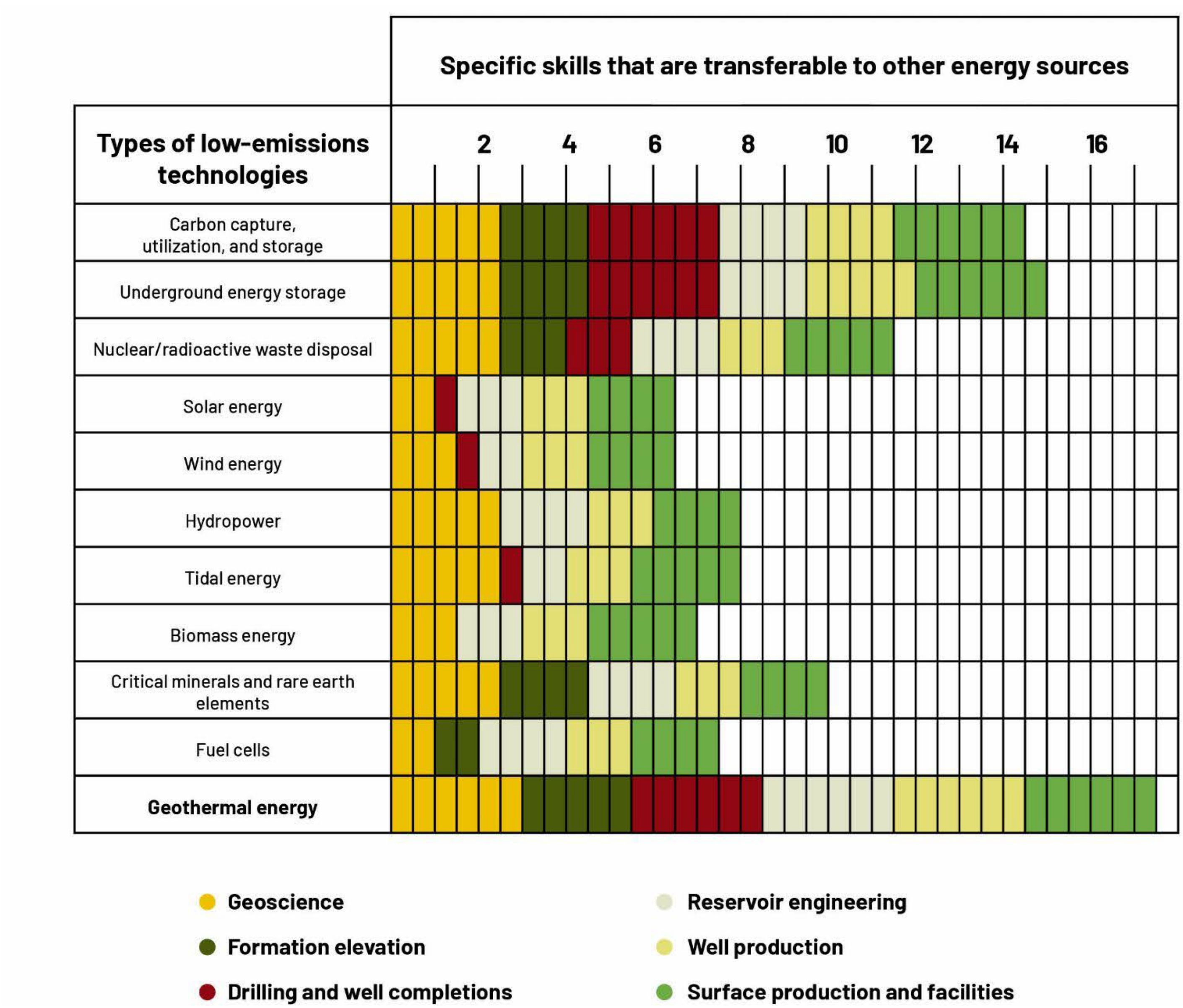

Figure 5.1: Geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). *Oil and gas skills for low-carbon energy technologies*. Society of Petroleum Engineers Annual Technical Conference and Exhibition.

infrastructure in subsurface extraction. Nearly all of the existing strengths of Indonesia's oil and gas operations can be adapted to suit geothermal development needs.[2] This is a huge asset for Indonesia, as it ensures a skilled workforce to help grow the geothermal sector while also maintaining the availability of quality careers for the current oil and gas workforce. This workforce can contribute to not only traditional geothermal power projects but also next-generation geothermal applications, including systems designed for direct industrial heat and thermal storage applications that support cooling and grid stability.

According to data from the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), as of 2023, the oil and gas sector employed 18,627 Indonesian workers.[3] The oil and gas workforce has many applicable skills for the geothermal sector, in areas ranging from geoscience to drilling and well completion as well as reservoir engineering and well production (see **Figure 5.1**). Proper retraining and reorientation can expand this existing talent pool to allow workers to participate in geothermal projects, which would help address emerging labor demands in the renewable energy sector while cushioning potential job losses in fossil fuel industries.

The global oil and gas (O&G) industry faces significant long-term structural challenges, including fluctuating prices, automation, and regulatory shifts driven by decarbonization goals. Indonesia's oil and gas workforce, specifically in upstream operations, began its decline more

POTENTIAL JOB TRANSITIONS FROM OIL AND GAS TO GEOTHERMAL

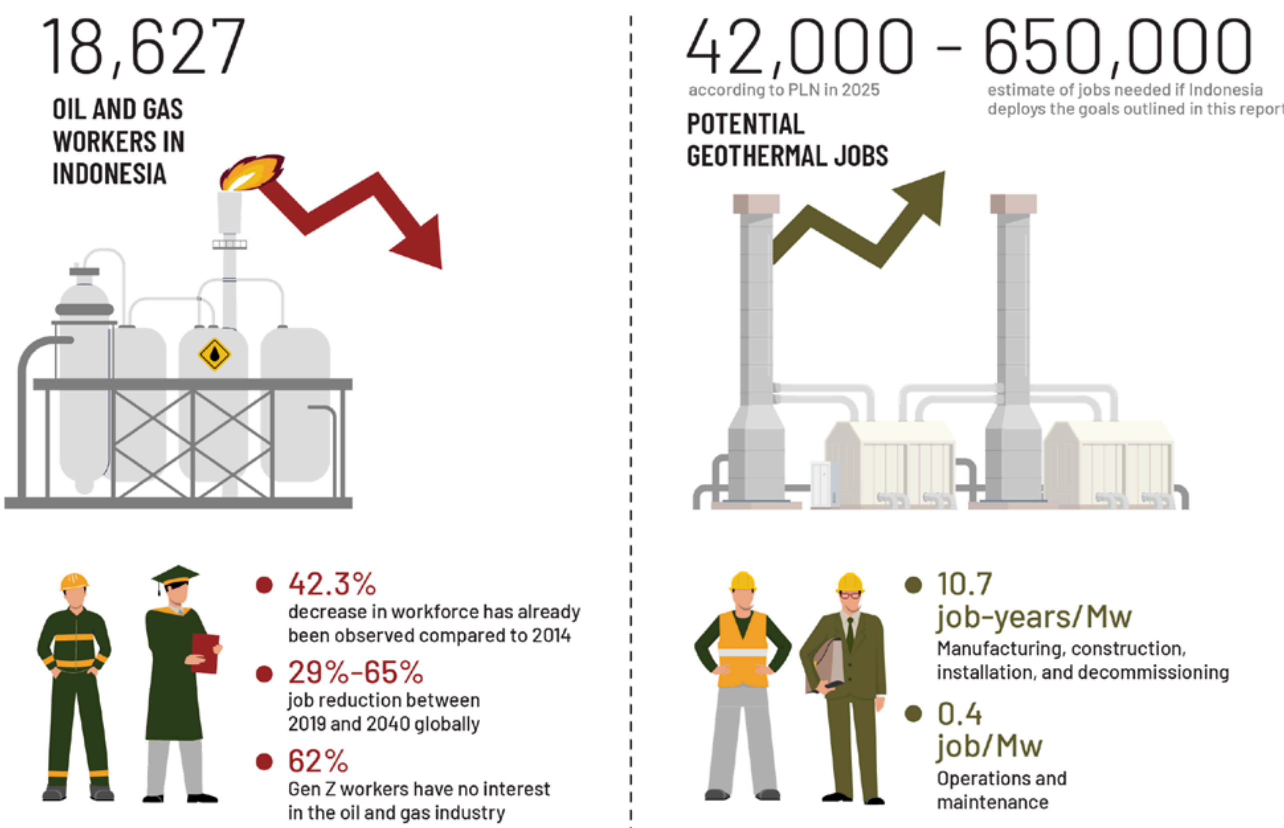

Figure 5.2: Estimated number of potential job transitions from oil and gas to geothermal. Source: Indonesian Petroleum Association. (2017). *Indonesia overview*; Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas). (2023). *Annual report 2023*; Ernst & Young. (2020). *Preparing for the future now: Rethinking the oil and gas workforce in 2040*. EY Global; Halimatussadiah, A., Irhamni, M., Riefky, T., Nur Ghiffari, M., & Razak Afifi, F. A. (2024). *Employment impacts of energy transition in Indonesia*. Institute for Economic and Social Research, University of Indonesia; PLN. (2025). *PLN electricity supply business plan (2025-2034): Enhancing national energy resilience and sustainability*. Government of Indonesia.

than a decade ago, with a total decrease of approximately 42.3% between 2014 and 2023.[4] This number is expected to drop even further if projections are accurate in Indonesia, which could mean a potential loss of between 6,500 and 14,700 additional jobs. This loss of jobs does not account for the accelerating impact of climate change and global decarbonization efforts, both of which will likely drive deeper reductions in the fossil energy global workforce. In contrast, the global O&G workforce experienced short-term recovery, adding approximately 590,000 jobs in 2023 to reach 12.4 million employees, fueled by the development of new projects.[5] However, despite this temporary rebound, long-term projections remain negative: The International Energy Agency's (IEA's) Net Zero Emissions by 2050 Scenario anticipates a decline of 1.7 million O&G jobs by 2030, and broader fossil fuel employment is expected to fall from 12.6 million to 3.1 million by 2050, underscoring the sector's ongoing structural contraction.[6]

PwC's 2015 oil and gas industry survey found that most respondents expected a decline in employment opportunities and workforce quality.[7] At the same time, Indonesia's government support for the O&G sector remains strong, and interest among fresh graduates is still relatively high—largely due to the industry's competitive salaries.

With abundant resources, the geothermal industry in Indonesia has significant potential for growth. As the country scales to meet energy transition targets, the Ministry of Energy and Mineral Resources (MEMR) estimates that geothermal development will create more than 4,000 new jobs; PLN estimates the number could be as high as 42,000. While these figures are not explicitly tied to specific gigawatt deployment targets (see Chapter 2, "Powering the Transition: Indonesia's Geothermal Market"), they reflect the government's evolving geothermal development plans. Career fields within MEMR's report include site exploration, drilling, plant construction, system installation, and long-term operation and maintenance. And if the bulk of the nation's geothermal resources were put to work, Project InnerSpace projects a figure far higher, upwards of 650,000 new jobs. (**Figure 5.2**).[8,9]

The geothermal industry has two major phases in which jobs are created: (a) construction and installation and (b) operations and maintenance. The construction and installation phase is labor-intensive, as it involves civil works, mechanical and electrical assembly, logistics, and other related services. This phase generates approximately 10.7 job-years per megawatt, but these jobs are temporary roles.[10] The operations and maintenance phase creates fewer jobs, generating approximately 0.4 sustained positions per megawatt, but these roles tend to be longer-term, permanent positions.[11] Positions created in this phase focus on the management, repair, and optimization of geothermal plants and infrastructure.

If Indonesia achieves its full potential of 23 gigawatts of conventional geothermal electricity generation by 2060 (as identified by MEMR and outlined in the National Electricity General Plan; see Chapter 2, "Powering the Transition: Indonesia's Geothermal Market," for more on national energy targets), the result could be as many as 255,300 jobs generated. This number would be far beyond the number predicted by MEMR and PLN—a trajectory that would depend on sustained year-over-year expansion of geothermal capacity. This number includes approximately 246,100 temporary jobs during the construction and installation phase, as well as at least 9,200 permanent jobs in operations and maintenance once full capacity is reached. This number would soar to more than 650,000 jobs if the nation meets the combined 60 gigawatts electric and thermal generation goal for 2045 (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation"), based on the methodology followed by the Institute for Economic and Social Research at the University of Indonesia and detailed later in this chapter.[12]

Realizing this level of growth, however, will hinge on the availability of skilled labor; research in the Indonesian geothermal sector indicates that personnel shortages and limited applied skill sets already constrain development,[13] underscoring the need to strengthen national workforce readiness.

For this chapter, the Purnomo Yusgiantoro Center (PYC) conducted research to better understand the outlook for geothermal in Indonesia's existing energy sector. Researchers collected primary data via in-depth interviews with industry officials and experts from a cross-section of government agencies, academic institutions, and energy companies, as well as through a survey of recent graduates looking to transition into industry careers (**Figure 5.3**).

The goal of this data collection was to highlight existing engagement in geothermal expansion and training, as well as to examine workforce readiness and general attitudes toward geothermal, whether as institutional opportunity or as potential employment path. Findings from this section provide the empirical basis for the following discussion on institutional engagement and workforce transition.

WORKFORCE TRANSITION: FROM OIL AND GAS, MINING, AND UTILITIES TO GEOTHERMAL

Effective policies developed in collaboration with players from across the industry are foundational for a successful workforce transition. Industry-wide alignment creates strong pathways for training, employee placement, and overall labor mobility. While institutional relationships are currently fragmented and can be difficult to navigate, the country has opportunities to build on existing alignment efforts within the industry and move toward a more cohesive sector-wide strategy.

STUDENT SURVEY RESPONDENTS

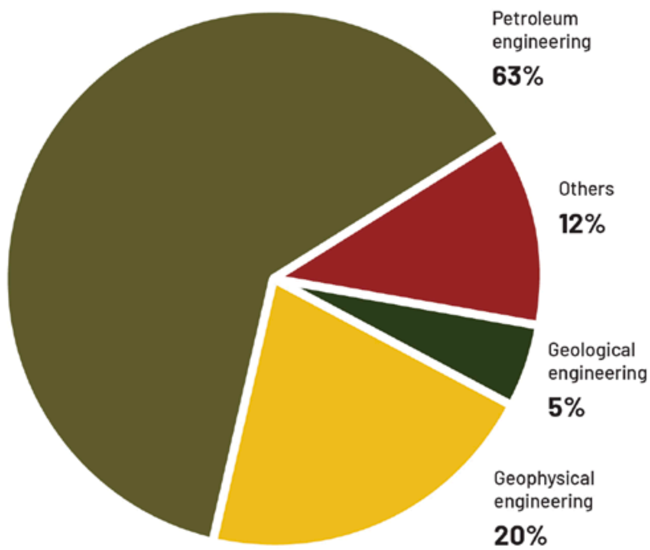

Figure 5.3: Breakdown of student survey respondents by degree. Source: authors.

INSTITUTIONAL WORKFLOW OF MINISTRIES INVOLVED IN WORKFORCE DEVELOPMENT FOR THE ENERGY SECTOR

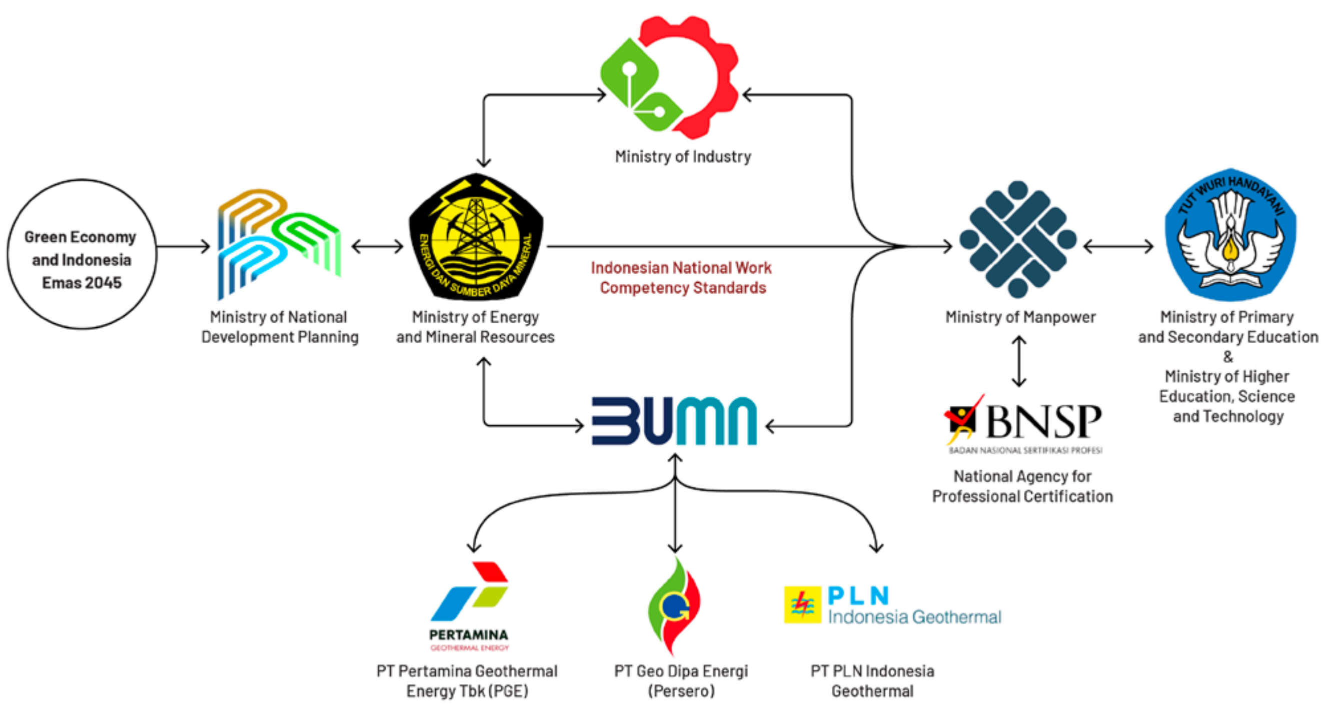

Figure 5.4: Workflow of key institutions involved in energy sector workforce planning and implementation. Source: authors.

A key element of Indonesia's energy transition plan is the development of a green economy, which includes a strong emphasis on renewable, low-carbon energy sources.[14] One tangible step in this direction was the launch of a Green Workforce Development Roadmap by the Ministry of National Development Planning (colloquially known as *Bappenas*) in 2025; this roadmap explicitly aligns with the National Medium-Term Development Plan for 2025–2029.[15] The plan helps guide sectoral strategies such as the National Energy Policy, informs derivative plans such as the National Energy General Plan, and provides the overarching framework for implementation documents such as the National Electricity General Plan and PLN's Electricity Supply Business Plan (see Chapter 2, "Powering the Transition: Indonesia's Geothermal Market"). This alignment reinforces the roadmap's policy legitimacy and firmly connects it to Indonesia's national planning hierarchy. While multiple governmental agencies are responsible for different elements of this long-term economic transformation, two ministries share the foundational work that is key to a successful workforce transition.

Bappenas sets the national strategic direction of environmentally stable employment opportunities—including geothermal—through the formulation of the Green Jobs Roadmap.[16] MEMR, as the primary authority in the energy sector, then translates these strategic targets into practical workforce policies.[17]

Today, the Ministry of Manpower (MoM) collaborates with sector-specific ministries such as MEMR and the Ministry of Industry to manage the development of standards that provide the framework for formal benchmarking across each industry. These standards are then administered through Professional Certification Bodies, under the National Agency for Professional Certification.

Government, industry, and academic experts in each sector develop these standards—Indonesian National Work Competency Standards (INWCS)—in a collaborative process. The sector-specific representatives propose different standards, and a technical committee then drafts the standards to send on for review by the MoM under the Directorate General of Vocational Training and Productivity Development. Once a set of standards is finalized, the standards become law via ministerial decrees. The INWCS provides the formal basis for national recruitment, training, and certification programs. For example, a technician aiming to become a certified steam field operator must complete training based on the relevant INWCS and pass a competency test conducted by an authorized Professional Certification Body.

WORK HAS BEGUN: AN OCCUPATIONAL MAP AND NATIONAL WORK COMPETENCY STANDARDS

An economic transition of this magnitude requires significant planning and coordination. Unfortunately, existing geothermal certification and training programs in Indonesia were not designed to take advantage of the nation's considerable technical capabilities and skills. However, because the sector is already deeply intertwined with Indonesia's oil and gas industry, the country has ample opportunity to course correct and accelerate the transition.

EXISTING WORK COMPETENCY STANDARDS RELATED TO GEOTHERMAL

No.	INWCS Title
1	Geothermal Well Fluid Flow Test Operator and Supervisor
2	Geothermal Steam Field Facilities Operator
3	Geothermal Operations Supervisor
4	Geothermal Geochemistry Expert
5	Geothermal Geology Expert
6	Geothermal Geophysics Expert
7	Steam Field Equipment Maintenance
8	Geothermal Well Fluid Sampling

Figure 5.5: Existing Indonesian National Work Competency Standards (INWCS) relevant to geothermal energy development and operations. The link for each INWCS title provides the corresponding INCWS information.

A clear, updated occupational map for geothermal can significantly ease these efforts by providing an overview of job types, skill requirements, and qualifications required at each stage of geothermal development. This occupational map would then serve as the foundational reference for the INWCS, ensuring that each standard accurately reflects industry roles and emerging workforce needs. Clarity at this level empowers each institution to carry out its mandate.

Some foundational efforts have begun. MEMR, through its Human Resources Development Agency, is developing a policy on human capital development that proposes the formulation of such a national occupational map tailored to clean energy sectors and specifically to geothermal.[18] As of the writing of this chapter, an update to the framework has not yet been published. Once completed, this map will serve as the foundation for the following:

- Occupational equivalency mapping to guide the integration of new workers, including vocational and university graduates, into industry-relevant roles. This mapping should be led by the MoM, with the Ministry of Higher Education, Science and Technology and relevant technical ministries (such as MEMR) as co-leads.
- Workforce demand projections that estimate how many workers will be needed, in what roles, and across which regions. Development of these projects will be coordinated by Bappenas as the lead institution, with MoM and MEMR as co-leads.
- Policy and regulatory recommendations tailored to each institutional partner, such as the Ministry of Manpower for labor protection and training and the Ministry of Higher Education, Science, and Technology for curriculum development.

Additionally, an ad hoc group has made efforts toward labor planning and produced a list of eight geothermal-specific INWCS (see **Figure 5.5**). In parallel, MEMR is working with the Ministry of Industry and the Ministry of State-Owned Enterprises to update and expand existing geothermal INWCS. However, the current certification plans still largely focus on narrow operational roles and do not yet comprehensively address cross-cutting or transitional roles critical to a modern geothermal workforce, such as geothermal project management, environmental permitting, digital instrumentation, or sustainability auditing.

TRANSITIONAL PLATFORMS: GEOTHERMAL WORKING AREAS IN INDONESIA

Out of 63 Geothermal Working Areas (WKPs) in Indonesia, 17 currently have one or more geothermal plants on site in operation. (The others are in various stages of development, exploration, construction, or tender preparation.) These sites can serve as "transitional platforms" where oil and gas skills, technologies, and experience can be deployed. Having these plants in operation means the industry has a lot of valuable knowledge and skills already that can help with expansion (see **Figure 5.1**). Most of these geothermal power plants are operated by companies with direct or historical affiliations to the oil and gas sector.

A 2023 study looking at the role of oil and gas in the geothermal industry highlighted the importance of knowledge transfer and learning in reducing the overall cost of geothermal development in order to leverage economies of scale and drive innovation.[19] The most immediate and practical benefits for an expanded next-generation geothermal industry can come from oil and gas spillovers, given the extensive technological base and accumulated operational experience of the O&G sector. Indonesia can expect to see similar benefits due to the comparable industrial overlap between O&G and geothermal.

Oil and gas companies are uniquely positioned to redeploy skilled O&G professionals into geothermal roles and contribute to the development of industry-specific training, certification, and competency standards. As shown in **Figure 5.6**, most active geothermal fields are operated by companies that originated in or remain connected to Indonesia's oil and gas ecosystem.

In addition to domestic players, global oil field service providers already established in Indonesia are also moving into geothermal work. This international engagement not only offers opportunities for technology and knowledge transfer but also increases competition for skilled local talent, underscoring the urgency of national workforce readiness. Halliburton and Schlumberger (now SLB) are both expanding into geothermal work. SLB acquired GeothermEx in 2010 specifically to focus on geothermal consulting and reservoir engineering.

GEOTHERMAL COMPANIES IN INDONESIA AND THEIR O&G AFFILIATIONS

No.	Geothermal Working Area (WKP)	Geothermal Power Plant (PLTP)	Company	O&G Affiliation
1	Sibayak – Sinabung, Sumatera Utara	Sibayak	PT Pertamina Geothermal Energy Tbk (PGE)	Subsidiary of PT Pertamina (Persero), Indonesia's national oil company
2	Lahendong – Tompaso, Sulawesi Utara	Lahendong		
3	Waypanas – Lampung	Ulubelu		
4	Karaha Bodas – Jawa Barat	Karaha		
5	Lumut Balai – Sumatera Selatan	Lumut Balai		
6	Kamojang – Darajat, Jawa Barat	Kamojang		
		Darajat	PT Star Energy Geothermal Darajat II	Initially operated by Chevron Geothermal, a subsidiary of Chevron Corporation (US)
7	Cibeureum – Parabakti, Jawa Barat	Salak	PT Star Energy Geothermal Salak, Ltd	
8	Pangalengan, Jawa Barat	Wayang Windu	PT Star Energy Geothermal Wayang Windu Ltd.	
		Patuha	PT Geo Dipa Energi (Persero)	Originally a joint venture between Pertamina and PLN
9	Dataran Tinggi Dieng, Jawa Tengah	Dieng		
10	Sibual-Buali – Sumatera Utara	Sarulla	PT Sarulla Operations Ltd (SOL)	A consortium consisting of: 1. Medco Power, owned by Medco Energi, an energy company with O&G roots 2. Inpex Corporation, a Japanese exploration and production company 3. Kyushu Electric Power Company 4. Itochu Corporation 5. Ormat Technologies, Inc.
11	Ulumbu – NTT	Ulumbu	PT PLN (Persero)	None
12	Muara Laboh – Sumatera Barat	Liki Pinangawan, Muara Laboh	PT Supreme Energy	Founders have backgrounds in Pertamina and Total E&P
13	Rantau Dedap – Sumatera Selatan	Rantau Dedap		
14	Sorik Marapi, Sumatera Utara	Sorik Marapi–Roburan–Sampuraga	PT Sorik Marapi Geothermal Power	Major shareholder is PT Supraco Inondeisa, member of Radiant Group, an O&G service company
15	Sokoria, NTT	Sokoria	PT Sokoria Geothermal Indonesia	Minor shareholder is Bakrie Power, member of Bakrie Group
16	Mataloko, NTT	Mataloko	PT PLN (Persero)	None
17	Blawan Ijen, East Java	Ijen	PT Medco Cahaya Geothermal	Subsidiary of PT Medco Power, 25 owned by Medco Energi, an energy company with O&G roots

Figure 5.6: Major geothermal developers in Indonesia and their links to oil and gas parent companies or subsidiaries. Source: Ministry of Energy and Mineral Resources. (2024). *Performance report of the Directorate General of New, Renewable, and Energy Conservation, Ministry of Energy and Mineral Resources, year 2024*. Government of Indonesia.

In 1974, the Volcanological Survey of Indonesia completed a five-year geothermal inventory of Sumatra, Sulawesi, and the Halmahera Islands.[20] At that point, a decree was issued to instruct the national state-owned oil company, Pertamina, to take up the leading role in the development of geothermal energy in Indonesia. With NZ$25 million in aid from the Government of New Zealand, deep exploration drilling was carried out at Darajat and Kamojang beginning that same year. This would lay the foundation for future five-year development plans, which formalized the reduction of dependence on oil in overall consumption and an increase in exploration for renewable energy resources.[21]

In the 1980s, the government ramped up its efforts to explore geothermal use, particularly in the electricity sector. In 1981, another presidential decree allowed Pertamina to enter joint ventures with local and international partners to further develop geothermal fields. Several partners started carrying out detailed exploration and exploitation drilling activities, providing several recommendations for power plant construction,[22] which eventually led to power plants in Darajat and Kamojang coming online in 1983 and 1991, respectively.[23,24]

Today, oil and gas companies operate, in terms of generating capacity, 15% of global geothermal power plants;[25] the other operators are either geothermal developers or energy utility companies. Utility companies hold the higher share at 62%. In Indonesia, 46.4% of geothermal power plants are owned by geothermal developers and independent power producers Star Geothermal Energy, KS Orka, Supreme Energy, and Geo Dipa Energi. The oil and gas companies Pertamina (through its subsidiary Pertamina Geothermal Energy) and MedcoEnergi (through its subsidiary Medco Power Indonesia) own just more than 30% of the nation's geothermal assets. (Medco's subsidiary formed a joint venture with Ormat Technology Inc., known as Medco Cahaya Geothermal.) Medco recently reached a commercial operation date for its 35 megawatt geothermal power plant in Blawan Ijen, East Java.[26] The utility (PLN) and one of its subsidiaries operate 23.5% (see **Figure 5.7**).[27]

The small portion of oil and gas industry ownership of geothermal power plants presents an opportunity.[28] After all, as much as 80% of the requirements for a geothermal project involve capacity and skills that are similar to those in the oil and gas industry. (See **Figure 5.1** to see overlapping skill sets between the oil and gas industry and geothermal development.)

INDONESIA GEOTHERMAL POWER PLANT OWNERSHIP

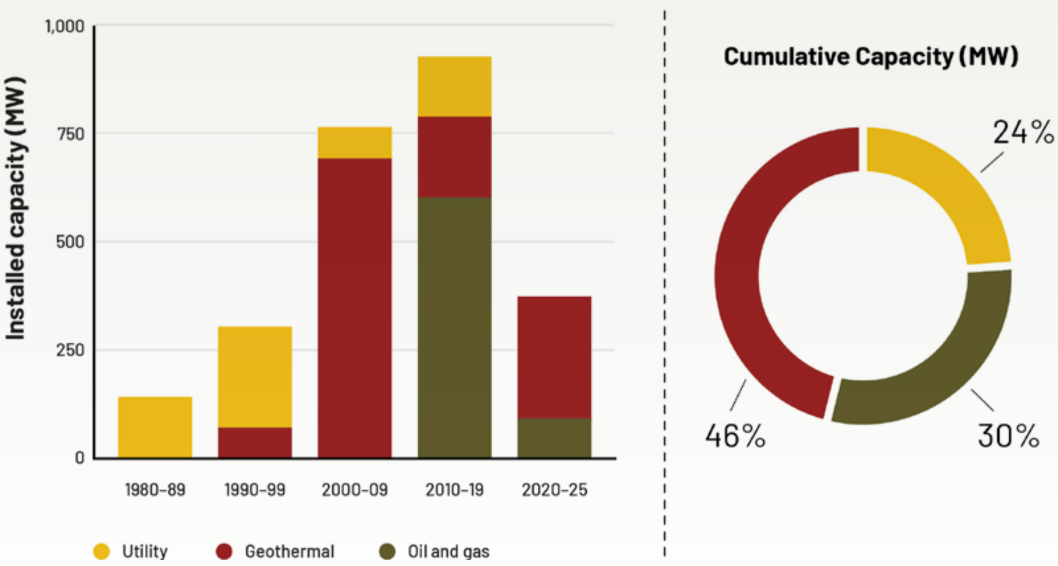

Figure 5.7: Distribution of ownership among public, geothermal, and O&G entities operating geothermal power plants. MW = megawatts. Source: Prepared by IESR using data from Global Energy Monitor. (2025). *Global Geothermal Power Tracker*; company profiles for Geo Dipa Energi, Pertamina Geothermal Energy, PLN and its subsidiaries, Sarulla Operation, Star Geothermal Energy, and Supreme Energy; Directorate General of New, Renewable Energy and Energy Conservation. (n.d.). *GENESIS: Geothermal Energy Information System/*.

Other multinational firms that typically support the O&G sector are in earlier stages of geothermal engagement in Indonesia. Viridien (formerly CGG) supports PGE from its European office and is awaiting further regulatory clarity to expand its local presence. Cegal (Norway), National Energy Services Reunited (Middle East), and Repsol (Spain) are also monitoring developments and preparing geothermal market entry strategies in Indonesia. These emerging international linkages position Indonesia to become a regional hub for geothermal technology and workforce development.

KNOWLEDGE AND SKILL GAPS

Exploration and Resource Characterization

Understanding overlapping technical competencies is essential for designing targeted reskilling programs. Both the oil and gas and geothermal industries need multi-source subsurface data to model and predict geologic conditions. For decades, the oil and gas industry has compiled such data (e.g., seismic, well logs, and core samples).[29] By adopting the same data-centric framework that leverages shared tools, data, and expertise, the geothermal sector can take the risk out of resource assessment and well location targeting.[30] The geothermal industry is also developing high-resolution subsurface data sets and models to guide economical resource development and plant operations.[31] However, to enable next-generation geothermal expansion, Indonesia needs a much broader and accessible subsurface database to guide investment and technology shifts; MEMR's Data and Information Center[32] could play this role.

Today, Indonesia's geothermal data are difficult to access because they are controlled by the state, fragmented across agencies, legally restricted, and poorly digitized. Improving the data's accessibility will be critical to growing the sector.

Data-sharing is further constrained by confidentiality provisions and fragmented ownership among MEMR, SKK Migas, and research institutions, underscoring the need for institutional cooperation to standardize access and reporting. The systematic public release of drilling and performance data from government and pilot programs would accelerate replication, reduce exploration risk, and build the technical foundation for advanced geothermal systems (see Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation").

Drilling and Well Completion

Both the oil and gas and geothermal industries use drilling and well completion technologies. For conventional geothermal, however, engineers need to learn about volcanology systems, which can require additional training in moving higher volumes of fluid than with oil and gas.[33] Geothermal engineers also must, at times, work in higher temperatures (up to 350°C) and harsher environments due to igneous rock.[34]

Stimulation Technologies

In next-generation geothermal, specifically engineered geothermal systems, stimulation technology is used to create additional permeability for accessing heat. Geothermal reservoir stimulation shares techniques with hydraulic fracturing but often targets reactivation of natural fractures rather than the creation of new ones.[35] Operating pressures and induced-seismicity hazards are site- and mechanism-dependent, and although the pressure and associated risks are lower than for oil field operations,[36] the best practice is to design for permeability while managing seismic risk with the use of established monitoring and threshold-based response systems.[37] This type of technology requires additional skill development, which should be introduced across MEMR through its Human Resources Development Agency, in coordination with the Ministry of Higher Education, Science, and Technology to align academic and professional training standards.

Operations and Risk Management

The oil and gas workforce has experience in financing and risk management for subsurface resource development, as well as existing relationships with investors familiar with the requirements of subsurface development. Leveraging these relationships could facilitate additional private sector investment in geothermal projects.[38]

DEVELOPING A NEW WORKFORCE: INTERVIEWS WITH EXPERTS

The interviews PYC conducted with education experts highlighted the broader scope of competency gaps for petroleum engineering graduates looking to transition to geothermal roles. While there are many transferrable skills (e.g., drilling, geomechanics), the scope of oil and gas studies is narrower than what geothermal requires (e.g., heat flow modeling, geothermal chemistry). Knowledge required in the geothermal energy sector includes exploration, exploitation, and downstream use such as electricity generation. As geothermal expands beyond power into industrial heat and cooling, necessary knowledge will include low- and medium-temperature applications, system integration for manufacturing, and building-scale geothermal technologies. **Figure 5.1** illustrates how a new graduate or experienced reservoir engineer's areas of expertise relate to the requirements for a geothermal reservoir engineer.[39]

Today, academic curricula in Indonesia lack coursework and training in key skills such as risk mitigation, project economics, and cross-functional project management—all vital skills in geothermal operations. These gaps highlight the need for curriculum modernization under the Ministry of Higher Education, Science, and Technology's vocational transformation agenda[40] and the Bappenas Green Workforce Development Roadmap.[41] Experienced industry players will have an essential role in guiding curriculum reform, offering practical training platforms, and bolstering the job-readiness of new graduates.

Indonesia currently has two formal education programs that specifically focus on geothermal engineering. Bandung Institute of Technology (ITB) has offered a master's program in geothermal since 2008, producing a total of 288 graduates, or 12 per year. Most alumni have successfully entered the workforce, with 36% working in geothermal development companies and 24% in related industries. Others have pursued careers in academia and government agencies or have furthered their

PROGRAMS RELATED TO GEOTHERMAL AT INDONESIAN UNIVERSITIES

No.	Universities	Program Offered	Details of the Program
1	Universitas Gadjah Mada	Geothermal Research Center	• Under the Department of Geological Engineering • Provide multidisciplinary collaboration, particularly researchers from the Geophysics Study Program, Faculty of Mathematics and Natural Sciences
		Master of Geological Engineering Study Program	Under the Geological Engineering Department
2	Universitas Indonesia	Geothermal geology course	Offered as mandatory course for third-year undergraduate students in Geological major under the Department of Geoscience, Faculty of Mathematics and Natural Sciences
3	UPN Veteran Yogyakarta	Geothermal Exploration Expertise Group	Under the Department of Geophysical Engineering
4	Universitas Padjajaran	• Geothermal Geochemical Exploration course • Geothermal Geology of Indonesia course • Geothermal Hydrogeochemistry course	Offered as elective courses for master's students in the Geological Engineering Department
5	Universitas Pertamina	Geophysics of New and Renewable Energy Concentration for Geophysical Engineering Major	Under Geophysical Engineering Program

Figure 5.8: Overview of geothermal-related degree and training programs across Indonesian higher-education institutions.

studies at the doctorate level.[42] The ITB program also offers a fast-track pathway for undergraduate students from petroleum engineering who want to study in the geothermal master's program by providing a bridging course related to geothermal topics in the third year. ITB also provides training courses in collaboration with Indonesian geothermal companies such as Geo Dipa Energi and PLN to improve employees' skills. The second program has been offered since 2012 by the University of Indonesia, where students can pursue a master's program in geothermal exploration. Indonesia's other universities offer only elective courses in geothermal or provide resources through research centers (**Figure 5.8)**.

In contrast, at least 13 universities across Indonesia offer petroleum engineering programs.[43] Each university produces an estimated 30 to 60 graduates, which means approximately 390 to 780 fresh graduates seek employment every year in the oil and gas industry—23 to 46 times more than for geothermal. Many of these graduates have competencies that are also necessary for geothermal jobs, particularly in subsurface engineering, drilling, and reservoir management. Leveraging the petroleum education pipeline for geothermal workforce needs would help diversify graduates' career prospects and accelerate the expansion of the geothermal talent pool.

According to MEMR, geothermal power plants currently operating nationwide employ more than 5,200 direct workers and an estimated 870,000 indirect workers.[44] Existing geothermal development plans have a projected workforce demand ranging from 4,000[45] to 42,000[46] direct workers by 2060 to meet national policy targets. (See Chapter 2, "Powering the Transition: Indonesia's Geothermal Market," for more on national targets.) To meet the lower target, Indonesia's academic institutions will need to produce 6 to 7 times the current number of qualified graduates—between about 115 and 120 graduates per year, up from the current 17. Producing 42,000 geothermal-certified workers will require 15 to 30 times

GAP BETWEEN GEOTHERMAL GRADUATE SUPPLY AND INDUSTRY DEMAND

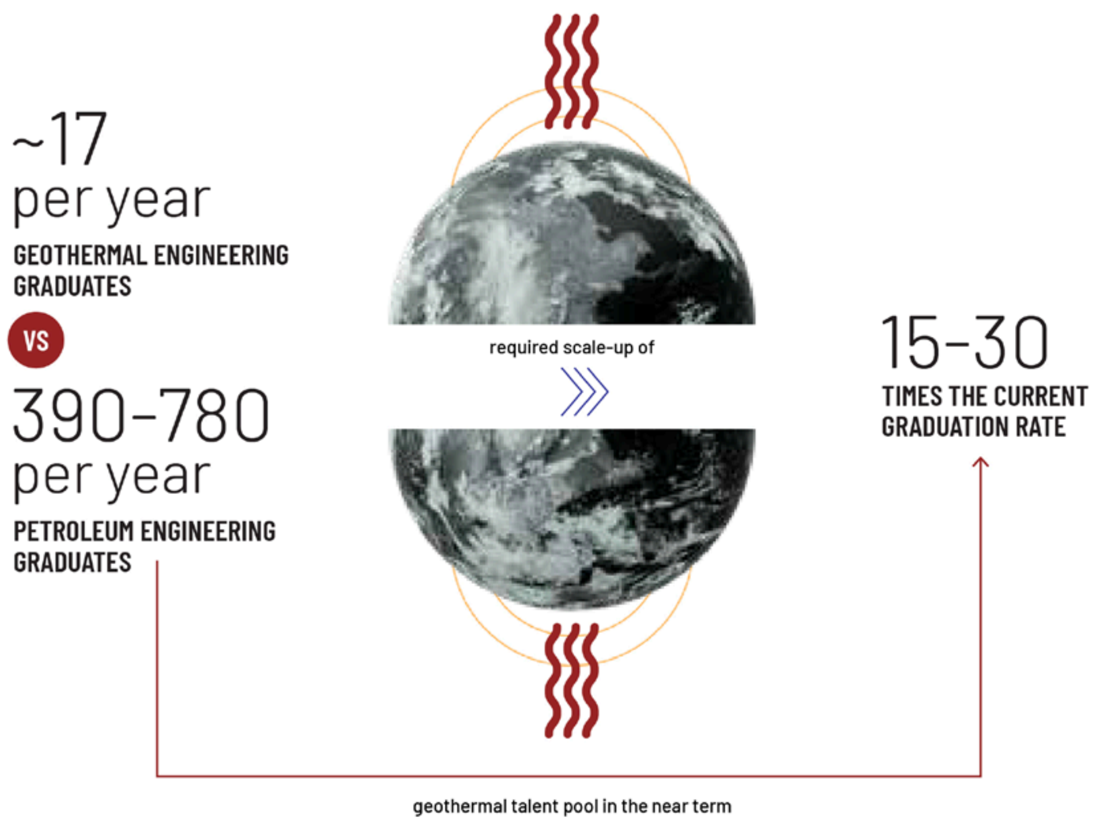

Figure 5.9: Comparison of projected geothermal workforce needs and current graduate output, highlighting the shortfall in skilled labor supply. Source: author calculations.

CONSTRAINTS IN DEVELOPING A GEOTHERMAL WORKFORCE FROM THE OIL AND GAS SECTOR

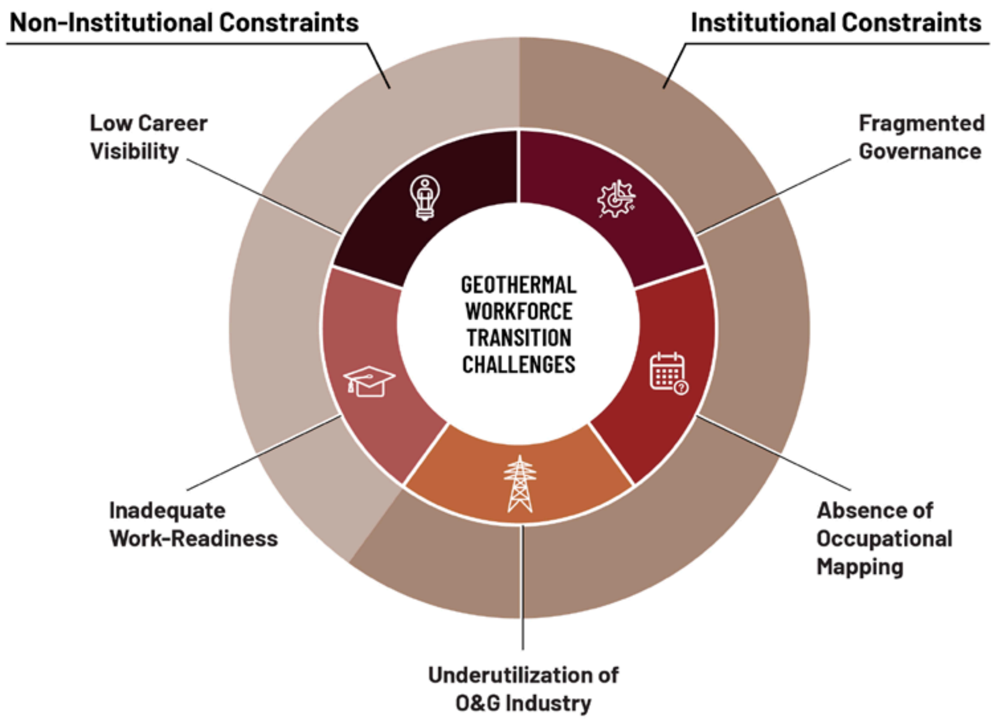

Figure 5.10: Key institutional and non-institutional barriers affecting workforce skills transfer from the oil and gas sector to geothermal development. Source: authors.

the current number of graduates (**Figure 5.9**). Scaling to this level will demand not only expanded academic programs but also robust accreditation systems, certification pathways, and closer industry alignment to ensure that training outcomes match workforce needs. With changes to certification programs, many of these jobs could potentially be filled by oil and gas workers.

BARRIERS TO GEOTHERMAL WORKFORCE DEVELOPMENT

Indonesia does face barriers to developing a strong and responsive geothermal workforce, particularly in the context of transitioning labor and expertise from the oil and gas sector. These barriers are categorized into institutional and non-institutional constraints (**Figure 5.10**).

An Unknown and Underskilled Career Path

In the PYC interviews and survey, employers in Indonesia's geothermal sector consistently reported that new graduates lack the interdisciplinary and site-readiness skills required for complex project environments. Training tends to be narrow and theoretical, offering minimal exposure to economics, permitting processes, and stakeholder engagement. As a result, graduates often struggle upon entry.

Despite Indonesia's vast geothermal potential, the sector remains relatively unknown and undervalued among students and early-career professionals. Geothermal is often perceived as technically limited and less lucrative than oil and gas. These issues hamper the sector's ability to compete for top graduates. Inclusion of geothermal modules in university outreach, government- or industry-supported scholarships, and job placements can all help overcome this perception.

The PYC survey found that despite their transferable skills, 84% of respondents preferred oil and gas as their first career choice; only 7% selected geothermal as their top option. Geothermal was selected as a second-choice pathway by 66% of respondents (see **Figure 5.11**). Close to 63% of graduates ranked attractive salaries

INDUSTRY SECTOR RANKING ACCORDING TO RECENT GRADUATES

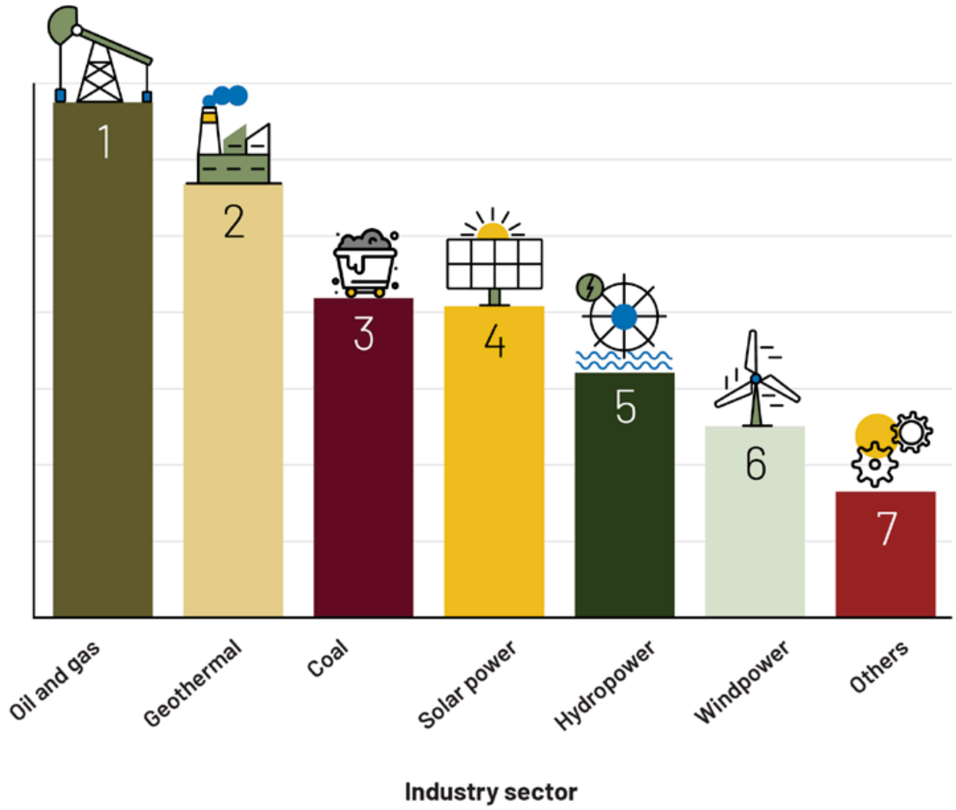

Figure 5.11: Survey-based ranking of industry sector preferences among Indonesia's recent graduates. Source: authors.

and benefits as their top priorities in career decision-making, reinforcing the perception that the oil and gas industry offers superior financial rewards. By contrast, social and environmental considerations ranked lowest among the factors influencing respondents' career choices, highlighting a persistent value gap that may hinder interest in clean energy careers.

To align geothermal workforce development with national capacity targets, Indonesia should scale up and diversify its geothermal education pathways, including establishing new degree programs, integrating geothermal content into related disciplines, and expanding vocational and diploma programs across the geothermal value chain.

During the interviews PYC conducted, one geothermal consultant mentioned they offer training to fulfill the "competency gap" for professionals looking for a career shift into geothermal. The courses range from beginner to advanced and cover technical skills such as well management and non-technical skills such as project management and economic aspects.

Fragmented Governance and Weak Institutional Coordination

As explained earlier in this chapter, Indonesia's workforce planning for the geothermal sector remains institutionally fragmented. The mandates of Bappenas (planning); MEMR (sectoral policy); MoM (manpower development); and the Ministry of Higher Education, Science, and Technology (education and training) are not aligned under a common operational framework, which makes policy formulation, funding, curriculum design, and training hard to execute. Indonesia would benefit from looking at how countries such as New Zealand and India work across ministries and align skills development with national energy transition goals.[47]

Absence of Comprehensive Occupational Mapping for Geothermal Transition

Without a clear taxonomy of emerging occupations, required competencies, and learning outcomes, institutions such as MoM and the Ministry of Higher

Education, Science, and Technology cannot design coherent programs to advance the level of skills needed for a workforce or develop curriculum strategies. The lack of occupational mapping also limits private sector alignment with national human resource development plans. International experiences such as the European Union's European Skills, Competences, Qualifications and Occupations (ESCO) platform[48] and India's Skill Council for Green Jobs[49] illustrate how structured occupational frameworks can facilitate labor mobility, standardization, and curriculum design. For Indonesia, these lessons emphasize the need to develop a National Geothermal Occupational Map under the INWCS to unify workforce planning and skill certification across the geothermal sector.

Underutilization of the Oil and Gas Industry as a Workforce Transition Partner

Despite the strong overlap of competencies between oil and gas and geothermal, the expertise of O&G professionals remains underutilized in Indonesia's workforce transition. Mechanisms for recognizing and transferring these skills into geothermal projects are still limited, resulting in missed opportunities to accelerate labor reallocation and address immediate capacity gaps.

STRATEGIES TO SURPASS BARRIERS

The following strategies and recommendations focus on practical mechanisms to surmount barriers. Each strategy is mapped to the specific constraints it addresses. As

MAPPING OF RECOMMENDATIONS TO CORRESPONDING CONSTRAINTS

Recommendations			Constraints				
			Fragmented Governance	Absence of Occupational Mapping	Underutilization of O&G Industry	Inadequate Work-Readiness	Low Career Visibility
Laying the Institutional and Strategic Foundation	Recommendation #1	Establish the Energy Workforce Transition Task Force (EWTT)	✓	✓	✓	✓	✓
	Recommendation #2	Develop Bridging Program Framework and Fast-Track Certification for Oil and Gas Professionals	✓	✓	✓	✓	✓
Program Implementation and System Building	Recommendation #3	Institutionalize a Geothermal Occupational Map and the INWCS	✓	✓	✓	✓	✓
	Recommendation #4	Pilot a Geothermal Immersion Program for Final-Year Students and Vocational Institutions	✓	✓	✓	✓	✓

Figure 5.12: Links between identified constraints in geothermal workforce development and corresponding strategic recommendations. Source: authors.

Indonesia refines its training and certification frameworks, it should design programs that reflect the full spectrum of geothermal technologies—conventional, next generation, and direct use—which will help prepare the workforce for not only power generation but also industrial heat and geothermal cooling systems (see **Figure 5.12**).

Laying the Institutional and Strategic Foundation

Indonesia has the pieces necessary to build a vibrant geothermal workforce with strong institutional mechanisms and policy coherence. The following four recommendations (some of which are explored in more detail in Chapter 7) could help the nation bridge sectors, mobilize stakeholders, and deliver programs that can scale.

#1: Establish the Energy Workforce Transition Task Force.

The Energy Workforce Transition Task Force (EWTTF) should be formalized through a presidential instruction to ensure strong cross-ministerial mandate, resource alignment, and policy continuity. The task force will be coordinated by the Human Resources Development Agency at MEMR, serving as the secretariat, with members from the MoM; the Ministry of Higher Education, Science and Technology; Bappenas; the National Agency for Professional Certification; and industry associations.

The task force's mandate will cover labor forecasting, occupational mapping, training, and designing certifications. Through a unified coordination platform, the EWTTF would bridge fragmented governance in workforce planning, align education and industry needs, and guide the development of geothermal and broader energy-transition job standards to enhance graduate work-readiness and sectoral labor resilience. See Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for more.

#2: Develop Bridging Program Framework and Fast-Track Certification for Oil and Gas Professionals.

A structured framework to connect the industries should formally recognize the oil and gas competencies that are relevant to geothermal. Developing this framework would begin with an equivalency matrix that maps oil and gas job roles to geothermal functions, followed by training to close the gaps. Embedding the program in the INWCS and using Recognition of Prior Learning under the National Agency for Professional Certification as the mechanism for validating existing competencies would enable current O&G professionals to make the transition efficiently.

Additionally, developing a fast-track certification program would validate oil and gas professionals' existing skills against geothermal INWCS. Laying out pathways to bridge the skills could close minor gaps, with certification tied to direct hiring pipelines. This process creates a formal mechanism to absorb skilled workers into geothermal and helps ensure the country will have the necessary labor pool to meet a large growth in geothermal power, heat, and cooling.

These actions would ensure that decades of experience in subsurface exploration, drilling, and project management are used for geothermal. They would also improve the visibility of geothermal careers by showing clear, formalized pathways for oil and gas professionals to enter the sector, making geothermal a more attractive career option.

Program Implementation and System Building

Once institutional foundations are in place, the next step is to scale programs and systems that ensure long-term workforce readiness.

#3: Institutionalize a Geothermal Occupational Map and the INWCS.

A national geothermal occupational map should define job families across the project life cycle and translate them into formal INWCS documents. This step would provide clarity on required skills while also establishing shared standards across ministries and training institutions. Moreover, it will strengthen graduate work-readiness, as curricula and certification would be directly tied to defined occupational outcomes recognized by both the government and industry.

#4: Pilot a Geothermal Immersion Program for Final-Year Students and Vocational Institutions. Geothermal project sites and the relevant ministries and institutions should develop a three- to six-month immersion program at geothermal project sites for students in their final years of study, which will provide practical exposure and mentorship in exploration, drilling, reservoir testing, and operations. This program would ensure that theoretical knowledge is complemented by real-world skills. This recommendation also responds to the low visibility and attractiveness of geothermal careers, as direct engagement with active projects would demonstrate geothermal's relevance, career potential, and contribution to Indonesia's energy transition.

CONCLUSION

Indonesia's geothermal potential offers not only a pathway to low-carbon energy generation but also a valuable opportunity to absorb and redeploy talent from its declining fossil fuel sectors. This alignment ensures that Indonesia's energy growth is decarbonized as well as socially just and employment secure. With the nation facing structural shifts in the global energy landscape, building a skilled and responsive geothermal labor force is essential to ensuring an inclusive and just energy transition.

Indonesia is uniquely positioned to pursue such a geothermal-centered workforce transition: It has the resources and the workforce. From exploration and drilling to reservoir management and plant operations, many of the technical functions in the nation's O&G and geothermal sectors are not only analogous but often interchangeable, with some targeted training. Moreover, institutional legacies in education, training, and industrial expertise—particularly within state-owned and O&G-affiliated companies—can serve as valuable assets for accelerating geothermal workforce readiness.

This transition should embrace all geothermal solutions. Direct-use heat, industrial applications, and geothermal cooling can multiply the benefits of power generation and create a resilient, integrated energy system that supports Indonesia's broader decarbonization and efficiency goals. Incorporating these next-generation and thermal applications into training, policy, and investment planning will ensure Indonesia captures the full economic and employment potential of geothermal energy.

With proper training and certification, geothermal could achieve enough growth to anchor more than 650,000 durable, skilled jobs across Indonesia.

However, progress has been slow due to several persistent barriers. Institutionally, Indonesia's workforce development ecosystem is fragmented. Ministries responsible for planning (Bappenas), sectoral policy (MEMR), training and certification (MoM and National Agency for Professional Certification), and education (Ministry of Higher Education, Science, and Technology) operate under separate mandates, with limited coordination, leaving gaps in labor forecasting, occupational standardization, and program implementation. Establishing a coordinated platform such as the Energy Workforce Transition Task Force would help align mandates, budgets, and monitoring systems across ministries. At the same time, most geothermal-specific competencies remain poorly defined in national occupational maps and the INWCS, which impedes curriculum development and limits alignment across academic and vocational institutions.

The recommendations offered in this chapter could form the building blocks of a national workforce transition program that can be integrated into Indonesia's National Medium-Term Development Plan, the National Energy General Plan, and a just transition agenda.

Now, Indonesia needs the political will, institutional alignment, and investment to connect these assets with the country's clean energy future. If implemented decisively, this approach could position Indonesia as a regional leader in green workforce transformation by 2035. By taking these steps, Indonesia can ensure that its energy transition is not only technologically feasible and economically viable but also socially inclusive and workforce driven.

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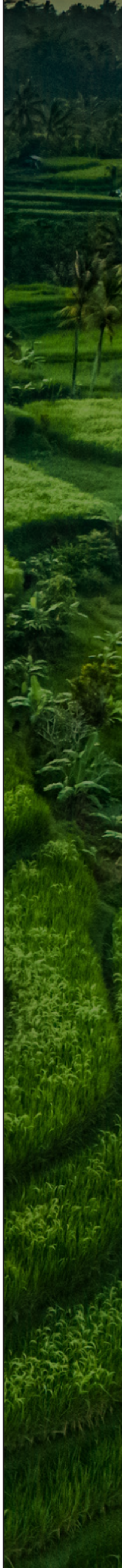
Part III

Policy Levers and Pathways for Stakeholder and Environmental Stewardship



Chapter 6

Common Ground: Building Trust and Transparency in Indonesia's Energy Transition

Filda C. Yusgiantoro and Michael Suryaprawira
Purnomo Yusgiantoro Center

Strengthening community engagement, improving benefit sharing, and integrating next-generation geothermal will be key to creating a geothermal industry that serves all of the nation's people.

Geothermal energy development is often approached as a purely technical subject—drilling wells, installing turbines, building transmission lines. But behind the drilling rigs lies a much more complex story involving people, histories, competing interests, and long-term consequences. Geothermal is not just a matter of technology; it is also about governing land, sharing benefits, and navigating the tension between national ambition and local realities.

Regions of Indonesia rich in conventional geothermal potential often contain environmentally or culturally sensitive areas and are home to communities with diverse and overlapping backgrounds—Indigenous groups, farmers, rural communities, and local government. All of these residents have a stake in what happens when a geothermal project moves in. Each group brings its own perspective: Some see opportunity, while others fear disruption. These responses are not irrational; they are grounded in memories of past extractive projects.

Geothermal projects often also include voices from universities, nongovernmental organizations, and researchers, many pushing the boundaries of geothermal. These stakeholders are studying reservoirs and rethinking policy frameworks, training young engineers, and linking geothermal energy to broader questions of justice and sustainability.

Local governments sit at a unique intersection. They must mediate between national targets, stakeholders

LOCAL REQUIREMENTS FOR INDONESIAN GEOTHERMAL POWER PLANTS

Installed capacity up to 5 MW/unit:	1. Minimum local content on goods: 31.30% 2. Minimum local content on services: 89.18% 3. Minimum combined local content: 42.00%
Installed capacity more than 10 MW up to 60 MW/unit:	1. Minimum local content on goods: 15.70% 2. Minimum local content on services: 74.10% 3. Minimum combined local content: 33.24%
Installed capacity more than 110 MW/unit:	1. Minimum local content on goods: 16.00% 2. Minimum local content on services: 58.40% 3. Minimum combined local content: 28.95%

Installed capacity more than 5 MW up to 10 MW/unit	1. Minimum local content on goods: 21.00% 2. Minimum local content on services: 83.30% 3. Minimum combined local content: 40.45%
Installed capacity more than 60 MW up to 110 MW/unit:	1. Minimum local content on goods: 16.30% 2. Minimum local content on services: 60.10% 3. Minimum combined local content: 29.21%

Figure 6.1: Requirements for geothermal developers based on the Geothermal Act of 2014. Goods refer to steam turbines, boilers, generators, electrical, instruments and controls, plant materials, and civil and steel structure. Services refer to feasibility studies, engineering, procurement, construction, inspection services, testing, certifications, and other support services. MW = megawatts. Source: Audit Board of Indonesia. (2014). *Law number 21 of 2014 concerning geothermal energy.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2025). *Performance report of the Directorate General of New, Renewable Energy and Energy Conservation (EBTKE) for 2024.* Government of Indonesia.

from various organizations, and community priorities, often with limited capacity or leverage. Yet their role can be decisive in accelerating or stalling progress.

Much of the historic, current, and planned geothermal development has focused on conventional geothermal power generation, also known as hydrothermal power. Today, emerging next-generation technologies and direct-use application development such as industrial heat and geothermal cooling systems have fewer impacts. These systems can operate at lower temperatures, closer to demand centers, and with a smaller surface footprint. Communities have more potential to benefit from geothermal resources rather than be harmed by their development. But for communities to attain these benefits, it is vital to ensure that development is transparent, inclusive, and aligned with *all* of the stakeholders involved with and affected by the installation of a geothermal system.

This chapter focuses on these people and institutions, how they engage with geothermal development, and how their roles ultimately shape the sector's future. By bringing these perspectives together, the chapter aims to offer a fuller picture of what is really at stake when we talk about geothermal—not just electrons, but equity; not just potential, but participation.

WHERE THE MONEY GOES: GOVERNING THE GEOTHERMAL DIVIDEND

As geothermal projects—including next-generation and direct-use projects—move from exploration into commercial operation, the revenues generated through royalties, taxes, and bonuses represent a form of geothermal dividend that can, if well governed, transform communities. The challenge lies in ensuring that this dividend is transparently managed and fairly allocated.

This section examines the current legal framework governing geothermal revenues and the obligations of geothermal permit holders. It also analyzes how existing mechanisms function and identifies areas where improved coordination and governance could multiply the impact of these revenues.

Legal Foundations and Permit Holder Obligations

The governance of geothermal revenues in Indonesia is rooted in Law No. 21/2014[1] on Geothermal Energy and broken down into several key regulations:

- Government Regulation No. 28/2016 on Amount and Ways to Allocate Geothermal Production Bonus[2]
- Government Regulation No. 7/2017 on Geothermal Energy for Indirect Utilization[3]
- Regulation of the Minister of Energy and Mineral Resources No. 37/2018 on Offering of Geothermal Working Areas, Granting of Geothermal Permits, and Assignment of Geothermal Business[4]
- Regulation of the Minister of Energy and Mineral Resources No. 33/2021 on Occupational Safety and Health, Environmental Protection and Management, and Geothermal Technical Principles for Indirect Utilization[5]

Power permit holders—officially recognized under Indonesia's geothermal licensing framework as *Izin Panas Bumi* (IPB) holders—carry responsibilities that extend far beyond building and running plants. The Indonesian government expects these companies to serve as agents of socioeconomic development, investing not

DIFFERENTIATING GEOTHERMAL WORKING AREAS (WKP)

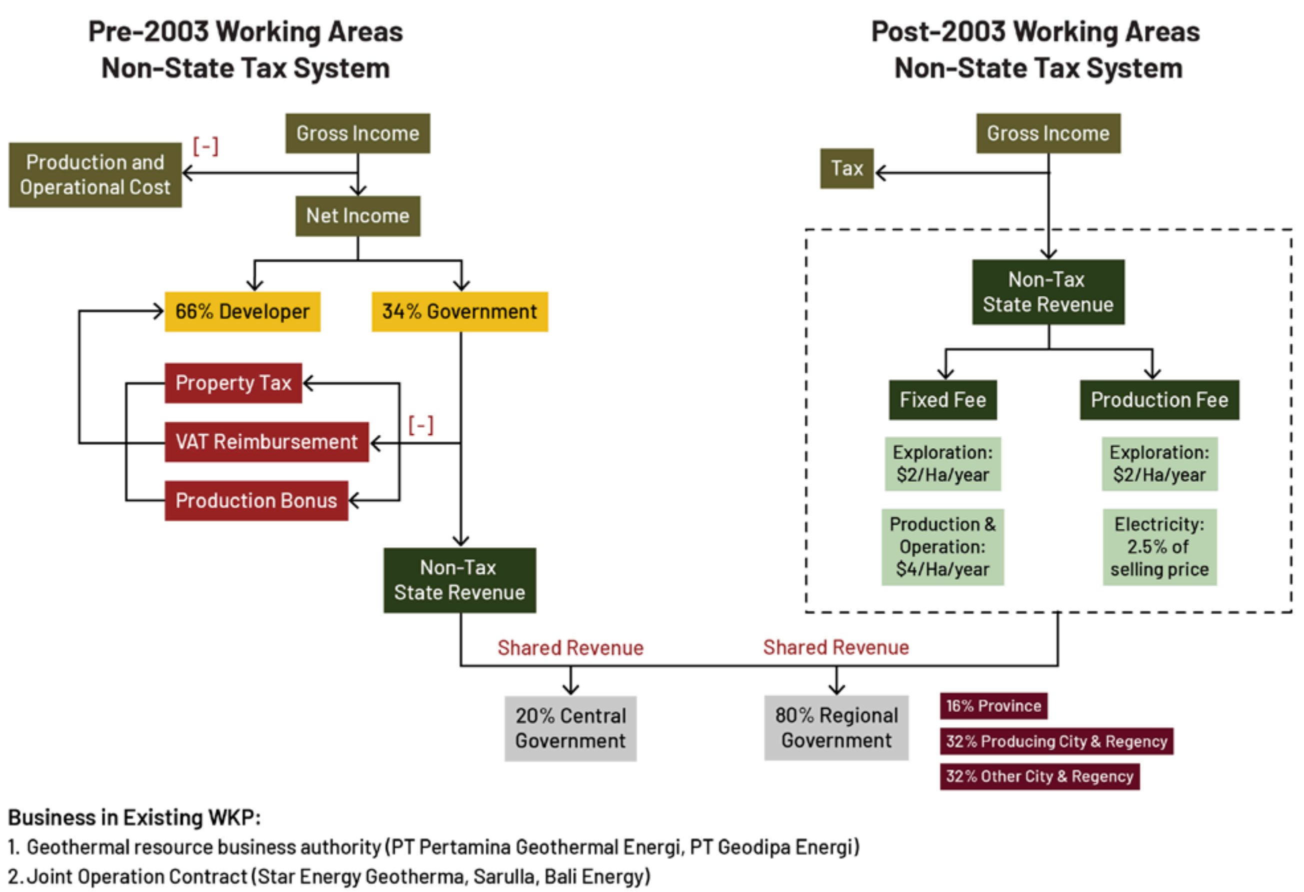


Figure 6.2: There are currently two types of Geothermal Working Areas (*Wilayah Kerja Panas*, or WKP). The first applies to plants that were running before 2003, when Law 27 was established; the second WKP is for plants that started operating after 2003. Ha = hectares; PNBP = non-tax state revenue; VAT = value-added tax; Source: Ministry of Energy and Mineral Resources. (2025). *2024 Directorate General of Renewable Energy and Energy performance report.* Government of Indonesia.

GEOTHERMAL NON-TAX STATE REVENUES

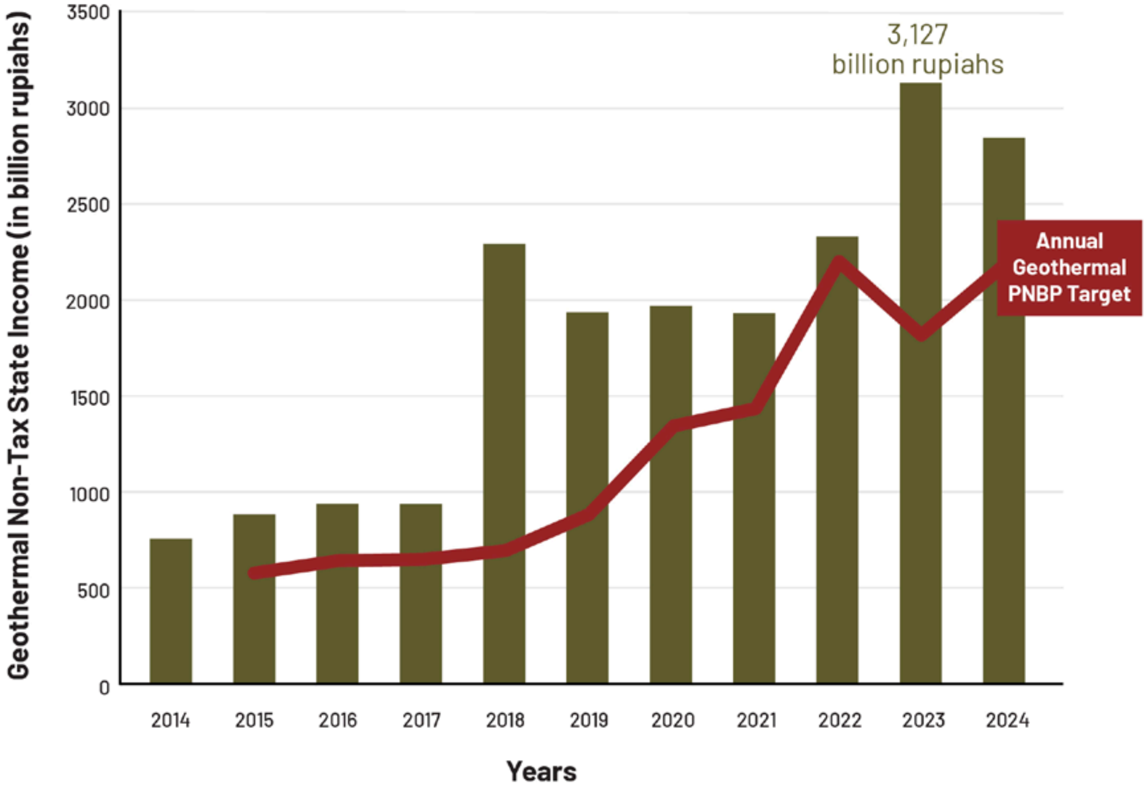


Figure 6.3: From 2014 to 2024, the geothermal sector contributed around Rp19.9 trillion or US$1.2 billion to Indonesia's geothermal non-tax state revenues. PNBP = non-state tax income. Sources: Ministry of Energy and Mineral Resources. (2025). *2024 Directorate General of New, Renewable and Energy Conservation performance report.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2019). *2014-2019 performance report of the Ministry of Energy and Mineral Resources of the Republic of Indonesia.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2021). *2020 performance report of the Ministry of Energy and Mineral Resources.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2022). *2021 performance report of the Ministry of Energy and Mineral Resources.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2023). *2022 performance report of the Ministry of Energy and Mineral Resources*. Government of Indonesia; Ministry of Energy and Mineral Resources. (2024). *2023 performance report of the Ministry of Energy and Mineral Resources.* Government of Indonesia; Ministry of Energy and Mineral Resources. (2025). *2024 performance report of the Ministry of Energy and Mineral Resources.* Government of Indonesia.

only in hardware but also in people, communities, and the broader ecosystem.[6]

IPB holders have an important obligation to support domestic industry and workforce development. They must prioritize local goods and services (the details of which can be seen in **Figure 6.1** on local requirements[7]) or, when they cannot source locally, ensure imported products and workers meet quality standards. Beyond procurement, IPB holders are expected to invest in geothermal research and development, collaborate with academic institutions, and facilitate knowledge exchange, often through joint studies, lab access, or overseas benchmarking programs to strengthen local expertise.

IPB holders have an equally vital obligation to support community development and empowerment. They must submit programs to local governments that prioritize communities near project sites, focusing on local employment, services, and essential needs such as education, health, and infrastructure.[8] They must align their programs with regional plans and implement them during a project's operational phases.

Contrary to common perception, the lion's share of Indonesia's geothermal revenues does not stay in Jakarta. Under the current revenue-sharing scheme, 80% of the revenue commonly known as Shared Revenue Funds (Dana Bagi Hasil; DBH) is allocated to regional governments.

Despite these mandates, real-world implementation has been mixed. Monitoring is inconsistent, data on outcomes are fragmented, and mechanisms for evaluation remain largely underdeveloped. Most companies and regional governments do not yet embed monitoring, evaluation, and learning systems into their efforts to support community development, making it difficult to assess effectiveness of particular activities or replicate good practices. Furthermore, governments and companies often coordinate reactively rather than strategically, causing inefficiencies and missing opportunities.

Current Revenue Streams from Geothermal Projects

The financial returns from Indonesia's geothermal sector can be significant. Once a project reaches the production phase, the local and national government begins receiving revenues through fixed and production-based fees paid by the IPB holders, as determined by their original IPB contracts. These payments are supplemented by standard tax obligations, such as property tax and value-added tax, alongside a particularly important category: non-tax state revenue. Non-tax state revenue includes fixed fees (US$2.00 per hectare for the exploration phase and US$4.00 per hectare after the Commercial Operation Date) and production fees (5% per kilowatt-hour for steam or 2.5% per kilowatt-hour from electricity), forming one of the largest and most direct fiscal returns from geothermal projects.[9] In addition, permit holders must pay administrative fees, licensing costs, and other government-imposed charges related to compliance.

Today, the government collects fees based on the plant and when it was built. **Figure 6.2** shows the differences between the two types of Geothermal Working Areas (*Wilayah Kerja Panas Bumi*, or WKP). The first WKP applies to plants that were running before 2003, when Law 27 was established; these contribute to 90% of geothermal non-tax state revenues (PNBP). The second WKP is for plants that started operating after 2003; these contribute 10% of the current non-tax state revenues.[10] Between 2014 and 2024, the geothermal sector contributed around Rp19.9 trillion or US$1.2 billion to Indonesia's geothermal non-tax state revenues (see **Figure 6.3**).[11,12,13,14,15,16]

Royalties: Who Benefits?

Contrary to common perception, the lion's share of Indonesia's geothermal revenues does not stay in Jakarta. Under the current revenue-sharing scheme, 80% of the revenue commonly known as Shared Revenue Funds (*Dana Bagi Hasil*; DBH) is allocated to regional governments, while the central government retains 20% of non-tax state revenues.

The 80% is intended to reward and support regions that host geothermal infrastructure and often bear the environmental and social impacts. The allotment also represents a significant commitment to decentralization.

Take the Kamojang Geothermal Power Plant in the Bandug Regency in West Java Province. Of the 80% that goes to the West Java government:

- 16% goes to West Java Provincial Government.
- 32% goes to Bandung City Government.
- The remaining 32% is distributed evenly to the other 26 cities or regencies in West Java.

Figure 6.4 shows the 13 provinces with the highest amount of geothermal shared revenue.[17]

All that said, while the allocation of money is measurable, its ultimate use is much more difficult to trace. Indonesia lacks a unified, transparent framework to tie these geothermal revenues to a broader development strategy. Most funds—whether from central taxes or regional levies—are absorbed into general budgets. Once pooled, these revenues are

GEOTHERMAL PROVINCIAL SHARED REVENUE FUNDS IN 2024

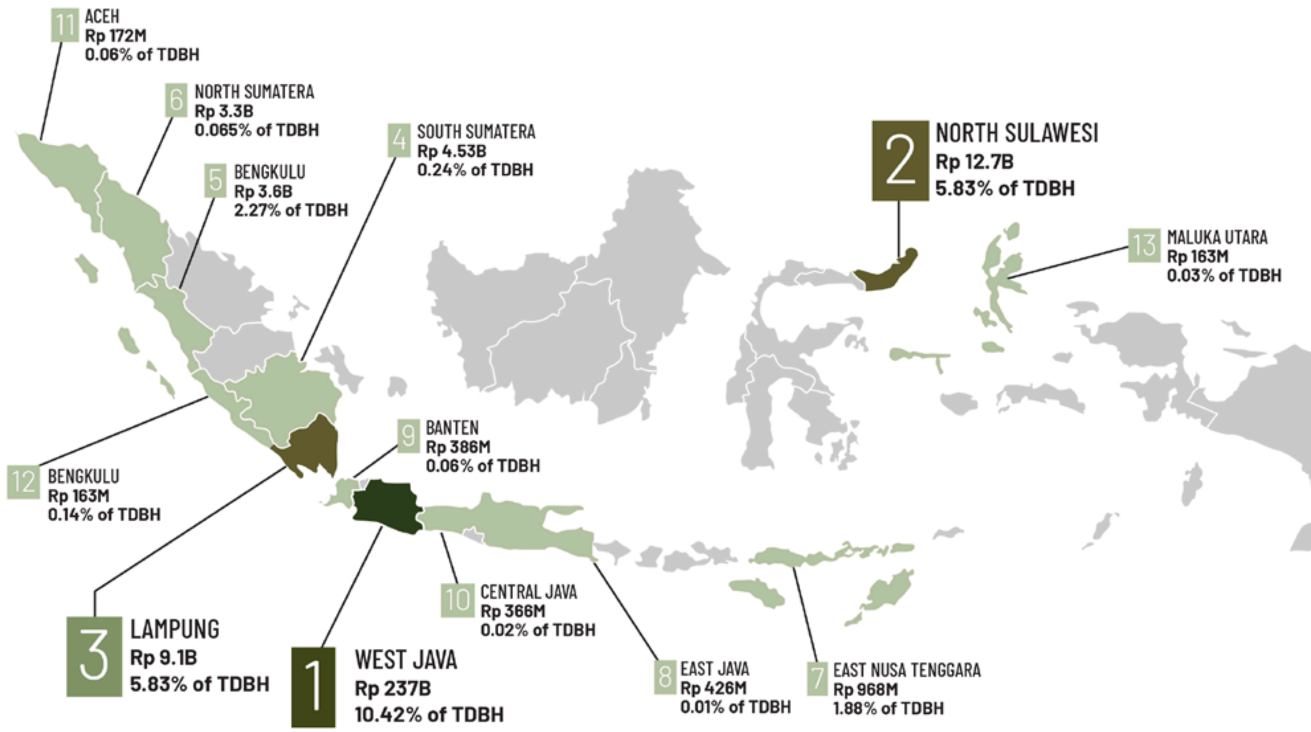


Figure 6.4: Geothermal provincial shared revenue funds (DBH) in 2024 and its percentage of total DBH (TDBH). Source: Directorate General of Fiscal Balance, Ministry of Finance of the Republic of Indonesia. (2023). *Details of the allocation of the General Allocation Fund and Revenue Sharing Fund for fiscal year 2024.* Government of Indonesia. Processed by Purnomo Yusgiantoro Center.

difficult to isolate, monitor, or evaluate regarding their specific contributions to geothermal-affected regions.

Without those tracking mechanisms, geothermal revenues risk becoming just another line item, rather than a development tool. As a result, local communities may see the steam from the power plant but not the benefits of the fiscal dividend, trapping geothermal-rich areas in the paradox of energy wealth and underdevelopment. In other words, while the revenue is shared, its impacts currently are invisible and untraceable to the host communities.

For geothermal to fulfill its promise as a source of clean energy and local prosperity, introducing a dedicated geothermal revenue management framework that has transparent spending requirements and participatory planning mechanisms would go a long way toward rebuilding trust between communities, companies, and the state. See Policy Recommendation #9 in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," for further details.

THE PEOPLE: MAJOR STAKEHOLDERS AND IMPACTED COMMUNITIES

Rural and Low-Income Communities

The development of geothermal energy in Indonesia is frequently framed in terms of geology, finance, and policy. However, the social dimensions that shape perceptions of projects are just as important. Geothermal expansion is not just a source of clean energy; it is a social process that intersects with land tenure systems, cultural values, local livelihoods, and public trust.

In future development models, direct-use geothermal could provide more tangible and less intrusive benefits for local communities. Supplying clean, affordable heat for processing, agriculture, and community services or providing cooling for buildings and tourism can align geothermal activity more closely with local economic priorities.

Indonesia's geothermal potential is among the highest in the world, yet its deployment remains uneven. In several regions—from North Sumatra to East Nusa Tenggara—projects have faced strong community resistance, ranging from peaceful protests to full project suspension (see **Figure 6.5**). Understanding where and why these tensions have emerged with past development can help with the design of more inclusive and sustainable projects going forward.

Social conflict in geothermal development rarely arises from a single trigger.[18] Instead, it is often the result of technical, environmental, economic, and cultural concerns left unaddressed in early project phases. Research conducted by the Purnomo Yusgiantoro Center (PYC) reveals these concerns tend to emerge around four core issues: land tenure ambiguity and insufficient consultation; perceived environmental risk; economic displacement and limited local benefit; and cultural and spiritual impacts.

Land Tenure Ambiguity and Insufficient Consultation

In many project areas, those with customary land systems (*wilayah adat*) often feel their rights and claims are overlooked. These systems involve land originally owned by Indigenous people who have resided on the land for thousands of years. Developers might receive official permits from the government to operate on the land, but residents may not recognize the legitimacy of these authorizations if they were not consulted in the process. This disconnect has caused locals to mistrust developers and oppose their projects.[19]

Perceived Environmental Risk

Communities frequently raise concerns about the use and safety of natural resources, particularly water and air quality. Drilling operations, fluid discharge, and accidental emissions are potential threats to health, agriculture, and ecosystems. Even when these risks are low or well managed, poor communication can heighten public anxiety. (See Chapter 8, "Keeping Geothermal Green: Safeguarding Nature and Communities in a New Era of Growth.")

Economic Displacement and Limited Local Benefit

Geothermal projects may be perceived as extractive rather than inclusive if residents are not offered meaningful employment, capacity building, or revenue-sharing mechanisms. Many geothermal sites are located in rural farming regions, where residents rely on plantations or rice paddies for their income. Land acquired for drilling infrastructure often takes that land out of the hands of those residents. Although compensation may be offered, it rarely offsets the full economic and social impact for local residents, especially when residents cannot transition into new roles within the project. This mismatch between economic disruption and employment opportunities often complicates community acceptance.[20]

Cultural and Spiritual Impacts

Geothermal zones are frequently located near or within culturally significant landscapes. Construction in or around sacred sites, ancestral forests, or burial grounds can trigger resistance that is deeply rooted in local identity and tradition. A developer's failure to acknowledge or adapt to these sensitivities can rapidly erode public support.

For example, PT Pertamina Geothermal Energy and Bali Energy Limited began developing the Bedugul Geothermal Power Plant in the 1990s at the Buyan-Bratan volcanic complex in Bali. The companies were permitted to do this development, but strong public opposition rooted in religious beliefs halted the project. Many Balinese Hindus consider the mountains—

COMMUNITY ISSUES ASSOCIATED WITH GEOTHERMAL ELECTRICITY PROJECTS IN INDONESIA

No.	Project	Location	Time	Community Concern
1	Tabanan (PT Pertamina Geothermal Energy and Bali Energy, Ltd.)	Bali	Aug. 2005	**Cultural:** Disturbance to a sacred place due to project activities **Environmental:** Water source scarcity and contamination; disruption of ecosystem preservation
2	Mount Rajabasa (PT Supreme Energy)	Lampung	May 2013	**Cultural:** Disturbance to several historical places (forts) **Environmental:** Water source scarcity and contamination **Economic:** Erase the occupation of the surrounding community
3	Tangkuban Perahu (PT Tangkuban Perahu Geothermal Power)	West Java	Nov. 2013	**Environmental:** Water source scarcity and contamination; man-induced natural disasters (floods and landslides)
4	Sorik Marapi (PT Sorik Marapi Geothermal Power)	North Sumatera	Dec. 2014	**Environmental:** Disruption of ecosystem preservation; drilling risk to the community (H_2S and blowout)
5	Mount Ciremai (PT Chevron Geothermal Indonesia)	West Java	March 2015	**Environmental:** Water source scarcity and contamination; community health
6	Baturaden (PT Sejahtera Alam Energy)	Central Java	Nov. 2016-Oct. 2017	**Environmental:** Disruption to forest ecosystem and water source contamination; man-induced natural disasters (floods and landslides) **Economic:** Disruption of the occupation of the surrounding community; threat to natural tourism attractions
7	Sokoria (PT Sokoria Geothermal Indonesia)	East Nusa Tenggara	Feb. 2017	**Economic:** Untransparent land acquisition mechanism
8	Mount Talang (PT Hitay Daya Energy)	West Sumatera	Nov. 2017	**Environmental:** Water source scarcity and contamination; earthquake induced by drilling activity; potential failure of geothermal power plant development **Economic:** Limiting the local agricultural potential
9	Mount Lawu (PT Pertamina Geothermal Energy)	Central to East Java	Jan. 2018	**Cultural:** Disturbance to a sacred place due to project activities **Environmental:** Disruption of ecosystem reservation due to infrastructure preparation; scarcity of water sources **Economic:** Minimal benefit to the community from geothermal projects
10	Kaldera Danau Banten (PT Sintesa Banten Geothermal)	Banten	March 2020	**Environmental:** Disruption of ecosystem preservation
11	Bittuang (Government drilling)	South Sulawesi	Jan. 2021	**Cultural:** Disturbance to customary lands (*wilayah adat*) **Economic:** Erase the local plantation area **Environmental:** Water source scarcity
12	Tampomas (PT Wijaya Karjya Jabar Power)	West Java	March 2021	**Environmental:** Water source scarcity and soil fertility issue; man-induced natural disasters (seismicity from drilling)
13	Dieng (PT Geo Dipa Energi, existing GWA)	Central Java	Jan. 2022	**Environmental:** Risk to the nearby village; drilling risk to the community (H_2S and blowout)
14	Wae Sano (Government drilling)	East Nusa Tenggara	Feb. 2022	**Cultural:** Disturbance to local village and traditional houses complex **Environmental:** Risk to nearby villages; water source scarcity and contamination. **Economics:** Limiting the local agricultural potential

Figure 6.5: Community issues in Indonesia associated with geothermal electricity projects, based on historic references. Source: Fadhillah, F. R., Al Asy'ari, M. R., Bagaskara, A., Valley Vie Vanda, D., Adityatama, D. W., Purba, D., Katmoyo, R., Djandam, A., & Gurning, L. (2023). Challenges in getting public acceptance on geothermal project in Indonesia. In *Proceedings, 48th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

SOCIAL CHALLENGES ORGANIZED BY GEOTHERMAL PROJECT STAGE

Geothermal Project Stages	Activities	Potential Impact	Potential Community Concerns and Perceptions
Preliminary and Survey	• LiDAR survey • Field mapping • Data and sample collection • Geophysics stationing • Early infrastructure survey and geohazard	• Small-scale land clearing • Trespassing on local land • Disturbing local activities • Raising community curiosity	• Relatively neutral perception • Field sampling can disturb the local community's daily activities since those activities are associated with water resources, local tourism, and sacred places.
Infrastructure Preparation and Drilling	• Detailed infrastructure and geotechnical survey • Land acquisition • Massive land clearing • Civil work and heavy equipment mobilization • Water supply gathering • Rig deployment and removal • Drilling and well testing	• Deforestation • Changes of local occupation • Soil material pollution • Area disturbance • Social acculturation with the foreign workers	• Fear of wild animals entering villages and ecosystem disruption • Unfair land acquisition process • Equipment mobilization that disturbs local activities • Air and noise pollution • Dirty road and dust pollution • Loss of water sources due to drilling activities • Loss of occupation • Cultural disruption • Fear of H_2S and blowout events
Construction Phase	• Detailed infrastructure and geotechnical survey • Land acquisition • Massive land clearing • Civil work and heavy equipment mobilization • Steam Gathering System (SAGS) construction	• Deforestation • Soil material pollution • Area disturbance • Social acculturation with the foreign workers	• Air, water, and noise pollution • Dirty road and dust pollution • Loss of occupation • Foreign workforce affecting public perception (replacement of the current position and alter those areas' social values/cultural disruption)
Production Phase	• Electricity generation • Make-up well drilling • Workover • Heavy equipment mobilization	• Social acculturation with the foreign workers • Changes in local occupation • Sound pollution • Water contamination from geothermal fluid	• Loss of occupation • Induced earthquakes and landslides • Replacement of the current position and altering of those areas' social values

Figure 6.6: Social challenges organized by geothermal project stage. Source: Fadhillah, F. R., Al Asy'ari, M. R., Bagaskara, A., Valley Vie Vanda, D., Adityatama, D. W., Purba, D., Katmoyo, R., Djandam, A., & Gurning, L. (2023). Challenges in getting public acceptance on geothermal project in Indonesia. In *Proceedings, 48th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

especially in the Bedugul area—sacred. The thought of drilling into these spiritually significant sites sparked widespread rejection from local communities, environmental groups, the provincial government, and religious councils.[21] Religious institutions in many parts of Indonesia greatly influence local communities, even more than local or regional governments.

A HEALTHIER PARTNERSHIP AHEAD

In Indonesia, geothermal projects rise or fall based on their social license to operate (SLO) granted by host communities, not by regulators. The primary "grantors" are nearby residents: landowners and farmers, customary tribal (*suku adat*) groups, village heads and councils, religious leaders, women's groups, youth

PROBLEM AND SOLUTION, SIMPLY STATED

The aim is practical: Spell out who does what by when, with verifiable indicators and a standing grievance pathway so commitments survive leadership changes and carry through from exploration to operations. Here are the four most frequent pain points and the moves that reliably de-risk them.

Land Tenure Ambiguity and Insufficient Consultation

- **Problem:** The overlooking of *wilayah adat* rights and claims.
- **Potential solution:** Adopt free, prior, and informed consent with participatory mapping that legally records customary boundaries and co-signs land-use agreements with *adat* leaders. Establish a standing community liaison forum and grievance mechanism, with independent mediation for disputes.

Perceived Environmental Risk

- **Problem:** Community concern over the use and safety of natural resources.
- **Potential solution:** Publish baseline and ongoing air and water data via a real-time dashboard, verified by third-party auditors, and co-design an emergency response plan with regular community drills. Use plain language and commit to stop-work thresholds tied to monitored indicators.

Economic Displacement and Limited Local Benefit

- **Problem:** Perception of geothermal as extractive rather than inclusive.
- **Potential solution:** Implement a Livelihood Restoration Plan that includes training and local hiring targets, supplier development for village small and medium enterprises, and time-bound income-bridge payments until new jobs mature. Allocate a community benefit or revenue-sharing fund, and support climate-smart agriculture to intensify remaining farmland.

Cultural and Spiritual Impacts

- **Problem:** Geothermal construction in or around sensitive cultural or natural environments that can erode public support.
- **Potential solution:** Conduct a Cultural Heritage Impact Assessment with authorities, and create thoughtful buffers to protect certain regions; redesign or relocate assets where needed. Formalize access protocols, observance of rituals and ceremonies, and co-management of sacred landscapes in a written pact.

organizations, and local small and medium enterprises. The grantors judge projects on concrete basics: fair land access and compensation, local hiring and suppliers, mitigation of drilling impacts, transparency, and benefit-sharing that matches village priorities. If developers align community programs with local development plans and forums and meet local content expectations early and continuously, projects can avoid protests and stoppages.[22]

Tribal groups are important grantors of SLOs. Because there are more than 1,300 distinct Indigenous cultures in Indonesia, geothermal prospects often sit on or near Indigenous lands (*wilayah adat*), which these groups have managed for generations.[23] Choices about where to place roads, drilling pads, pipelines, and ponds can affect access to forests and springs, disturb sacred places, and change the daily routines of adat communities.

These communities usually have clear social rules even when their land is not fully certified by the state. Leadership can include adat councils, clan heads, respected elders, women's groups, youth, and religious figures. Livelihoods often depend on forest products; small farms; fisheries; and seasonal work tied to springs, groves, or hunting lands. Culture is tied to places, too—burial grounds, ritual trees, caves, and walking routes—so projects should plan buffers around these areas. (For more about how impacts change through the various phases of a project, see Chapter 8, "Keeping Geothermal Green: Safeguarding Nature and Communities in a New Era of Growth.")

Indonesia's rules already offer entry points to manage wilayah adat so they co-exist with geothermal sites. The country's constitution recognizes implicit rights for some people, or *Masyarakat Hukum Adat* (the formal name for suku adat), and serves broader public interests. The country's environmental law requires an Environmental Impact Assessment (EIA), which includes assessing social impact and handling grievances. Customary areas can be recognized through regional regulations and participatory mapping, and wilayah adat can be formalized under forestry rules. Geothermal licensing and its implementing regulations require engagement and community programs and promote local procurement. If developers deal with these issues early, explain plans clearly, and set up fair benefits, projects run smoothly and trust grows on both sides. At the end of a project's life, communities will care about how well developers restored the sites and whether they kept their promises.

But the SLO arena is also shaped by more than local communities. Developers should use Indonesia's legal framework as living, site-specific processes, in turn co-producing baselines with universities and provincial environmental agencies, publishing monitoring data, and running a credible grievance mechanism. They must also capture commitments by local governments into memoranda of understanding and update the memoranda at each phase. When SLO weakens, delays arise via EIA challenges, permit bottlenecks, and reputational hits; recovery requires facilitated mediation among regulators, independent experts, and community representatives to reset expectations and timelines and restore long-term acceptance.

The status of wilayah adat in Indonesia has four categories: newly registered, registered, verified, and certified. These land status categories hold varying levels of legal protection—certified areas are fully protected from external use, verified areas are formally acknowledged and awaiting certification, and registered or newly registered areas require any prospective business activity to be reconfirmed with the Indigenous Territory Registration Agency before proceeding. **Figure 6.7** shows the percentage of locations in each category, their total land area, and their geographic relation to geothermal resources.

One effective way to build social license in geothermal development is to prioritize direct-use applications that bring clear, early benefits to suku adat communities. Many sustain their livelihoods through farming, forest product harvesting, and artisanal fishing, activities well suited to low- and medium-temperature geothermal heat. Farmers could use geothermal energy to dry crops like coffee or rice more quickly and consistently, improving product quality and reliability. Fishing families could use it to dry fish or seaweed where refrigeration is limited. Community-scale systems could also provide cold storage or ice for harvests, expanding market access. (See Chapter 4, "Beyond Electricity: Thermal Energy Demand and Direct

LOCATIONS OF INDONESIAN WILAYAH ADAT OVERLAID WITH GEOTHERMAL POTENTIAL

Figure 6.7: Locations of Indonesian wilayah adat on Indonesia's Geothermal Potential, and associated land area for each wilayah adat category. Source: Indigenous Territory Registration Agency. (n.d.). [Land registration map and status](). Government of Indonesia; Project InnerSpace. (2025). *Subsurface Favorability WOA* [Data Layer], Global module. [GeoMap]().

Subsurface Favourability Weighted Overlay Analysis

- Power generation
- Potential power generation
- District heating/cooling
- Low-temperature industrial heating/cooling
- Residential heating/cooling

Newly registered	7.279.906,09 Ha	23,03%
Registered	15.922.265,08 Ha	50,37%
Verified	5.957.573,61 Ha	18,85%
Certified	2.453.158,99 Ha	7,76%
Total	**31.612.903,77 Ha**	**100,00%**

Use Potential," for further insights.) By integrating geothermal heat into local industries without requiring large infrastructure, these applications offer a practical path to strengthen adat economies and improve rural livelihoods in a sustainable, community-driven way.[24]

Equally important is how these projects are developed. Direct-use systems can be designed in partnership with suku adat leadership to respect sacred sites and traditional land use. Unlike power plants, they require little heavy machinery, and their locations can be flexible, reducing the risk of displacement or disruption.[25]

Past geothermal projects have shown how industrial-scale development can damage ancestral areas and undermine livelihoods. A community-led approach, by contrast, centers on mutual benefit and local decision-making. Communities can guide where and how heat is used and share in the services and income it generates. This early collaboration fosters trust, builds local capacity, and makes geothermal technology more familiar and less feared. By honoring suku adat governance and pursuing direct-use applications that fit local needs, future projects can become a source of pride and empowerment rather than conflict.

STATE ACTORS IN INDONESIA'S GEOTHERMAL DEVELOPMENT

Regulatory Stakeholders

Indonesia's geothermal permitting and delivery run through several state actors whose mandates often intersect. The Ministry of Energy and Mineral Resources leads, but progress in any field depends on how well the ministry's decisions line up with environmental approvals, investment licensing, economic coordination, and local government processes.[26]

1. **Ministry of Energy and Mineral Resources (MEMR)—Lead regulator**
   MEMR is the sector anchor and can act through various sub-agencies.[27] Through the Directorate General of New Renewable Energy and Energy Conservation (NREEC), MEMR sets policy, plans and tenders WKPs, and supervises permits from exploration to exploitation. Through the Geological Agency, it supplies resource mapping, geoscience data, and hazard information. Through the Directorate General of Electricity, it handles grid codes, interconnection standards, and coordinates with Perusahaan Listrik Negara (PLN), the state electricity company, on dispatch and Power Purchase Agreement (PPA) technicalities. In practice, MEMR's choices shape a project's bankability and timeline from the first survey to the Commercial Operation Date.

2. **Ministry of Environment (MoE)—Environmental responsibilities**
   MoE oversees environmental impact management (such as EIAs), environmental management and monitoring reviews, and safeguards for biodiversity and watersheds.

3. **Ministry of Forestry (MoF)—Forest land use responsibilities**
   MoF governs forest area access and issues Forest Area Borrow-to-Use Permits (PPKH) when wells, pads, or pipelines intersect protection or production forests. Because many prospects sit within or near forest zones, the timing and scope of the decisions by MoE and MoF often determine whether site preparation and drilling can start on schedule.

4. **Ministry of Investment (MoI)—Licensing gateway and investor facilitation**
   MoI runs the Online Single Submission (OSS) system that issues business identification numbers and aligns risk-based licenses with ministerial approvals. For geothermal developers and engineering, procurement, and construction contractors, OSS status needs to match MEMR and MEF progress to avoid permitting gaps that stall procurement and financing. MoI also coordinates investment incentives and helps resolve licensing conflicts across ministries, making it an important interface for new entrants and projects seeking expansion.

5. **Coordinating Ministry for Economic Affairs (CMEA)—Cross-ministerial coordination**
   Geothermal projects frequently involve trade-offs between forestry rules, grid readiness, pricing policy, and local development plans. CMEA convenes the relevant ministries to align decisions and, where needed, escalates cases into the national priority pipeline. Effective coordination in this area can convert sequential approvals into parallel tracks with clear service-level agreements.

6. **Local Governments (Provinces, Regencies, and Cities)—Host authorities and day-to-day gatekeepers**
   Local governments translate national decisions into workable site access and community acceptance. They manage spatial planning alignment, chair EIA commissions at the regional level, issue construction and location permits, facilitate land acquisition, and coordinate community development so benefits reach adjacent villages. They also receive and program geothermal revenue shares. Capacity, experience, and public trust at the local level often determine whether operations proceed smoothly or face repeated delays.

Several other agencies have critical roles in Indonesia's geothermal development framework.

The Ministry of National Development Planning directs the implementation of national and sectoral development plans, aligning geothermal expansion with broader economic, spatial, and low-carbon growth strategies under Indonesia's National Long-Term Development Plan (see Chapter 2, "Powering the Transition: Indonesia's Geothermal Market"). This ministry also coordinates donor support and climate finance mechanisms that often underpin geothermal investment readiness.

The Ministry of Home Affairs and Regional Governments ensures that geothermal activities align with provincial and district governance structures, providing regulatory oversight on regional planning, land administration, and public information processes that affect local permitting and community engagement. Its coordination with regional governments is particularly important for land designation, spatial planning, and licensing at the subnational level.

The Ministry of Finance formulates and implements fiscal policies that directly influence geothermal project viability—covering state budgeting for infrastructure, taxation incentives, customs treatment for imported equipment, and management of public-private risk. The ministry's instruments, including guarantees and blended-finance schemes, are essential to de-risk early-stage exploration and attract private investment into the geothermal sector.

Taken together, the mandates of these various agencies create a chain of decisions rather than a single permit: A WKP must be planned and awarded, licenses aligned in OSS, environmental and often forest clearances secured, grid access confirmed, and local permissions and benefits established (**Figure 6.8**). The order and timing of those steps—and how handoffs are managed between groups—largely determine whether a project advances smoothly or stalls. As noted in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation," targeted fixes include, for example, OSS dashboards that mirror sectoral status in real time and structured support to local governments for EIA review, land processes, and community development and empowerment initiatives.

THE LOCAL EXPERTS: INDONESIA'S INNOVATION STAKEHOLDERS

Indonesia has many experts who understand the unique landscape of geothermal, as discussed in this section.

State Research Agencies—National Research and Innovation Agency (BRIN)

BRIN sets the national research and development agenda and runs labs, pilot plants, and consortia that turn ideas into field-ready solutions.[28] Priority areas include exploration geoscience, drilling, reservoir modeling, surface systems, and direct-use applications. BRIN also handles national intellectual property (in coordination with the Directorate General), standardization with industry partners, and technology transfer—bridging the technology readiness gap so developers can de-risk early wells and lower the levelized cost of energy.[29] Despite being the main research and innovation agency, BRIN is impacted by the nation's budget and currently is short on funding. As BRIN and universities refine national research and development priorities, incorporating direct-use geothermal research such as heat network design, absorption cooling, and industrial symbiosis models can help prepare Indonesia to lead in next-generation geothermal deployment. These efforts could link geothermal research to industrial policy, workforce training, and regional innovation hubs.

Energy and Utility Companies

Pertamina Geothermal Energy (PGE)

PGE is a subsidiary of PT Pertamina (Persero), Indonesia's main non-electricity energy state-owned enterprise. PT Pertamina anchors Indonesia's domestic operating base. It sets de facto norms for contractors, lenders, and insurers on well design, lost-circulation control, brine handling, separation pressures, and make-up well strategy. Because PGE operates a large, diverse portfolio, it can pilot improvements and scale what works across fields, pushing sector learning curves down and availability factors up. Pertamina generally collaborates pragmatically with foreign engineering, procurement, construction and management firms, original equipment manufacturers, and technical advisers while enforcing local content requirements and standard procurement rules, so global know-how blends with local supply-chain growth.

INSTITUTIONAL FRAMEWORK FOR GEOTHERMAL GOVERNANCE IN INDONESIA

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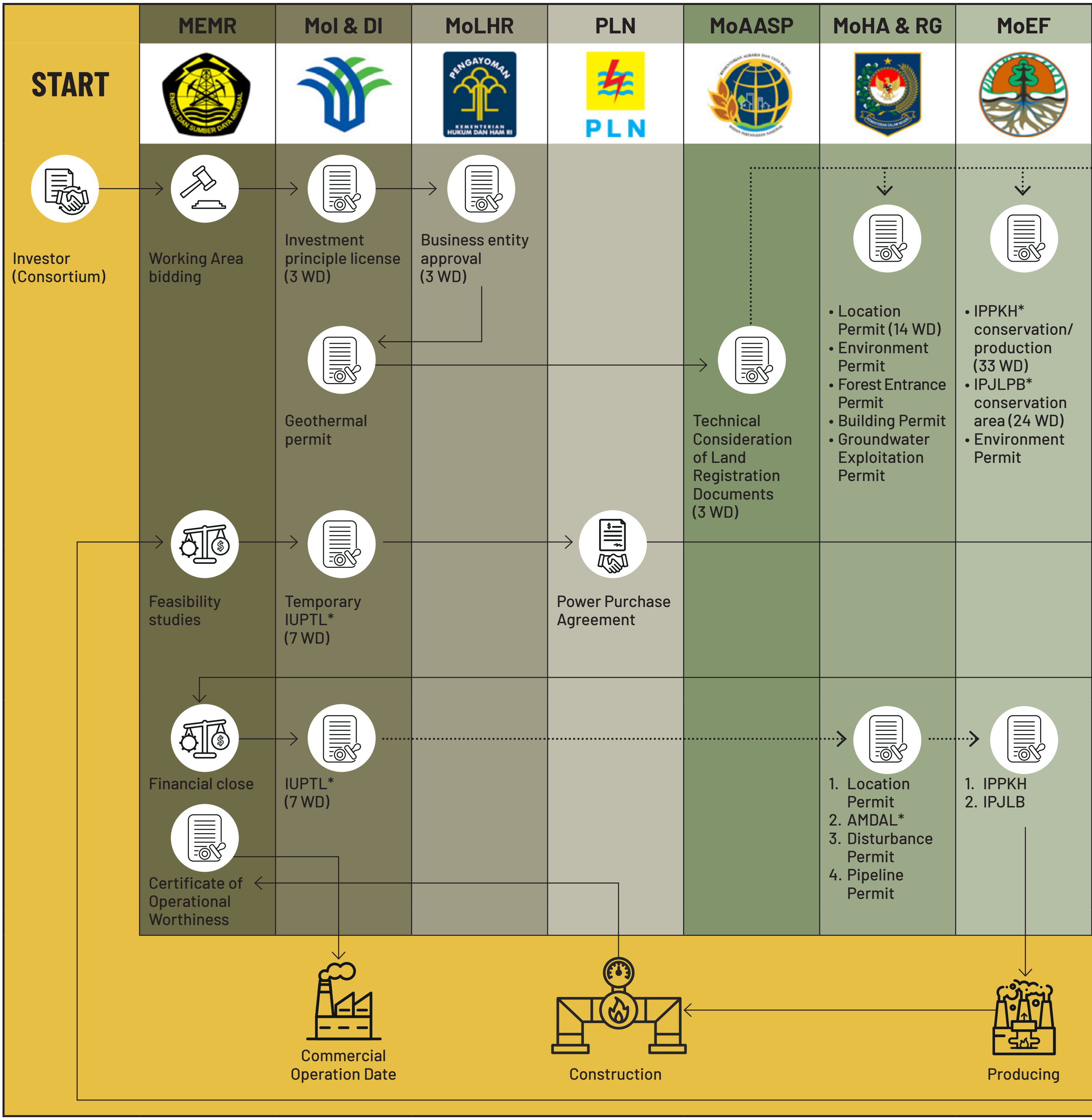

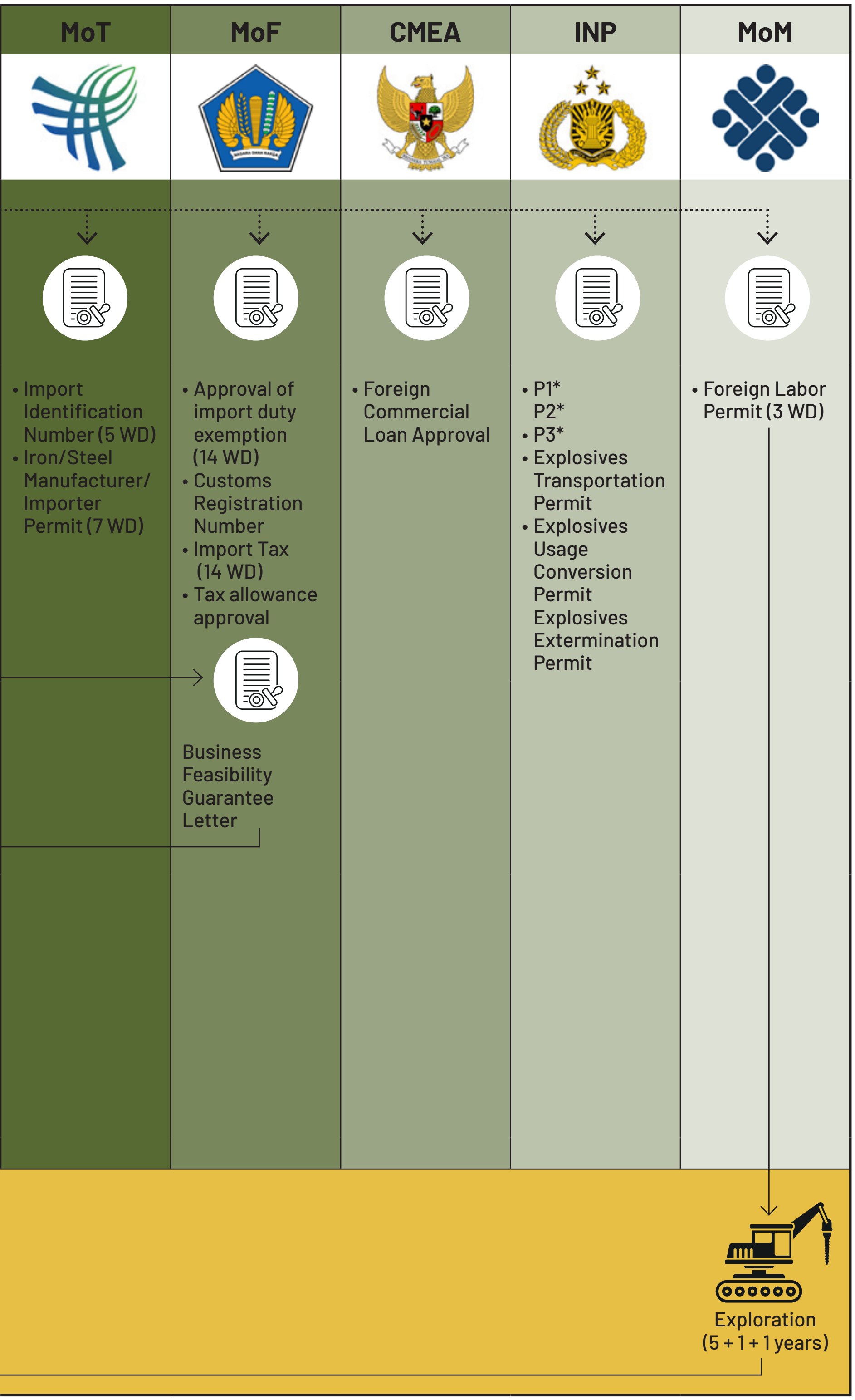

Business Process

Open Bidding of Geothermal Working Areas

Note:

→ Finish-to-Start Process

⋯> Parallel Process

Ministries Abbreviations:

MEMR	Ministry of Energy and Mineral Resources (KemenESDM)
MoI & DI	Ministry of Investment and Downstream Industry
MoLHR	Ministry of Law and Human Rights (Kemenkumham)
PLN	State Electricity Enterprise (Perusahaan Listrik Negara)
MoAASP	Ministry of Agrarian Affairs and Spatial Planning (KemenATR/BPN)
MoHA & RG	Ministry of Home Affairs & Regional Governments (Kemendagri dan Pemda)
MoEF	Ministry of Environment and Forestry (KemenLHK)
MoT	Ministry of Trade (Kemendag)
MoF	Ministry of Finance (Kemenkeu)
CMEA	Coordinating Ministry for Economic Affairs
INP	Indonesia National Police (POLRI)
MoM	Ministry of Manpower (Kemnaker)

Ministry names written in red have been changed or divided into several ministries since October 2024.

Permits Abbreviations:

IPPKH	Borrow-to-Use Forest Area Permit
IPJLPB	Geothermal Environmental Services Utilization Permit
P1	Use of Remaining Explosives Permit
P2	Purchase and Use of Explosives Permit
P3	Possession, Control, and Storage of Explosives Permit
IUPTL	Electricity Supply Business License
AMDAL	Environmental Impact Assessment

Figure 6.8: Interactions between ministries and agencies in Indonesia related to geothermal energy. WD = working days. Source: Ministry of Energy and Mineral Resources. (2018). *Doing business in geothermal*. Government of Indonesia; processed by Purnomo Yusgiantoro Center.

Perusahaan Listrik Negara (PLN)

PLN is Indonesia's state-owned electricity company tasked with the generation, transmission, and distribution of power across the archipelago. It effectively holds a monopoly on electricity distribution in Indonesia while also coordinating with independent power producers to meet national demand. It operates under full government ownership via the Ministry of State-Owned Enterprises and plays a central role in implementing the country's electricity planning.

Three important stages at PLN influence a project's destiny:

1. First, a geothermal electricity project needs to be included in PLN's Electricity Supply Business Plan (ESBP), a 10-year roadmap for developing generation, transmission, and distribution assets.[30] (The ESBP is required by statute; it is also referred to as the RUPTL.) In practice, PLN is the only entity that issues a comprehensive RUPTL, and it covers the majority of the electric grid. (There are a few other licensed operators in specific business areas such as industrial parks, but these cover only limited territories.[31]) If a geothermal project is not listed in PLN's RUPTL, it means the capacity is not needed or prioritized in the near term for the region. Being left out of RUPTL effectively stalls a project's progress. Conversely, when a project is included in RUPTL, it signals that PLN has forecasted a need for the capacity and gives developers a green light to proceed.[32]

2. The second stage is proving the grid can accept and deliver a project's power. As the sole owner-operator of Indonesia's transmission and distribution networks, PLN conducts the interconnection studies; designs any required upgrades or connections; and sets technical requirements, the timeline for grid enhancements, and the allocation of interconnection costs. The process is tightly linked to system planning in the RUPTL, which pairs generation additions with planned transmission reinforcements. Developers may propose connection plans, but PLN reviews, approves, and often dictates the needed reinforcements via a feasibility study that includes the grid interconnection study.[33] This step is critical because excellent geothermal energy resources can still stall if the nearest grid node is weak or distant, forcing major upgrades that delay schedules or undermine project economics.[34] Practically, this second stage determines when and how the plant can connect: PLN sets the technical specs, clarifies who pays for which interconnection elements, and coordinates the Commercial Operation Date (COD), or the point at which the project's commercial terms take effect and bankability is proven with transmission readiness.

3. The final pivotal step with PLN is negotiating the PPA and carrying out the project through commissioning to COD. In the PPA, the tariff structure and key performance requirements are fixed, and the tariff typically applies from COD for the full contract term—commonly between 25 years and 30 years, with geothermal frequently at the upper end.[35] PPAs codify availability targets, dispatch obligations, curtailment rules, remedies and penalties, and the COD deadline with liquidated damages for delay.[36] Recent regulations aim to standardize terms, but as the sole buyer, PLN retains substantial negotiating leverage, making a balanced, bankable PPA essential for financial close.

PLN's role also extends to pre-COD testing and ongoing operational compliance. In short, this third stage—finalizing the PPA and achieving COD—locks in the project's economic and operational regime: Tariff and tenor are fixed from COD, while the PPA and grid code set the reliability, availability, and dispatching obligations that ultimately determine whether the project is financeable and operable at scale.

Private Independent Power Producers

Private developers (e.g., Medco, Star Energy, Barito Renewables) bring capital discipline, delivery speed, and specialist capabilities in drilling, reservoir surveillance, binary/Organic Rankine Cycle retrofits, and digital optimization. These companies join a project via WKP tenders from MEMR, acquisitions of stakes in existing projects, or partnerships with state holders. The teams that break through usually pair deep experience with robust balance sheets and strong local partners who can navigate permitting, land acquisition, and community engagement.

However, several consistent pain points consistently arise in Indonesia's geothermal development:

- Front-loaded exploration risk: expensive wells that ultimately lack necessary resources
- Sequential permitting processes (e.g., EIA, forest access, local approvals) that stretch schedules
- Tariff-cost gaps and prolonged Power Purchase Agreement negotiations that complicate financing, create grid constraints, or cause curtailment without clear make-up energy provisions
- Foreign exchange and interest rate exposure over long construction periods
- Local content requirement compliance for critical equipment

Clearer PPAs that value flexibility, concurrent permitting processes, and more transparent data-sharing will allow independent power producers to streamline work and focus on areas such as greenfield exploration and slim-hole pilots, brownfield optimization, and binary retrofits. Competition should push the levelized cost of energy down, expand domestic vendor bases, and deliver a steadier cadence of midsize additions that elevate geothermal's role as both baseload and balancing power. Together, Pertamina's scale and standards, PLN's planning and commercial rules, and independent power producers' specialization and agility create the feedback loops that govern cost, schedule, and reliability. When these players align, exploration risk falls, financing closes faster, and commissioning becomes more predictable.

Research-Intensive Public Universities and the Programs They Can Support

Programs	Public Universities
Subsurface science, drilling engineering, fluids and chemistry, environmental systems	Bandung Institute of Technology, Gadjah Mada University, University of Indonesia, Sepuluh Nopember Institute of Technology, Bogor Agricultural University
Industry-embedded curriculum to bridge the classroom to the field	Universitas Pertamina
Well engineering, drilling management, production operations, finance, social research, policy	National Development University "Veteran" campuses, Trisakti University, University of Indonesia (economics and public policy faculties), Prasetiya Mulya University, Bina Nusantara University, Padjadjaran University, and Gadjah Mada University

Sources: Faculty of Mining and Petroleum Engineering. (n.d.). *Master's program in geothermal engineering*. Institut Teknologi Bandung; Department of Geological Engineering. (n.d.). *Geothermal Research Center (GRC)*. Gadjah Mada University.

Equally important is the hands-on workforce that keeps plants running and schedules on track. As explained in Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions," polytechnics and vocational institutions—such as MEMR's Energy and Mineral Polytechnic "Akamigas" in Cepu, or other major institutes under the Ministry of Education, Culture, Research, and Technology, along with secondary vocational training programs in electrical, plumbing, welding, and instrumentation—should be mobilized via coursework, site rotations, and competency-based credential programs aligned to geothermal job standards. MEMR training centers and the Ministry of Manpower's Vocational Training Center can deliver micro-credentials for drill crews; rig mechanics; electricians; welders; health, safety, and environment officers; and instrumentation technicians, ensuring local hires are work-ready for exploration, construction, and operations and maintenance.

And to make the ecosystem truly work, regulatory stakeholders, state research agencies, energy and utility companies, private independent power producers, and universities should operate as a single ladder: shared "living lab" sites near WKP, joint curricula co-designed with developers and original equipment manufacturers, credit transfer between diploma and degree tracks, and incubators that back entrepreneurs in direct-use applications (e.g., process heat for agro-industry, cold storage, district heating for tourism). With this integrated approach, Indonesia can produce the engineers, analysts, and tradespeople needed to scale geothermal from exploration to grid-reliable operations.

CONCLUSION

Community consultations across Indonesia echo a simple message: Build geothermal *with* people, not for them. Engagement must be continuous and two-way so that suku adat communities, village governments, women and youth groups, and local small and medium enterprises feel included and respected. A fracture in these relationships can stall a project and sour the pipeline for years. Many of the concerns raised in this chapter arise from hydrothermal projects near sensitive areas; these are less applicable to next-generation systems or direct-use heat and cooling. The following practical considerations aim to encourage positive, durable collaboration on all types of geothermal development. Some are explored in more detail in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation."

CONSIDERATIONS TO ENCOURAGE DURABLE COLLABORATION

1. **Strengthen co-governance with host communities.** Uphold meaningful participation and free, prior, and informed consent for wilayah adat; provide early technical assistance, translation, facilitation, and grant-writing support so communities can participate as equal partners.

2. **Create a provincial/community geothermal fund.** Define the share of non-tax geothermal revenues (PNBP Panas Bumi) and corporate obligations into predictable, multiyear funding for host areas—allocated through participatory village planning, with public budgets and outcome-based contracts.

3. **Prioritize community development.** Offer grants for youth groups, cooperatives, and women-led enterprises to participate in upskilling training; micro, small, and medium enterprise upgrades; and local services that align with plant needs and regional development plans.

4. **Streamline permitting into a single critical path.** Appoint a lead agency, require pre-application scoping (e.g., land/forest status, water, grid, pricing), shift to parallel approvals with time-bound service-level agreements, and provide a shared OSS tracker with automatic escalation when timelines slip.

5. **Integrate land, environment, and grid decisions early.** Utilize a "single map" data set, standardize benefit-sharing clauses, and secure early interconnection studies with PLN to minimize redesigns, de-risk timelines, and enhance bankability.

6. **Make local content deliver real capability.** Pair local content requirements and targets with vendor development, accredited training, and BRIN–university–industry consortia; earmark a portion of geothermal revenues for research and development, testing services, and workforce pipelines.

7. **Publish what matters and fix it fast.** Establish transparent Monitoring–Evaluation–Learning dashboards, independent social audits, and credible grievance mechanisms with time-bound remedies so results are visible, comparable, and improvable.

8. **Align finance with risk and speed.** Implement targeted steps to reduce the financial risk tied to meeting social license to operate and local content milestones, and reward on-time permitting performance with fiscal incentives.

9. **Prioritize anchor offtakers and direct-use hubs.** Target industrial parks, data centers, tourism zones, cold-storage and water facilities, and defense sites such as border posts and defense installations to convert heat into local jobs and durable demand.

10. **Pilot, learn, and replicate.** Launch pilot projects, evaluate them and ensure information is transparent, then scale the model across provinces with clear roles for MEMR, the Ministry of Environment and Forestry, the Ministry of Investment and Downstream Industry, PLN, and local governments.

11. **Build the talent pipeline.** As discussed in Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions," MEMR and Ministry of Education, Culture, Research, and Technology should establish a national geothermal talent coalition that unites research universities, polytechnics, and the Ministry of Manpower's Vocational Training Center into a single ladder—WKP living labs, joint original equipment manufacturer and developer curricula, co-ops, micro-credentials, and credit transfer—to supply the workforce needed to scale geothermal from exploration to grid-reliable operations.

12. **Expand geothermal beyond power.** Expand the definition of geothermal development beyond power generation to include direct-use applications and geothermal cooling. Establish pilot programs and clear policy frameworks to support these applications as part of Indonesia's industrial decarbonization and community energy strategies.

These actions can turn geothermal projects into visible community progress, shorten project timelines, and build Indonesian capability. They will make geothermal both a reliable source of heat and power and a generator of fair opportunity wherever the resource heat is found.

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Chapter 7

Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation

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With some of the planet's richest geothermal resources, Indonesia is a world leader in conventional geothermal deployment—and the nation also has thousands of gigawatts of untapped next-generation geothermal potential. The policies outlined in this chapter can help Indonesia leverage that potential into electricity, direct-use heat, and cooling.

To date, the Ring of Fire nation has deployed almost 3 gigawatts of geothermal electricity—less than 10% of its proven hydrothermal reserves. The country has a stated goal of increasing its geothermal output by 5 gigawatts by 2034 to reach more than 8 gigawatts of power production.[1] By following the policy roadmap outlined in this chapter, however, the nation could deploy 15 gigawatts of firm geothermal electricity and 15 gigawatts thermal of geothermal heat by 2035. This 15 gigawatts electric is a combination of the government's 2034 target and an additional 6 gigawatts electric from next-generation technologies and resources. Those figures could even grow to reach 25 gigawatts electric and 35 gigawatts thermal by 2045.

As shown by the data in the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities," the nation's technical geothermal potential runs to 2,160 gigawatts outside of protected areas, making the stated goals ambitious—yet achievable.

In fact, achieving even a fraction of its geothermal potential would strengthen Indonesia's grid resilience, lower peak demand, reduce fuel imports, sharpen industrial competitiveness, expand affordable cooling—and cement Indonesia's role as a global leader in clean, firm energy. This chapter outlines a roadmap for how to achieve these goals by scaling next-generation geothermal power, urban cooling, and industrial heat. By implementing the 10 policy

GEOTHERMAL POLICY RECOMMENDATIONS FOR INDONESIA

UNLEASH INDONESIA'S NEXT-GENERATION GEOTHERMAL POTENTIAL

- Update Geothermal Laws to Clearly Address Next-Generation and Direct-Use Geothermal
- Set National Targets for Geothermal Electricity and Industrial Heat and a Pathway to Get There
- Power Industry and Data Centers with Geothermal Heat and Cooling
- Make Geothermal Cooling Core to Urban Development

MOBILIZE INVESTMENT AND ACCELERATE SCALE

- Fast-Track Permitting, Administrative Coordination, and Other Procedures
- Reduce Financial Risk with Open Data and Expanded Exploration Programs
- Use Collective Procurement to Lower Project Costs
- Standardize Long-Term Geothermal Power Contracts

STRENGTHEN COMMUNITY TRUST AND BENEFITS

- Empower Community Participation and Guarantee Community Benefits by Reforming Geothermal Production Bonuses
- Expand the Geothermal Ecosystem to Unlock Local Jobs

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recommendations offered in this chapter, Indonesia could put itself on track to meet its climate targets while also lowering consumer and industrial energy bills, creating more than 650,000 quality jobs, and unlocking billions in private investment.

Grounded in Indonesia's geological strengths and state capacity—and informed by global best practices—this package ensures communities share the benefits, strengthens energy security, and delivers these outcomes with significantly lower environmental risk than fossil fuels or conventional geothermal.

10 RECOMMENDATIONS TO EXPAND GEOTHERMAL DEVELOPMENT IN INDONESIA

Unleash Indonesia's Next-Generation Geothermal Potential

Indonesia is a global leader in conventional geothermal, but an important next step for the country to take is incorporating next-generation geothermal power—as well as geothermal cooling and industrial process heat—into its frameworks.

1. Update geothermal laws to clearly address next-generation and direct-use geothermal.
2. Set national targets for geothermal electricity and industrial heat and a pathway to get there.
3. Power industry and data centers with geothermal heat and cooling.
4. Make geothermal cooling core to urban development.

Mobilize Investment and Accelerate Scale

Creating project finance certainty and unleashing private capital will be key to growing Indonesia's geothermal opportunities.

5. Fast-track permitting, administrative coordination, and other procedures.
6. Reduce financial risk with open data and expanded exploration programs.
7. Use collective procurement to lower project costs.
8. Standardize long-term geothermal power contracts.

Strengthen Community Trust and Benefits

Expand benefits for communities and workers while reducing environmental risks.

9. Empower community participation and guarantee community benefits by reforming geothermal production bonuses.
10. Expand the geothermal ecosystem to unlock local jobs.

Taken together, these measures can provide Indonesia with a decisive pathway: a modern legal foundation that embraces next-generation geothermal and geothermal heating and cooling; a risk-sharing framework that mobilizes private and public capital; market rules that create predictable demand and fair pricing; and safeguards that guarantee communities share directly in the benefits.

INDONESIA'S CURRENT GEOTHERMAL LEGAL FRAMEWORK

Indonesian law used to classify geothermal exploration as mining operations, which subjected power project development to complicated rules and regulations.[2] But the enactment of Geothermal Law No. 21/2014, designed around conventional hydrothermal systems, reclassified the use of geothermal as a non-mining activity and helped streamline geothermal development.[3] The law also distinguished geothermal development for electricity—"indirect use"—from "directly used" geothermal.

While helpful, this change put geothermal electricity licensing in the hands of the central government[4]—and left direct-use geothermal licensing split, inefficiently, between the central and local governments.[5]

Today, developers of geothermal applications require distinct permits depending on the type of installation:

1. Electricity generation requires a Geothermal Business Permit.[6]
2. Under Ministry of Energy and Mineral Resources (MEMR) Regulation 5/2021, direct-use projects instead require a Certificate of Operational Worthiness specific to geothermal direct-use.[7]
3. If a geothermal site is located in a forest area, a developer must also obtain an official Approval for the Use of Forest Areas.[8]

In 2017, legislators introduced more detailed regulations for electricity generation permitting processes via Government Regulation No. 7/2017[9] and MEMR Regulation No. 37/2018.[10,11]

Business licensing in the energy sector is governed by MEMR Regulation No. 5/2021,[12] which links geothermal activities to their respective Indonesian Standard Industrial Classifications (KBLIs) within the national Online Single Submission (OSS) system. This regulation also outlines requirements for operational readiness through the Certificate of Operational Worthiness for geothermal facilities. However, this is the extent of Indonesia's current national regulatory framework for geothermal direct-use projects, as the government has not yet issued a dedicated KBLI or implementing regulation for direct-use activities. Since the enactment of Omnibus Law No. 11/2020 (Job Creation Law),[13] Indonesia's government has expressed its intent to simplify regulations governing direct-use geothermal activities, but it has yet to do so.

CURRENT FRAMEWORK GOVERNING GEOTHERMAL ELECTRIC POWER PLANT DEVELOPMENT

PLN, Indonesia's state-owned national electricity utility, owns and operates the national power grid. The utility controls generation, transmission, distribution, and retail. Private sector participation happens mainly through independent power producers selling power to PLN under Power Purchase Agreements. Direct sales to industrial consumers are allowed under limited conditions. This structure is governed by Electricity Law No. 30/2009 and MEMR Regulation No. 10/2018.

For the geothermal power, Government Regulation No. 7/2017 under the Geothermal Law establishes the framework for indirect use—electricity generation—placing MEMR in charge of Geothermal Working Areas and permits and providing the basis for power sales to PLN. As the government revises Government Regulation No. 7/2017 through 2025 to streamline development,[14] it should ensure that emerging technologies such as advanced geothermal systems and engineered geothermal systems are explicitly incorporated into the updated framework. (See Recommendation 1.)

The Directorate General of New, Renewable Energy and Energy Conservation in MEMR leads the implementation of geothermal policy, pricing, and licensing. MEMR also coordinates financing and policy support with other ministries such as the Ministry of Finance, the Ministry of State-Owned Enterprises, the Ministry of Industry, the Ministry of Investment and Downstream Industry, the Ministry of Environment, and the Ministry of Forestry. Recent reforms include the OSS system for permits and MEMR Regulation No. 11/2024 on domestically made equipment. MEMR also formulated ceiling prices for renewables under Presidential Regulation No. 112/2022, the current geothermal electricity tariff regulation.

PLN indicates that the shift to the current price regime has made it easier to offer more attractive prices to developers and provides a stronger legal basis for Power Purchase Agreement negotiations. However, some geothermal power plant developers have suggested that the current ceiling price still falls short of private sector expectations, particularly in terms of desirable internal rates of return.

As mentioned, the Geothermal Law and related regulations set out the geothermal licensing process for electricity generation. Key stages include (i)

SUMMARY OF GEOTHERMAL DEVELOPMENT SCHEMES AND KEY IMPLEMENTING ENTITIES IN INDONESIA

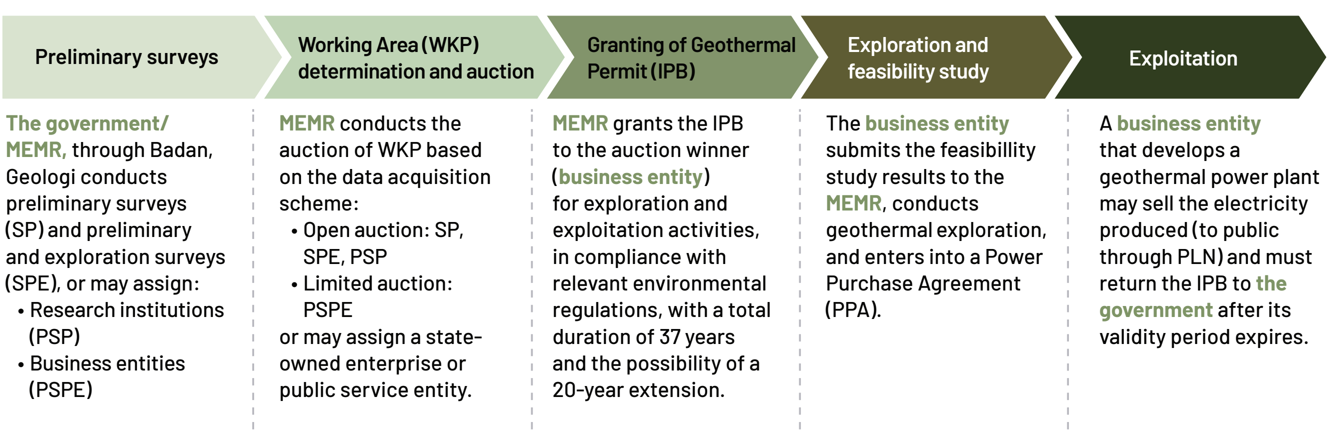

Figure 7.1: Summary of geothermal development phases and plans and related key entities. Source: authors.

preliminary surveys; (ii) government auctions of Geothermal Working Areas (WKP) where developers obtain a Geothermal Business Permit (IPB); (iii) exploration and development (up to seven years) covering studies, drilling, and assessments; and (iv) the signing of a Power Purchase Agreement (PPA) with PLN. (See **Figure 7.1**.)

To reach a commercial phase, PLN currently offers three main programs:

1. Independent Power Producers' WKP partnerships, which operate under several possible arrangements:
   - Power Purchase Agreement: The Geothermal Business Permit (IPB) holder develops and operates the power plant independently or jointly with a PLN subsidiary.
   - Special Project Company: The project is developed through a dedicated joint venture entity formed between the geothermal developer and PLN (or its subsidiary).
   - Steam Purchase Agreement: The IPB holder supplies steam to a PLN subsidiary that owns and operates the power plant, as in the Kamojang plant in West Java.
2. PLN-owned and operated WKPs (self-management) in which PLN develops and manages plants, including well operations, directly.
3. Geothermal Exploration and Energy Conversion Agreements, which bring private partners into PLN-owned WKPs. These agreements share the risks and rewards by assigning PLN responsibility for permitting, land acquisition, and site preparation while offering early drilling cost payments to improve project returns.

In addition, the national government has introduced a series of policies to accelerate geothermal power plant development. Key measures include the Government Drilling Scheme (Ministry of Finance Regulation No. 62/2017),[15] which is expected to reduce early-stage risks by financing exploration; the shift from Build-Own-Operate-Transfer (BOOT) to Build-Own-Operate (BOO) (MEMR Regulation No. 4/2020), which should make projects more bankable by allowing developers to retain ownership; and the Carbon Economic Value framework (MEMR Regulation No. 16/2022), which enables revenue via carbon credits. Further support comes from the relaxation of local content requirements (MEMR Regulation No. 11/2024) to improve project bankability. Together, these policies were established to lower costs, share risks, and move stalled projects along.

GEOTHERMAL DIRECT-USE OVERVIEW AND DEVELOPMENT PLANS

In 1999, Pertamina Geothermal Energy and the National Research Institute developed the nation's first direct-use geothermal system—a mushroom-harvesting project in the Kamojang geothermal field in West Java.[16] At the time, Indonesia's geothermal framework, Law No. 27/2003, had only one mention of direct use.[17] Unfortunately, 15 years later, geothermal direct use remains relatively underutilized considering the nation's rich subsurface resources, with Indonesia ranked 74th among 88 surveyed nations in total megawatt thermal use.[18] (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," for more information.)

Even more striking, analysis undertaken by Project InnerSpace suggests that Indonesia has thousands of gigawatts of thermal potential across the whole country. This finding tracks with analysis explained in Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," that shows geothermal could cost-effectively meet 66.5% of Indonesia's thermal demand by 2030—which would be 44% of the nation's climate goal. What's more, these resources could serve nearly 90% of the country's thermal demand by 2050. The lack of direct-use geothermal in Indonesia today is not surprising: While Law No. 21/2014 lists four categories of potential geothermal direct-use applications to guide developers (tourism, agri-business, industry, and other activities),[19] it prioritized the development of geothermal for *indirect* use—in other words, for electricity generation.[20] Add to that, Government Regulation No. 25/2021 lists 13 obligations for Geothermal Business Permit holders. The development of direct use is 12th on the list.[21]

Although the nation did issue important regulations and guidelines to stimulate local economic growth and drive the national energy transition,[22,23] they are mostly procedural and do not create the enabling conditions required for large-scale commercial deployment of direct-use geothermal.

Creating conditions that can enable the use of direct-use geothermal would be an impactful step for Indonesia. The policy roadmap outlined in this chapter includes several recommendations that would help Indonesia deploy direct-use geothermal either for urban cooling or industrial heat applications nationwide. Doing so would simultaneously improve air quality and the health of its citizens and help the country reach its climate goals.

POLICY RECOMMENDATIONS

The 10 recommendations in this chapter offer a mix of short-, medium-, and long-term ideas for how Indonesia can unlock more geothermal potential across the country. One of the most important steps Indonesia can take now is to implement Recommendation 1, which would establish a legal framework for next-generation geothermal projects and clarify the use of geothermal for industrial heat and cooling.

Recommendation 1: Update Geothermal Laws to Clearly Address Next-Generation and Direct-Use Geothermal

Who Takes Action: MEMR Directorate General of New, Renewable Energy and Energy Conservation and Directorate General of Mineral and Coal; House of Representatives of the Republic of Indonesia

Geothermal Law No. 21/2014 provides the principal legal foundation for geothermal development, but it was written for conventional hydrothermal systems. Since the law was passed, next-generation technologies—such as engineered geothermal systems and advanced geothermal systems—have emerged that use engineered reservoirs, closed-loop wells, or advanced heat-exchange methods rather than relying on naturally occurring hydrothermal fields. (See Chapter 1, "Geothermal 101: Overview of Technologies and Applications"). Yet Indonesian law still defines geothermal resources largely as underground water and steam, leaving these new technologies outside the nation's legislative scope and creating uncertainty for licensing, investment, and environmental safeguards for next-generation geothermal power projects.

At the same time, Indonesia's energy demand is shifting rapidly toward heat and cooling. Many industrial clusters rely heavily on low- to medium-temperature heat (less than 225°C), and urban cooling demand is projected to rise sharply. Today, geothermal direct-use projects—industrial heat and district-scale cooling—lack a clear statutory basis that treats them as energy infrastructure on par with electricity generation. The government also lacks a clear regulatory framework that manages the use of geothermal brine and excess heat for commercial direct-use purposes. Without such frameworks, developers face ambiguity regarding pricing, incentives, and planning integration.

To address these gaps, Law No. 21/2014 should be amended to define geothermal energy. The current definition is as follows: "Geothermal energy means thermal energy sources as contained in hot water, steam, and rocks along with associated minerals and other gasses that are genetically inseparable in a geothermal system."

To clearly address next-generation and direct-use geothermal, this definition could be changed to the following: "Geothermal energy means thermal energy originating from the Earth's subsurface, regardless of its medium of transfer or method of extraction, including but not limited to naturally occurring steam and hot water, artificially stimulated reservoirs, closed-loop systems, and other advanced geothermal technologies." This definition should explicitly encompass current and future methods of heat harvesting to ensure regulatory clarity, investment certainty, and alignment with global technological progress. In parallel, revisions to Government Regulation No. 7/2017 should integrate these technologies into the licensing and pricing framework for both power and direct-use applications. The amended law should also designate geothermal direct-use systems as "priority infrastructure," granting them eligibility for streamlined permitting, regulated tariffs, and coordinated planning support under Indonesia's national infrastructure policy.[24]

In addition to changing the definition of geothermal and granting direct-use projects priority infrastructure status, the government could take several other concrete next steps to operationalize this recommendation, including the following:

- **Establishing a national tariff framework for geothermal heat and cooling**—benchmarked against displaced fossil fuels—and pairing the framework with a value-added tax (VAT) and customs relief for geothermal cooling systems and components in designated zones, drawing on models from Turkey's geothermal district heating networks[25] and France's Paris Basin regulated tariffs.[26]
- **Introducing standardized heat and cooling supply agreements (HSAs/CSAs)** with indexed pricing, minimum-take obligations, and long-term commitments—modeled on international best practices[27]—to ensure bankability, pricing transparency, and reliable heat delivery.
- **Implementing rights-of-way and connection rules** for thermal loops and buried pipelines, modeled after European district-heating frameworks to enable integration into urban and industrial planning.
- **Funding targeted pilot projects** to jump-start direct-use heating, geothermal cooling, and next-generation power projects, which can help demonstrate viability, build investor confidence, and accelerate deployment.

Local governments should also play a central role in geothermal direct-use planning, tailoring implementation to regional industry, community, and tourism needs. Lampung Province's Regional Regulation No. 11/2019 on surface-water use illustrates how provinces can lead by creating a fiscal

CRITICAL MINERAL EXTRACTION FROM GEOTHERMAL BRINES

Indonesian law defines geothermal development and mineral extraction as two different activities.[31] But geothermal exploration, particularly from conventional geothermal systems, can also produce critical minerals such as lithium, silica, and rare earth elements that are dissolved in geothermal brines. These brines have the potential to be a solid source of lithium; they contain concentrations of up to 60 ppm,[32] compared with 0.2 ppm of lithium concentration from seawater. (Silica can also be extracted from geothermal sludge.[33])

Minerals extracted from geothermal fluid can be used for agriculture and the cosmetic industry. In Iceland, several skincare products and supplements, namely MýSilica and GeoSilica, come from the by-product water of geothermal power plants.

In Indonesia, several research initiatives focused on geothermal byproducts for the agriculture sector are underway. Katrili and Sulasih-Sulanjana are fertilizer-booster products developed through collaborations between University of Gadjah Mada and PT Pertamina Geothermal Energy, as well as PT Geo Dipa Energi (Persero).[34] The products use nano-particulate silica to strengthen plants' resistance to pests and improve moisture retention in soil. They have demonstrated promising results, with local farmers reporting larger, more resilient crop yields and improved overall crop stability.

The country's lithium needs are growing. For example, Indonesia is targeting 2 million electric cars and 13 million electric motorcycles by 2030, which could mean it would need hundreds of thousands of tons of lithium in the next five years.[35] Extracting the lithium from geothermal brine is less environmentally impactful than mining it from the Earth.

In updating laws, the government should recognize mineral extraction as a permissible co-activity within geothermal concessions and write regulations specifically to allow mineral extraction from geothermal brines.

Along with legal reforms outlined, the government should also offer streamlined licensing procedures that allow geothermal operators to apply for mineral extraction rights under their existing concession, rather than requiring separate permits. Fiscal incentives such as import duty exemptions for mineral recovery technologies could reduce financial risks for early-stage projects.

and governance framework—defining who pays, how fees are calculated, and how revenue is allocated.[28] A similar model could establish permitting and registration systems for direct-use wells and pipelines; set usage fees or royalties based on heat extracted, application type, and scale; and channel revenues toward community infrastructure, regional industrial parks, and eco-tourism facilities. A national regulation could then replicate and standardize this approach across Java, Sumatra, and other regions with high thermal demand. (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential.")

Issuing a higher-order regulation for geothermal direct use and elevating the "encouragement and/or prioritization of direct-use geothermal in WKP" within Government Regulation No. 25/2021[29] would send a clear signal that Indonesia intends to treat industrial heat and building cooling with the same strategic importance as electricity. These actions can create the policy certainty needed for large-scale investment[30] and signal to domestic and international partners that Indonesia intends to unlock new opportunities for industrial competitiveness, national resilience, and green sovereignty.

Recommendation 2: Set National Targets for Geothermal Electricity and Industrial Heat and a Pathway to Get There

Who Takes Action: MEMR Directorate General of New, Renewable Energy and Energy Conservation and Directorate General of Electricity; PLN

Two related steps that Indonesia could take are to (i) set coordinated national targets for firm geothermal electricity and direct-use geothermal heat—complementary pillars that can cut coal use, stabilize the grid, and decarbonize industry; and (ii) introduce a dedicated clean and firm procurement path within PLN's Electricity Supply Business Plan (RUPTL) to ensure a pathway to meet these goals.

Based on the technical potential discussed in this report, we recommend the goal of 15 gigawatts electric and 15 gigawatts thermal heat by 2035, scaling to 25 gigawatts electric and 35 thermal by 2045. These paired goals align procurement, planning, and finance so that power and heat grow together.

To help ensure the country meets these targets, the government could create a clear procurement path inside PLN's RUPTL with multi-year capacity awards dedicated to geothermal and carve-outs for next-generation systems. Although the ceiling prices established under Presidential Regulation No. 112/2022 are higher than the current average electricity supply cost, many developers still view the prices as insufficient to stimulate investment, noting that an internal rate of return of around 14% is often needed for geothermal projects. In addition, geothermal plants should receive capacity credits at or above 90% to reflect their round-the-clock reliability, with bonus payments for high availability.

In line with Indonesia's commitment to phase out coal-fired power plants—most notably MEMR Regulation No. 10/2025 on the Roadmap for Energy Transition in the Electricity Sector,[36] which mandates early retirement of coal plants—geothermal should be recognized as a central pillar of that transition. Repurposing or co-locating next-generation geothermal facilities at existing coal sites can preserve grid stability and infrastructure value while advancing the national phase-out agenda.[37] Multiple coal plants in Indonesia sit on top of high geothermal heat and are early candidates for further investigation. (For more details see Chapter 2, "Powering the Transition: Indonesia's Geothermal Market.")

Recommendation 3: Power Industry and Data Centers with Geothermal Heat and Cooling

Who Takes Action: MEMR Directorate General of New, Renewable Energy and Energy Conservation and Directorate General of Electricity; Ministry of Industry; Ministry of Communication and Digital

Indonesia's biggest and most immediate geothermal opportunity lies in cleanly and efficiently meeting thermal energy demand. In 2023, industrial and process heat demand totaled 2,998,059 terajoules, generating approximately 241 million metric tons of carbon dioxide emissions—almost one-quarter of Indonesia's total energy-related emissions. As explored in Chapter

4, “Beyond Electricity: Indonesia’s Thermal Energy Demand and Direct Use Potential,” if geothermal and other clean heat solutions decarbonize two-thirds of this thermal demand by 2030, the emissions savings could reach close to 160 million metric tons of carbon dioxide—44% of Indonesia’s 2030 reduction pledge in the energy and industrial sectors. The Nationally Determined Contributions have not yet assigned an energy-only quota for Indonesia’s 2060 net-zero pathway, but direct-use geothermal could decarbonize 90% of thermal demand by 2060, a nationally significant cut. In other words, geothermal for cooling and for providing industrial heat is a pivotal lever for Indonesia to accomplish its energy goals.

The ideal place to start this work and drive geothermal deployment at scale is in industrial clusters and data centers. Industries such as textiles, food and beverage, pulp and paper, and chemicals all use process heat with temperatures below 250°C—ideal for geothermal. Additionally, Indonesia’s rapidly expanding digital economy is driving exponential growth in energy-intensive data centers, which require year-round, highly reliable cooling that can be efficiently supplied through geothermal and mine-water systems.

In addition to the legal and regulatory updates suggested in Recommendation 1, the government could take several other concrete next steps to operationalize this recommendation, including in the following areas:

- **Thermal zoning and mandates:** MEMR and the Ministry of Industry, along with provincial governments, should designate geothermal heat priority zones in major industrial estates and urban districts; secure rights-of-way for piping as mandated under regional land use and infrastructure laws; and require that large new heat users locate in, or connect to, these systems.
- **Financing:** Through the Indonesia Infrastructure Guarantee Fund, PT SMI, and state banks, offer concessional loans and credit guarantees for shared thermal networks and retrofits, including pooled Special Purpose Vehicles at the industrial estate and urban district levels to aggregate credit.
- **Public procurement and project siting:** Require government-backed data centers and industrial parks in development to adopt geothermal-ready design standards and prioritize the integration of geothermal systems when siting a project in order to meet green certification requirements.
- **Replicable pilots:** Fund between three and five flagship industrial clusters (in Java, Sumatra, and Sulawesi) and two or three geothermal-cooled data center campuses, providing standardized HSAs/CSAs, technical and procedural rules that define how end-users connect to a shared network, and monitoring protocols—thus creating a national template that can be replicated.

By aligning industrial clusters and data centers with geothermal supply, Indonesia can produce the first gigawatts of direct-use heat deployment this decade. As a result, the country would cut fuel imports, stabilize energy costs, and help position itself to achieve up to one-third of its 2030 pledge and a significant share of its 2050–2060 climate goals.

Recommendation 4: Make Geothermal Cooling Core to Urban Development

Who Takes Action: Ministry of Agrarian Affairs and Spatial Planning; Ministry of Public Works; Ministry of Housing and Residential Areas; Ministry of National Development Planning

The International Energy Agency projects that between 2021 and 2030, Indonesia will have added more than 2 billion square meters of new housing. The agency also projects that by 2030, the number of households with air-conditioning units is likely to jump from about 1 in 10 to more than 1 in 3.[41] In parallel, Indonesia’s National Cooling Action Plan (I-NCAP) estimates electricity use for cooling will rise from 79 terawatt-hours in 2020 to 183 terawatt-hours in 2030 and about 265 terawatt-hours in 2040.[42] (See Chapter 2, “Powering the Transition: Indonesia’s Geothermal Market.”) The I-NCAP emphasizes the need for passive and district-scale solutions to reduce cooling-related emissions—an area where geothermal systems could provide continuous, low-carbon cooling with far lower peak electricity requirements.

The Ministry of Agrarian Affairs and Spatial Planning, the Ministry of Public Works and Housing, the Ministry of National Development Planning (Bappenas), MEMR

GEOTHERMAL-POWERED DATA CENTERS: INDONESIA'S PATH TO A GREEN DIGITAL ECONOMY

Co-locating data centers with geothermal resources offers a direct, always-on, and clean source of on-site power. A recent U.S.-based analysis shows this approach can cut the levelized cost of electricity by between 31% and 45% compared with traditional grid-dependent models.[38] With global technology companies racing to secure low-carbon, 24/7 power for data centers, few countries have more potential—and expertise—than Indonesia.

As of August 2024, PLN was serving 128 data center customers with nearly 1 gigawatt of load. Demand is projected to reach 4 gigawatts by 2033.[39] The rapid growth of AI could accelerate that demand by two or three times. With its exceptional subsurface heat resources, Indonesia is uniquely able to meet—and even surpass—this demand. Today, some existing data center activity overlaps with conventional geothermal production, but the fastest-growing digital load centers lie in areas where next-generation geothermal technologies come into play.

The Project InnerSpace GeoMap Beta tool highlights wide zones with favorable geothermal resources that sit directly below Indonesia's emerging data center corridors—Jakarta, Purwakarta, Surabaya, Batam, and Medan.[40] This match can enable off-grid geothermal generation near major fiber and industrial nodes, providing reliable, low-carbon baseload power exactly where it is needed.

Aligning Energy and Digital Growth

- **In Java,** the Jakarta–Purwakarta corridor hosts the country's highest concentration of data centers—and has some of the nation's best subsurface power potential.
- **In Surabaya,** strong geothermal resources can anchor the development of green data centers, while submarine cable interconnections can extend this digital and energy capacity to emerging hubs in South Kalimantan and Makassar.
- **In Sumatra,** geothermal resources align with fiber nodes in Lampung and Medan, creating potential for data center hubs powered by geothermal.
- **In the Riau Islands (Batam),** subsurface heat resources make the islands Indonesia's most strategic location for next-generation geothermal data centers because Singapore, next door, is constrained by land and renewable energy limitations and searching for ways to sustain its position as a global data hub. Next-generation geothermal systems in Batam can deliver reliable baseload power and ultra-low latency for one of Asia's most critical fiber nodes.

This confluence of demand and resources means Indonesia makes one of the world's most compelling cases for geothermal-powered digital infrastructure.

Policy Pathways and Incentives

The Indonesian government can take decisive steps such as the following to accelerate geothermal integration in the data center sector:

- **Mandate geothermal integration:** Electrify 50% of new or expanding data center loads within the next one or two years, aligned with Presidential Regulation No. 112/2022 on renewable tariffs.
- **Leverage geothermal heat for cooling:** Meet 50% of cooling demand via geothermal heat using direct-line (private wire) models, especially in Java and Sumatra.
- **Create fiscal incentives:** Offer tiered tax holidays by capital expenditure or energy load and VAT or import duty exemptions for geothermal and cooling equipment such as drilling tools, Organic Rankine Cycle units, absorption chillers, pumps, heat exchangers, immersion cooling hardware, and more.
- **Support co-location and clustering:** Establish geothermal industrial parks near major load zones, and grant land and building tax reductions for data centers that are situated on top of—or within 20 kilometers of—a geothermal field.
- **Offer flexible off-site incentives:** Extend special PPAs or partial benefits for off-site geothermal power users.

With strong regulatory direction, targeted fiscal incentives, and continued exploration of next-generation geothermal technologies, Indonesia can transform its geothermal endowment into the foundation of Asia's clean, connected future.

(as the energy sector coordinator), and provincial governments could take the following concrete steps to operationalize this recommendation:

- **Designate geothermal cooling zones** in dense districts, industrial clusters, and new developments (including Nusantara), reserving pipe corridors and shared borefield space.
- **Require geothermal-ready design** in municipal standards and large public or commercial projects.
- **Integrate district cooling** into urban master plans and procurement rules, using standardized connection codes, HSAs, and CSAs.

Geothermal cooling should be established as a core design principle of the new capital city to anchor the city's early growth. The Nusantara Capital Authority, in collaboration with the Ministry of Public Works and Housing and Bappenas, should adopt geothermal district-cooling pilots, which would reduce electricity demand during peak hours, lower emissions, and demonstrate a scalable and replicable model for other cities.

By embedding geothermal cooling in planning frameworks, Indonesia can keep cities livable without overloading the grid. If just 10% of Indonesia's projected 2040 cooling demand was

INDONESIA COOLING ELECTRICITY DEMAND PROJECTIONS

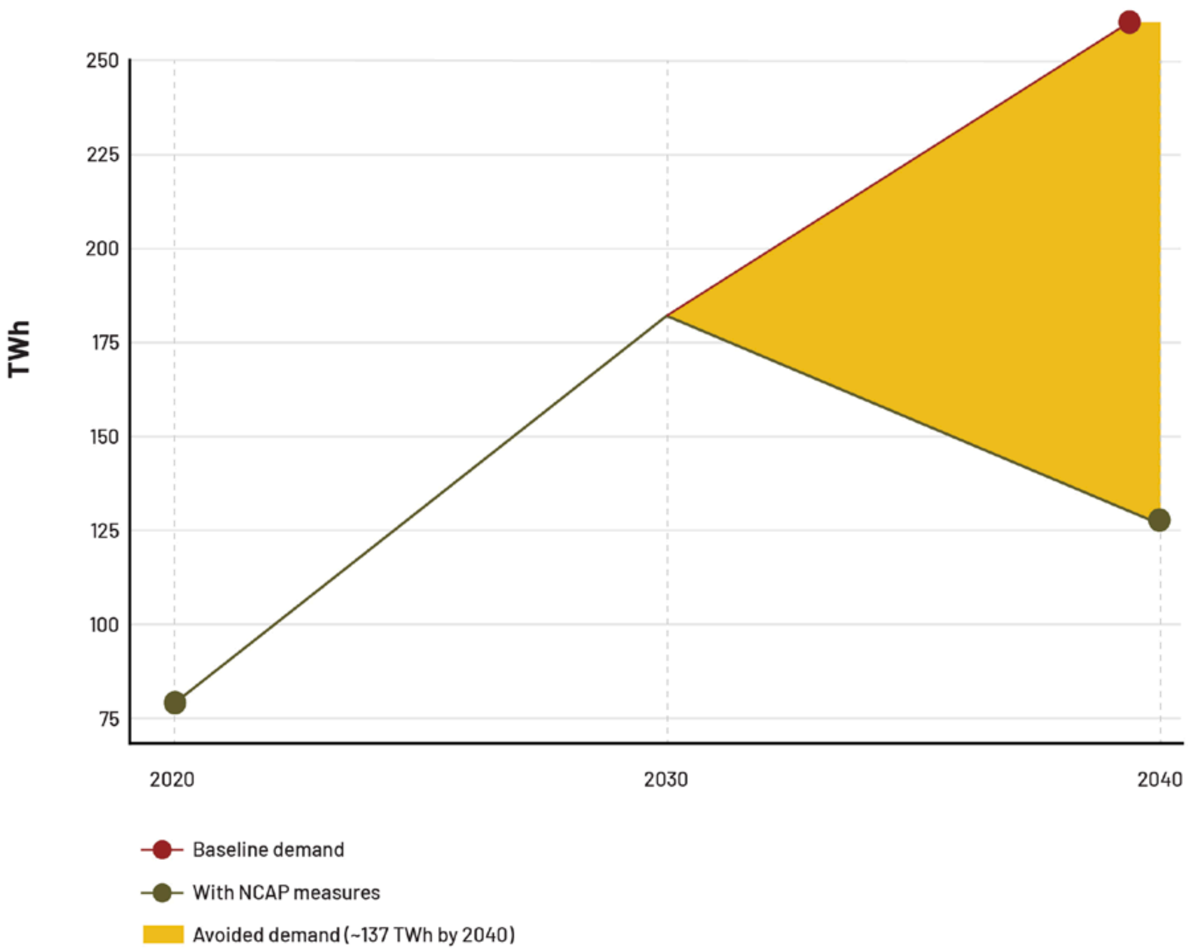

Figure 7.2: Positioning geothermal district cooling as the anchor technology for designated zones can shoulder a meaningful share of the national cooling efficiency wedge. NCAP = National Cooling Action Plan; TWh = terawatt-hours. Source: Adapted from United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) & United Nations Environment Programme (UNEP). (2024, August 6). *Indonesia sets path for climate-friendly cooling with National Cooling Action Plan (I-NCAP).*

met with geothermal instead of conventional air-conditioning, the country could avoid up to 130 terawatt-hours (see **Figure 7.2**) of peak electricity demand and tens of millions of tons of carbon dioxide emissions annually—the equivalent of taking several coal plants offline. This estimate is based on national projections that cooling could contribute more than 100 gigawatts to peak load by 2040,[43] and it assumes a conservative 10% substitution with low-power geothermal cooling systems. (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential.")

By treating geothermal cooling as priority urban infrastructure, Indonesia can meet its surging cooling needs without overburdening the power system. Early planning and zoning will reduce costs compared with retrofitting while also ensuring that urban populations remain protected from rising temperatures and risks of heat waves.

Recommendation 5: Fast-Track Permitting, Administrative Coordination, and Other Procedures

Who Takes Action: Ministry of Investment and Downstream Industry; MEMR Directorate General of New, Renewable Energy and Energy Conservation and Directorate General of Electricity

Indonesia has taken an important step with its OSS system that centralizes investment licensing across sectors, but the system functions primarily as a routing platform rather than a true one-stop authority, and geothermal projects still face multi-year delays. The process to obtain important permits such as environmental clearances, forest-use approvals, land rights, and water licenses remains fragmented across agencies and levels of government. Integrating geothermal permitting into a unified, delegated OSS track would streamline investment licensing and turn administrative coordination into a catalyst for faster project delivery.

The government should establish a geothermal-specific fast lane within the OSS system, granting the MEMR a dedicated role as a single coordination point for geothermal licensing in exploration, Working Areas assignments, and production. MEMR would coordinate directly with the Ministry of Environment, the Ministry of Forestry, the Ministry of Agrarian Affairs and Spatial Planning, the Ministry of Public Works and Housing, Ministry of Investment, and provincial and district governments. This process should also acknowledge that some projects have lower risk than others. Smaller projects and projects that involve drilling in already developed areas are less risky than larger projects in forested areas. A tiered approach to approvals would recognize this fact.

To ensure accountability, the law should introduce statutory permit clocks—fixed deadlines for agencies to process applications, with automatic approval if the agency misses a deadline without cause. A 180-day statutory clock for geothermal projects would significantly reduce lead times, boost investor confidence, and align Indonesia's process with international best standards for renewable infrastructure.

In Indonesia's OSS system, geothermal activities currently fall under KBLI 06202 for geothermal exploration and extraction[44] and KBLI 35111 for electricity generation from geothermal sources.[45] KBLIs for direct-use projects fall under the purview of these two overarching classifications, with 16 specific licenses for heat use. However, there is no dedicated KBLI for geothermal direct use that would allow the industry to submit new KBLIs as technologies advance. For example, there is currently no KBLI for permitting ground source heat pumps. Once MEMR issues a regulation establishing the legal basis for direct-use activities—such as by updating MEMR Regulation No. 5/2021,[46] as described in Recommendation 1—it can formally coordinate with the Central Bureau of Statistics to create a new KBLI classification specific to geothermal direct use. This sequence would ensure that the new classification is grounded in a clear regulatory mandate and aligns with Indonesia's national licensing framework. As a result, investors could then register direct-use projects through the OSS system, access licensing pathways, and qualify for sectoral incentives under Indonesia's investment framework.

LICENSING FOR GEOTHERMAL DIRECT USE IN INDONESIA

For all geothermal direct-use projects, licensing is a critical step to ensure regulatory compliance, technical reliability, and operational safety.

In Indonesia, licensing for geothermal direct-use projects is regulated under the Ministry of Energy and Mineral Resources Regulation No. 5 of 2021 on Business Activity Standards and Products in the Implementation of Risk-Based Licensing in the Energy and Mineral Resources Sector.[47] Developers that hold a geothermal permit must obtain certificates that prove operational worthiness for direct-use applications. Submissions for these certificates are routed through the OSS system (**Figure 7.3**) to the Directorate General of New, Renewable Energy and Energy Conservation or the relevant provincial/district energy office.

While these safeguards are important, the licensing process plays a significant role in determining how geothermal development progresses. To support this chapter's vision for expanding direct-use geothermal, the government can strengthen the licensing framework so it is more enabling. This step can include clearer procedures, well-defined institutional roles, and efficient coordination while still maintaining rigorous personnel capabilities and safety and environmental standards.

The government could take several concrete next steps to operationalize this recommendation, including the following:

- **Establish a fast-track Certificate of Operation Worthiness** channel with clear service-level deadlines.
- **Clarify agency roles** via a joint decree and standardized checklist.
- **Adopt tiered approvals** so small and low-risk projects move quickly.
- **Build regional review capacity** and provide developer guidance.
- **Integrate permits** within the OSS system to cut duplicative submissions.

These improvements must be paired with a strong capacity-building program for provincial and district governments to ensure inspectors and local workers have the technical competencies to properly assess, certify, and monitor geothermal direct-use installations.

Recommendation 6: Reduce Financial Risk with Open Data and Expanded Exploration Programs

Who Takes Action: MEMR Directorate General of New, Renewable Energy and Energy Conservation and Geological Agency; Ministry of Finance; PT Sarana Multi Infrastruktur; Indonesia Infrastructure Guarantee Fund; Special Task Force for Upstream Oil and Gas Business Activities

Indonesia already has two key mechanisms to reduce the financial risk of early-stage geothermal development: the Government Drilling Scheme (Ministry of Finance Regulation No. 62/2017)—where the state directly funds and executes drilling before tendering working areas—and the Geothermal Resource Risk Mitigation Project (GREM, P166071), launched in 2018 with support from the World Bank and Climate Investment Funds. GREM became operational in June 2021 and is managed by PT Sarana Multi Infrastruktur (PT SMI), providing contingent financing to private and state-owned developers for exploration drilling. The program's structure allows partial loan forgiveness if wells prove non-viable, which reduces risk and encourages private participation.

To date, GREM has advanced several prospects—including Toka Tindung (Klabat-Wineru), Wapsalit, and Hu'u Daha—to the due diligence and financing stages, and a memorandum of understanding with Ormat Technologies was signed in September 2025. However, no publicly documented GREM-financed wells have yet been drilled,[48] underscoring both the promise of the program and the urgency of accelerating its

NAVIGATING THE CERTIFICATE ISSUANCE PROCESS

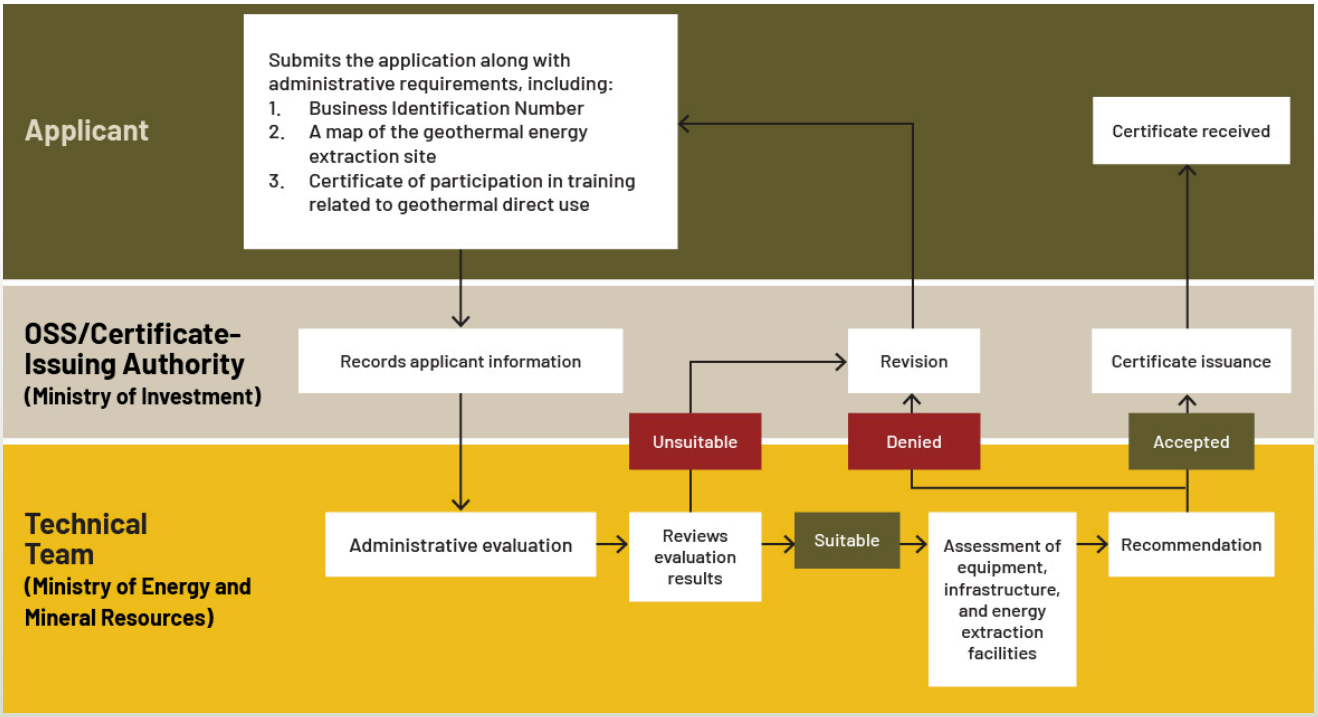

Figure 7.3: Process diagram outlining the stages of and responsible authorities involved in issuing the Certificate of Operational Worthiness for geothermal direct-use installations. OSS = Online Single Submission. Source: Audit Board of Indonesia. (2021). *Regulation of the Minister of Energy and Mineral Resources number 5 of 2021 concerning standards for business activities and products in the implementation of risk-based business licensing in the energy and mineral resources sector*. Government of Indonesia; Al Asy'ari, M. R., Adityatama, D. W., Brilian, V. A., Erichatama, N., & Purba, D. (2024). Beyond electricity: Geothermal direct use business models and potential applications in Indonesia. In *Proceedings, 49th Workshop on Geothermal Reservoir Engineering.* Stanford, CA, United States.

implementation. By expanding existing mechanisms rather than creating duplicative structures, Indonesia can leverage multilateral capital, strengthen PT SMI's role as a financial intermediary, and accelerate private sector participation.

Today, geothermal information in Indonesia is still compartmentalized—spread across multiple agencies, research institutions, and state entities with varying data standards and access rules. Confidentiality provisions and overlapping ownership between MEMR, the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), and universities further complicate information-sharing and make coordination essential for a unified national database. Establishing consistent governance and interoperability standards will ensure that publicly funded exploration contributes to an open, cumulative knowledge system that benefits both investors and researchers. (See Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions.")

MEMR, through its Data and Information Center, should establish a centralized geothermal data and sample repository linked to a national thermal atlas. The repository should be supported by modern APIs and digital platforms for seamless data integration, mapping, and analysis, and it should store both digital data sets and physical core and fluid samples accessible to government, academia, and industry. Developers that fail to comply with these reporting requirements should be ineligible for future exploration rights to ensure transparency and public benefit.

At the same time, Indonesia should expand public-private partnership (PPP) models for geothermal exploration and early development. With this approach, public entities would finance and execute initial drilling, while proven wells would be transferred to private developers for build-out under transparent tendering. Such models would lower entry barriers, distribute risks equitably, and speed up resource assessment. Comparable frameworks in Kenya, where the Geothermal Development Company leads government-backed exploration, and in the United States with the Frontier Observatory for Research in Geothermal Exploration (FORGE) program[49] show how blended public and private investment can rapidly scale geothermal capacity (see **Figure 7.4**).

Formally integrating geothermal into Indonesia's National PPP Strategy would enable projects to access viability gap funds, project-preparation facilities, and credit guarantees through PT SMI, the Indonesia Infrastructure Guarantee Fund, and state banks.

In addition, the government can take several concrete next steps to operationalize this recommendation, including the following:

- **Scale and accelerate GREM's developer-led window** to finance early exploration and feasibility work.
- **Extend eligibility** to direct-use and next-generation geothermal projects, including industrial heat, district cooling, and agricultural applications.
- **Mandate standardized data reporting,** requiring geological, geophysical, and geochemical results to be submitted in a common format and released publicly after a confidentiality period of between three and five years to ensure that state-supported drilling expands the national geothermal knowledge base.

By coupling open-data policies with expanded risk-sharing and PPP-based exploration programs, Indonesia can move from isolated project preparation to dozens of wells drilled each year by the late 2020s. This result would, in turn, create the exploration pipeline required for sustained growth across all types of geothermal. These reforms would reduce investor risk, expand scientific knowledge, and establish Indonesia as a regional leader in transparent and innovation-driven geothermal development.

GEOTHERMAL SECTOR GOVERNANCE ACROSS FOUR COUNTRIES

Aspect	Kenya	Turkiye	United States	Indonesia
Market structure	Liberalized, single buyer with open Independent Power Producer (IPP) access	Liberalized generation, state-controlled grid	Mixed: deregulated and regulated by state	Single-buyer (PLN)
Public sector role	Geothermal Development Company (GDC) funds exploration	Directorate of Mineral Research and Exploration (MTA) initial role, now private-led	Incentives + grants (federal & state)	Gov. drilling, limited PPPs
Private sector role	Post-exploration entry	Private-led via feed-in tariffs	Dominant, competitive	IPPs under PLN contracts
PPP usage	Build-Own-Operate-Transfer (BOOT), Build-Own-Operate (BOO), Build-Own-Transfer (BOT) widely used	Limited PPPs, some BOO	No formal PPPs, private financing + aid	Institutional PPPs, no geothermal focus

Figure 7.4: A comparative analysis of geothermal developments across four countries. PPP = public-private partnership. Source: Modified from Sutama, C. S., Ashat, A., Nur, S., & Alkano, D. (2024). Comparative analysis of geothermal PPPs: International insights and Indonesia's cases. In *Proceedings, the 10th Indonesia International Geothermal Convention and Exhibition (IIGCE) 2024*. Jakarta, Indonesia.

COLLABORATIONS, PILOT PROJECTS, AND DATA COLLECTION

The government could establish a pilot program in collaboration with Indonesian universities, state-owned enterprises, and global technology providers for geothermal innovation. This initiative would focus on reusing depleted or marginal oil and gas fields as test beds for next-generation geothermal concepts, including engineered and advanced geothermal systems, closed-loop designs, and superhot rock exploration. By building where there are existing wells, pads, and pipelines, and with existing seismic data, such a program could reduce costs and shorten timelines while demonstrating new approaches under Indonesia's geological conditions.

The program could be structured around competitive grants and concessional finance for university–industry consortia, encouraging partnerships that combine academic research, local operators, and international service companies. Flagship pilot clusters to test power generation and direct-use applications could be launched in regions with direct connections to industrial parks or data centers such as Sumatra, Java, and Kalimantan. These clusters would also serve as field laboratories for training Indonesian engineers, students, and regulators, building a skilled workforce for the next generation of geothermal development.

Data Collection and Sharing

All pilot projects should be subject to open-data requirements, with performance results and subsurface information made public within a fixed period to accelerate replication. Fiscal incentives and cost-sharing from industry—potentially financed through carbon pricing revenues or existing innovation funds—would help take the risk out of early-stage investment while anchoring long-term private sector participation. By 2028, such a program should aim to deliver at least five advanced geothermal pilot wells, validated techno-economic data for scaling, and a cohort of Indonesian professionals with hands-on expertise. Together, these outcomes would establish Indonesia as a regional leader in adapting advanced geothermal technologies to tropical and oil field settings.

Recommendation 7: Use Collective Procurement to Lower Project Costs

Who Takes Action: MEMR Directorate General of New, Renewable Energy and Energy Conservation; Ministry of Finance; National Public Procurement Agency

The government could support geothermal developers by conducting collective (or joint) procurement, especially in the early stages of exploration when costs and risks are significant (see **Figure 7.5**). This action can reduce the overall cost of a project by securing lower prices on key components such as generators, turbines, and drilling equipment.

Such support can be vital in Indonesia. Indonesia's geothermal resources are often located in remote areas with limited infrastructure, which increases the complexity and cost of a geothermal project. In some cases, developers have to create their own infrastructure, including roads and bridges, which can lead to high drilling costs; today, a typical well between 2,000 meters and 2,500 meters deep can cost between US$4 and $6 million in Indonesia.[50]

To bring costs down and make the market more viable for developers, the government should create a dedicated "geothermal procurement coordination unit." Under MEMR, such a unit would facilitate a centralized tender for drilling services to be used at multiple WKPs in the same province or island. The unit could also create a prequalified supplier database that includes contractors and other service providers with proper experience.

The unit would also ensure that procurement procedures align with regulatory requirements and industry best practices. It could offer incentives such as subsidies or tax benefits for joint collective procurement initiatives. The unit should also set clear guidelines to prevent anti-competitive practices.

Local governments play vital roles in collective procurement, and the unit would be responsible for working with governments on mobilization routes and permits. Alongside reducing cost, this approach can also minimize idle periods between projects for contractors.

GEOTHERMAL PROJECT RISKS, COSTS, AND HISTORIC FUNDING SOURCES

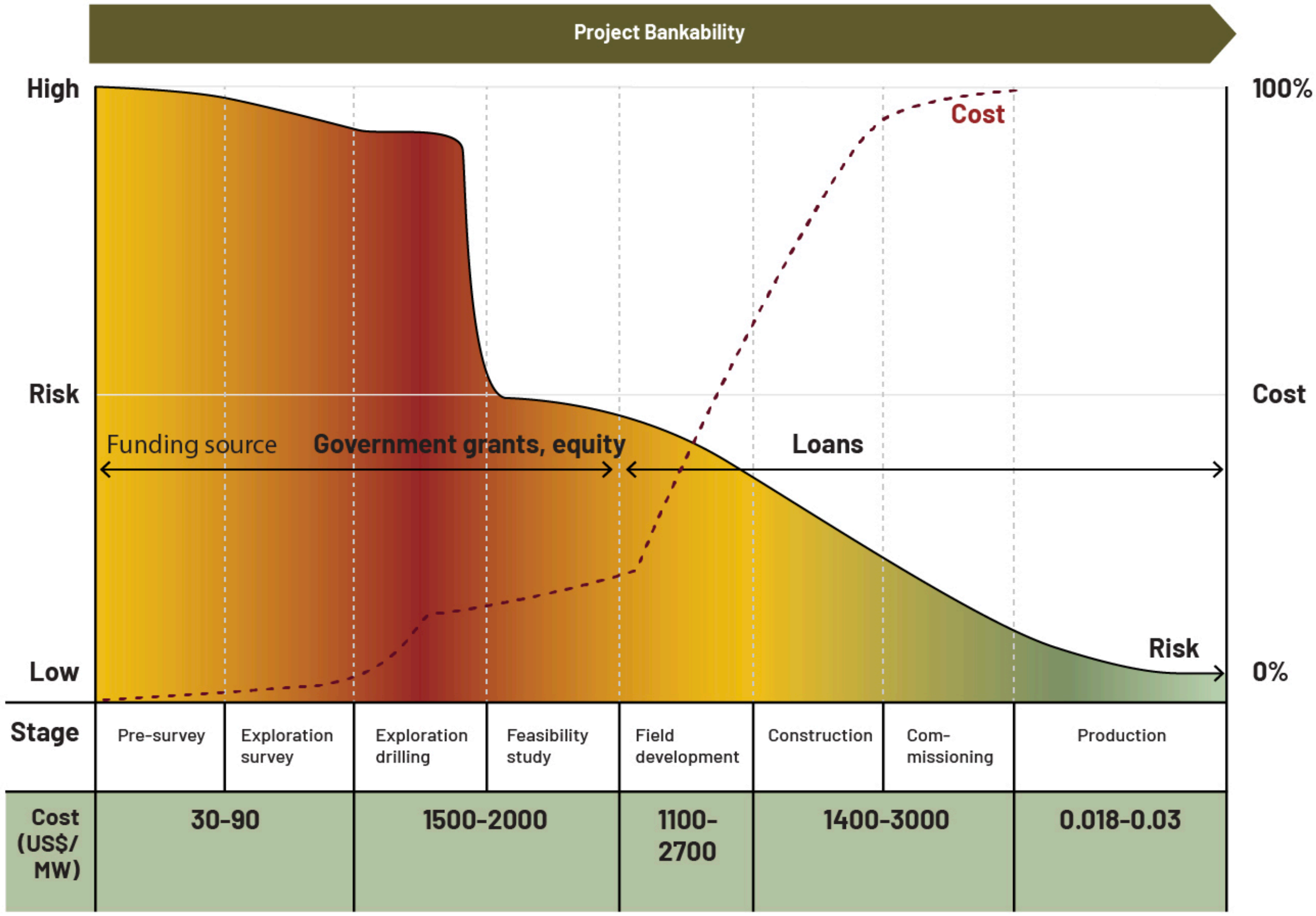

Figure 7.5: Geothermal project risk, costs, and funding sources. Source: Modified from Fridriksson, T., Matek, B., Albertsson, A., & Bertani, R. (2016). *Comparative analysis of approaches to geothermal resource risk mitigation: A global survey*. Energy Sector Management Assistance Program (ESMAP), World Bank; Purwanto, E. H. (2019). *Assessment of exploration strategies, results and costs of geothermal fields in Indonesia*. United Nations University Geothermal Training Programme.

Recommendation 8: Standardize Long-Term Geothermal Power Contracts

Who Takes Action: MEMR Directorate General of Electricity; PLN; Ministry of Finance Directorate General of Financing and Risk Management

Today, even when tariffs are adjusted, developers remain reluctant to commit capital due to risks that others in a contract will fail to meet their obligations. PLN is currently the sole purchaser of electricity in Indonesia, and its financial condition has limited its ability to sign bankable PPAs. Revising the pricing mechanism can help, but without confidence that there are secure offtakers, investors remain hesitant.

To remedy this situation, the government should require that all PLN geothermal PPAs be structured as bankable, long-term contracts with provisions related to curtailment, termination, and payment obligations aligned with international norms. To reduce counterparty risk, PPAs for high-capital expenditure geothermal projects should be backed by a sovereign guarantee. This guarantee would significantly reduce financing costs, improve credit ratings for projects, and unlock the scale of investment required for Indonesia's geothermal potential.

Recommendation 9: Empower Community Participation and Guarantee Community Benefits by Reforming Geothermal Production Bonuses

Who Takes Action: Ministry of Finance Directorate General of Treasury, Directorate General of Financing and Risk Management, and Fiscal Policy Agency; MEMR Directorate General of New, Renewable Energy and Energy Conservation; Ministry of Home Affairs

Indonesia already shares most geothermal revenue with host regions—80% of Revenue Sharing Funds (DBH) flows to regional governments and 20% to the central government.[51] While this sharing supports decentralization, it lacks transparency and tangible local outcomes. Once transferred, revenues often disappear into general budgets, leaving communities with visible infrastructure but no clear fiscal dividend—fueling distrust and resistance. (See Chapter 6, "Common Ground: Building Trust and Transparency in Indonesia's Energy Transition," for further context.) This perception is heightened in areas such as Wapsalit,[52] Mount Talang,[53] Tampomas,[54] and Tangkuban Perahu,[55] where poor consultation, weak benefit-sharing, and environmental concerns have sparked opposition and delayed projects.[56]

To rebuild trust, Indonesia should consolidate geothermal revenues through a unified geothermal production bonus (BPPB) mechanism—an instrument within the Non-Tax State Revenue system (PNBP)—bringing together DBH, PNBP, and voluntary developer contributions. Jointly managed by the Ministry of Finance and MEMR, this enhanced BPPB mechanism would serve as the central vehicle for delivering local benefits. It should finance tangible outcomes such as schools, clinics, training centers, geothermal cooling networks, and industrial-heat pilots—ensuring communities see and feel the dividends of hosting geothermal projects. Access to BPPB-supported benefits should be contingent on verified compliance with corporate social responsibility (CSR) commitments; free, prior, and informed consent (FPIC) protocols; and the Certificate of Operational Worthiness. All operations should be published on a public dashboard that is maintained by MEMR and Bappenas and shows audited revenue flows and approved projects.

This approach can build on local leadership. Lampung Province's Regional Regulation No. 11/2019[57] on surface-water use (outlined in Recommendation 1) offers a strong precedent—creating a transparent, community-driven system for managing natural resources. A similar geothermal model could define permitting, usage fees, and revenue allocation frameworks at the provincial level, then be scaled nationally.

To strengthen implementation, MEMR and the Ministry of Home Affairs should convert CSR from a voluntary practice into a mandatory, verifiable obligation. Indicators such as local job creation, community procurement, and delivery of social assets should be independently verified and publicly disclosed. Developers that fail to meet obligations should face enforceable penalties.

An independent geothermal governance body should be established to oversee BPPB revenue collection, allocation, and spending, which can ensure transparent formulas for distributing royalties and PNBP among national, regional, and local stakeholders. This governance function could be administered through PT SMI—a trusted state-owned financial intermediary—to provide fiduciary integrity and accountability. It should also support pilot projects for geothermal cooling and industrial heat and earmark a portion of revenue for domestic equipment manufacturing—helping Indonesia build a strong national supply chain.

Geothermal projects must respect rights of Indigenous and *adat* communities. MEMR should make FPIC a procedural requirement for developments affecting customary land, while developers should work with local universities and environmental agencies to co-produce social baselines, monitor environmental and social impacts, and maintain accessible grievance systems with pathways to mediation. Local governments should lead participatory planning, nominating community representatives to serve on advisory panels that guide BPPB-supported investment and disbursement.

Finally, local content must extend beyond procurement to people. Educational and training centers in geothermal regions should equip local residents with skills in construction, operations, and safety—enabling long-term employment and deeper community integration.

These reforms align with Indonesia's legal architecture: together, Law No. 33/2004 on fiscal balance[58] and Law No. 21/2014 on geothermal energy provide authority for fiscal and sectoral coordination. Development should also comply with Environmental Law No. 32/2009[59] and the Ministry of Environment's implementing regulations on Environmental Impact Assessment (EIA) and post-operation restoration.

A reformed BPPB mechanism consolidated with DBH, PNBP, and developer contributions could unify scattered obligations into a single, transparent system—linking every rupiah to tangible outcomes and showing how Indonesia's geothermal wealth can power a model of green sovereignty that uplifts host communities.

Recommendation 10: Expand the Geothermal Ecosystem to Unlock Local Jobs

Who Takes Action: Ministry of Manpower; Ministry of Education, Culture, Research, and Technology; MEMR Center for Human Resource Development; National Research and Innovation Agency

Several regions in Indonesia reject the development of geothermal. In part, this rejection may be due to a lack of information about the benefits of the energy source for the public. Increasing public awareness about geothermal's economic and climate benefits can foster social acceptance and public support. To address the knowledge gap, the government should initiate geothermal educational programs for energy workers and the public into broader national energy policies.

This action could involve establishing dedicated funds for training programs, promoting geothermal-related research and innovation, and including geothermal energy and direct use topics in school curricula. These educational efforts can also align with national energy targets.

Through the Center for Human Resource Development, MEMR should collaborate with universities on educational events such as Geothermal Goes to Campus, an initiative timplemented at several universities in Indonesia, including Sepuluh Nopember Institute of Technology,[62] Diponegoro University,[63] and the University of North Sumatra.[64] Such events can foster students' interest in exploring geothermal energy development in Indonesia.

PRIORITIZE DEVELOPMENT IN LOWER-RISK ZONES

On the islands of Sumatra, Java, Sulawesi, and Maluku, Indonesia's significant geothermal potential often overlaps with ecologically sensitive areas.[60] To minimize environmental and biodiversity impacts, the government should prioritize development in non-forest use zones, which contain about 38% of the nation's conventional geothermal capacity. These areas typically offer easier road access, favorable geology, and lower investment costs, enabling faster and less disruptive development.

Geothermal projects in forest areas—often remote and mountainous—can require up to 10 kilometers of road per 100 megawatts of capacity,[61] increasing the risk of environmental harm to forests, wildlife, and water sources. Developers should avoid such sites where possible. If development in forest areas is necessary, MEMR and the Ministry of Forestry must enforce strict safeguards: promoting directional drilling from outside forest boundaries, minimizing land clearing, limiting road size, and integrating fauna crossings and erosion controls. Developers should also be required to train personnel on biodiversity protection and regulatory compliance.

Ultimately, Indonesia must ensure geothermal development does not increase pressure on forest ecosystems. Expanding the legal definition of geothermal to include low-impact applications—such as direct use for cooling and industrial heat—can shift development toward less sensitive, non-forested zones. This approach aligns environmental stewardship with energy goals, enabling sustainable growth without sacrificing biodiversity.

To address a broader audience, MEMR should collaborate with nongovernmental organizations or universities to give free webinars on geothermal topics. Several organizations have given geothermal webinars on various topics, including Indonesia's Center for Renewable Energy Studies; the Institute for Essential Services Reform (IESR) conducted a webinar about the social and economic benefits of geothermal energy.[65]

According to the *Specialized Workforce for Indonesia's Transition (SWIFT) Roadmap 2025–2060*, the need for labor in the geothermal sector will increase by 130,000 workers by 2060,[66] but if the country strives to produce 25 gigawatts electric and 35 gigawatts thermal, the direct and indirect workforce requirements could be more than 650,000 by 2045.

It is important to highlight the distinction of adding direct-use and thermal heat applications into this equation. After a conventional geothermal energy plant is up and running, the number of on-site jobs needed is relatively limited, which is why geothermal graduates have historically faced challenges with securing long-term work in the sector. But emerging commercial opportunities—such as direct-use applications, geothermal cooling networks, geothermal mineral extraction, and green hydrogen production—can generate substantially more workforce demand and create new value chains that diversify geothermal-related employment. If Indonesia successfully captures these wider geothermal-based opportunities, workforce needs could increase significantly across drilling services, industrial heat networks, district cooling, mineral recovery, and hydrogen production—making capacity-building efforts more relevant and impactful.

As explained in Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions," the government needs to develop a comprehensive occupational map to help institutions get ready to prepare a skilled geothermal workforce. This map would identify current skills, workforce distribution, and future labor market requirements. It would also identify existing capacities and gaps so the government can plan relevant policies and training programs.

To coordinate this workforce agenda, the government should establish an Energy Workforce Transition Task Force authorized by presidential instruction and led by MEMR's Human Resources Development Agency. This task force would align forecasting, training, and certification across ministries, ensuring geothermal and energy-transition skills develop in a unified, industry-ready pathway. See Chapter 5, "Deploying the Workforce of the Future: The Role of Indonesia's Oil and Gas Workforce and Institutions," for more.

An established occupational map can guide policy initiatives, including vocational training, curriculum development, and certification programs. It would also promote strong links between educational institutions, industry demand, and government development plans. The map should also involve the oil and gas industry because there are so many translatable workforce skills and competencies across the two energy industries—up to 80% of the workforce effort required in the geothermal industry involves skills that are common in the oil and gas industry.[67]

CONCLUSION

If Indonesia achieved even a fraction of its geothermal potential, it would strengthen the nation's grid resilience, lower peak demand, reduce fuel imports, sharpen industrial competitiveness, and expand affordable cooling. By implementing the recommendations offered in this chapter, Indonesia could put itself on track to meet its climate targets while lowering the long-term costs of energy and creating hundreds of thousands of jobs.

The very first place to start: simply updating geothermal laws to clearly address next-generation and direct-use geothermal, as laid out in the first policy recommendation in this chapter.

Grounded in Indonesia's geological strengths and state capacity—and informed by global best practices—the set of recommendations offered in this chapter could cement Indonesia as a global leader in geothermal energy.

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Chapter 8

Keeping Geothermal Green: Safeguarding Nature and Communities in a New Era of Growth

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Geothermal energy combines low life cycle greenhouse gas emissions, round-the-clock reliability, and the smallest surface footprint of any renewable or fossil source. Many issues tied to conventional hydrothermal are minimized with next-generation, district cooling, and heat projects. Smart siting, real-time monitoring, transparent data, and community partnerships can minimize these risks so leaders can scale geothermal while safeguarding forests, waters, wildlife, and public health.

When geothermal energy is used instead of coal, diesel, or heavy fuel oil, air quality improvements are immediate: Nitrogen oxide, sulfur dioxide, fine particulate matter, and carbon dioxide levels fall sharply, improving public health in urban and industrial corridors. Modern geothermal energy designs such as closed-loop systems (advanced geothermal system, or AGS) and reinjection programs (engineered geothermal system, or EGS) circulate water rather than consuming it, therefore mitigating water stress. Add to that, brines and non-condensable gases are contained and treated, and well pads, pipeline corridors, and compact plants can be built on brownfields or within existing industrial estates, which limits the disturbance of natural areas and habitats.

For Indonesia, geothermal's multi-use profile is especially powerful. As Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Geothermal Direct Use Potential," describes in more detail, the same subsurface know-how that enabled world-leading conventional geothermal power can also build geothermal district cooling for heat-stressed cities; geothermal networks for hospitals and campuses; and direct-use geothermal heat for food processing, textiles, pulp and paper, and pharmaceuticals. These facilities are much smaller than utility-scale power plants and therefore not as intensive to build. Drilling time is shorter, and the facilities use less fluid, resulting in less impact and more local environmental gains, including cleaner air, steady-state operations, minimal visual impact, and less noise.

As with every other type of energy generation, however, geothermal presents environmental risks that need to be addressed. The risks for geothermal vary depending on the location and the type of geothermal system being installed. Risks can range from groundwater contamination and land subsidence to loss of biodiversity and damage to conservation lands. Historically, building geothermal has been tricky in Indonesia, particularly for conventional hydrothermal systems. Today, however, new technology helps minimize impact, and mitigation strategies have improved.

Countries around the world offer examples worth emulating. Costa Rica, the United States, and Germany have developed geothermal projects while protecting the environment and engaging local communities. There are also plenty of examples of next-generation geothermal and cooling-focused projects (with short construction times) that have eliminated most hydrogen sulfide pathways, enabling geothermal production outside of conventional fields.

With clear technical guidelines, transparent monitoring, reinjection and well integrity standards, and biodiversity safeguards, Indonesia can expand geothermal while protecting forests, wildlife, and ecosystem services.

By pairing its world-class geothermal expertise with these best practices, Indonesia can extend its geothermal leadership to create more benefits and fewer impacts. This chapter details potential environmental effects in the Indonesian context and lays out strategies and standards to minimize them.

PACIFIC RING OF FIRE

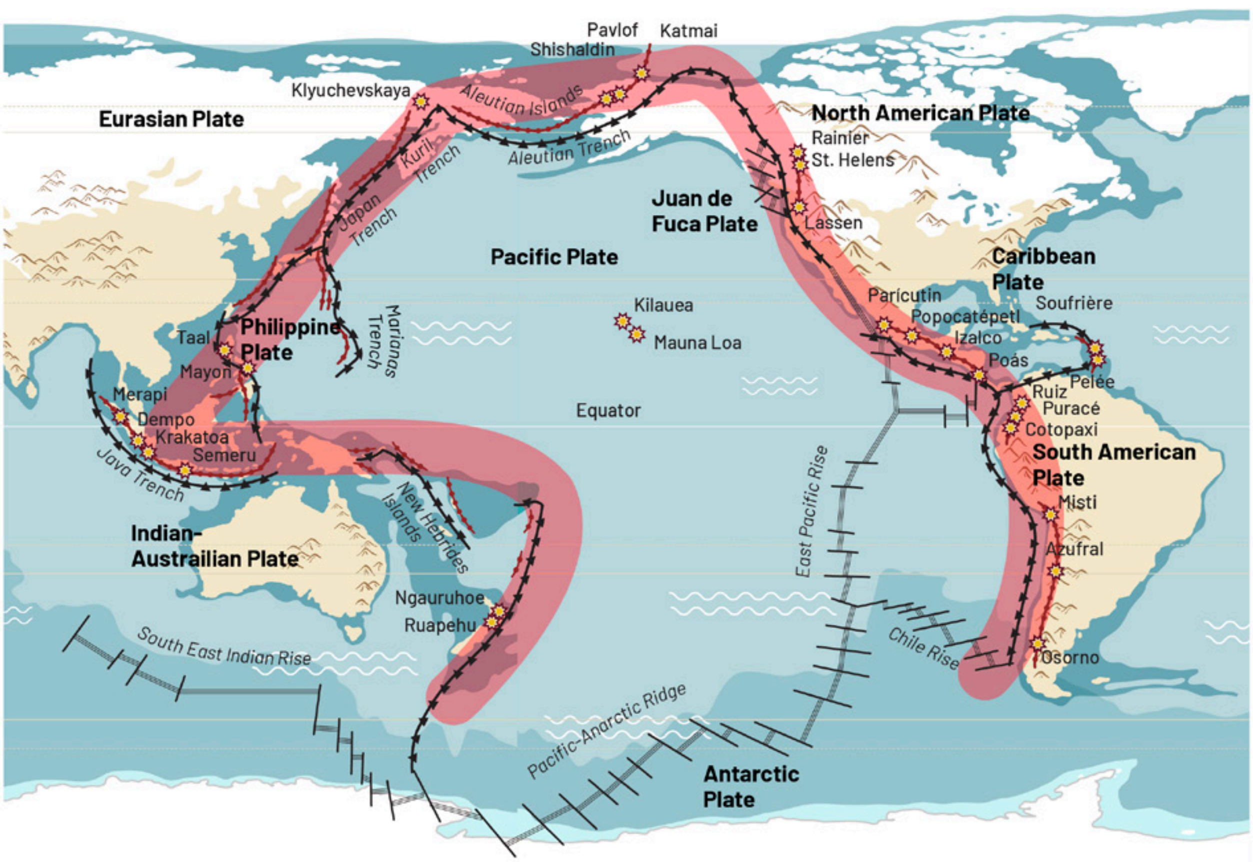

Figure 8.1: Countries located in the Pacific Ring of Fire, with relevant tectonic and volcanic features. Source: Encyclopaedia Britannica. (2025). Ring of fire; Roque, P. J. C., Violanda, R. R., Bernido, C. C., & Soria, J. L. A. (2024). Earthquake occurrences in the Pacific Ring of Fire exhibit a collective stochastic memory for magnitudes, depths, and relative distances of events. *Physica A: Statistical Mechanics and Its Applications, 637,* 129569.

AN OVERVIEW OF INDONESIA'S UNIQUE ENVIRONMENTAL CONDITIONS

Geographic and Volcanic Activity

Indonesia stands among the most volcanically active regions in the world because it sits directly on the Pacific Ring of Fire, a roughly 40,000 kilometer zone that hooks around the Pacific Ocean like a horseshoe (**Figure 8.1**). This belt marks the meeting point of several major lithospheric plates, including the Indo-Australian, Pacific, and Eurasian Plates, causing tectonic activity such as earthquakes and volcanic eruptions to frequently shift the landscape. About 90% of the world's earthquakes happen in the Ring of Fire, including most of the large ones.[1] These same unique subsurface attributes also give Indonesia an abundance of geothermal resources and present unique challenges for developing and managing energy infrastructure, including geothermal systems.

Most of Indonesia's islands lie near the equator and receive between about 2,000 millimeters and 4,000 millimeters of rainfall each year.[2] Many conventional geothermal resources, including hot springs, are also located along steep, unstable, high-relief stratovolcano slopes. The combination of heavy rainfall and unstable terrain creates a high risk of geohazards, such as collapses, landslides, and flash floods.[3] Landslides are a particular concern because they can be triggered by several factors, namely intense rainfall, seismic activity, land use changes, and overloading of slopes.[4] At least four significant landslides have been documented at conventional Indonesian geothermal fields: Wayang Windu (2015), Sungai Penuh (2013), Hululais (2016), and Lembata Island (1979). A few of the slides were tied to geothermal-related factors, including natural hydrothermal manifestations that weakened slopes and project-related activities such as vibrations from heavy equipment. These findings underscore the importance of managing landslide risks in hydrothermal development.[5]

ILLUSTRATION OF FLASH FLOOD RELATED TO GEOTHERMAL AREA

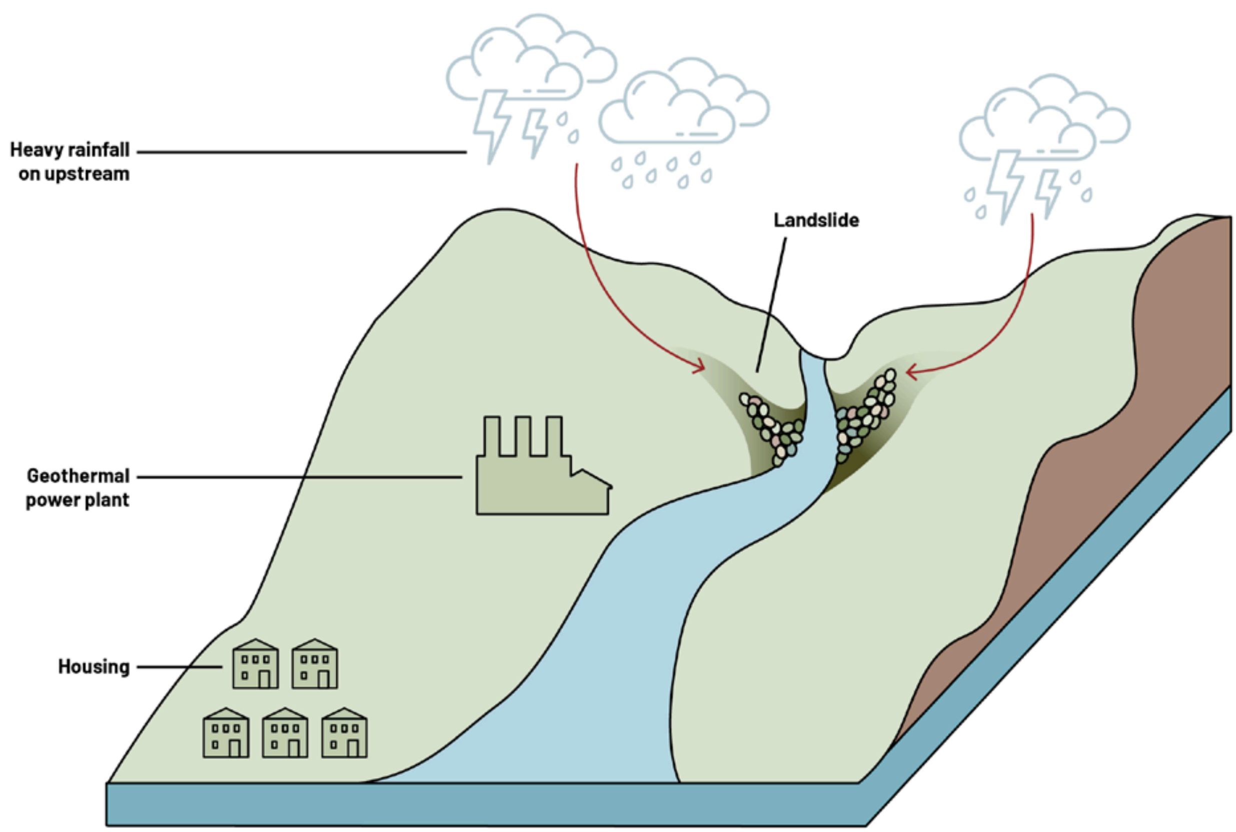

Figure 8.2: Illustration of a flash flood related to geothermal area. Source: Chandra, V. R., Purba, D. P., Nayoan, A. G. P., Fadhillah, F. R., Ramadhan, R. F., &. Anggara, R. (2021). Identifying and assessing geohazards in Indonesia geothermal area: How difficult is it? In *Proceedings of the 46th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

Flash floods—in which rainfall in upstream areas generates water volumes beyond a stream's capacity—are also a particular hazard in certain terrain and need to be considered. If a landslide blocks a stream and forms a temporary dam, water will accumulate behind it. The eventual breach of such a blockage can send a sudden torrent downstream (**Figure 8.2**).

Volcanic eruptions are, of course, a risk as well. Indonesia has 128 active volcanoes (around 13% of the world's total),[6] and nearly all of the country's conventional geothermal fields are in volcanic zones, making eruption hazards a major concern. An eruption at Mount Tangkuban Perahu in August 2019, for example, temporarily closed a nearby hydrothermal field. The incident prompted calls for closer cooperation between geothermal developers and volcanology agencies to better mitigate such risks.[7,8]

BIODIVERSITY AND ECOSYSTEMS

According to Conservation International, Indonesia is one of the world's 17 mega-diverse countries,[9] a classification denoting nations with exceptionally high levels of species richness and endemism. With rainforests, peatlands, mangroves, and coral reefs on more than 17,000 islands, the country contains about 17% of the world's bird species, 12% of mammals, and 10% of flowering plant species.[10,11] These ecosystems deliver vital services—regulating floods; storing vast amounts of carbon; and supplying food, clean water, and raw materials—yet deforestation, habitat fragmentation, and overexploitation threaten this biodiversity. Between 2001 and 2022, the country lost roughly 9.75 million hectares of tree cover, much of it in biologically rich areas such as Kalimantan and Sumatra.[12] Indonesia's conservation framework—through the Indonesian Biodiversity Strategy and Action Plan (IBSAP) and a pledge to expand protected areas to 32.5 million hectares by 2030—seeks to address these challenges. The IBSAP mentions the role of biodiversity in supporting environmental services, including those relevant to geothermal development.

Because many high-potential geothermal resources lie within or near conservation forests, expanding this renewable energy source must balance climate benefits with the imperative to protect biodiversity. Geothermal has a very small footprint—the smallest of any renewable power source (see **Figure 8.3**). Still, about 28,600 hectares of deforestation—less than half of one percent of the total—can be directly attributed to existing geothermal development projects.[13]

At the same time, according to a study conducted by Profor and the World Bank, around 8,000 megawatts of conventional geothermal power potential lie outside forest areas,[14] representing an opportunity to prioritize development in these lower-risk zones (see **Figure 8.4**). However, when adding next-generation geothermal resources, that number jumps to 2,160 gigawatts of potential outside of protected areas. (See **Figure 8.8** and the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities," for more information.)

COMPARING SURFACE FOOTPRINT

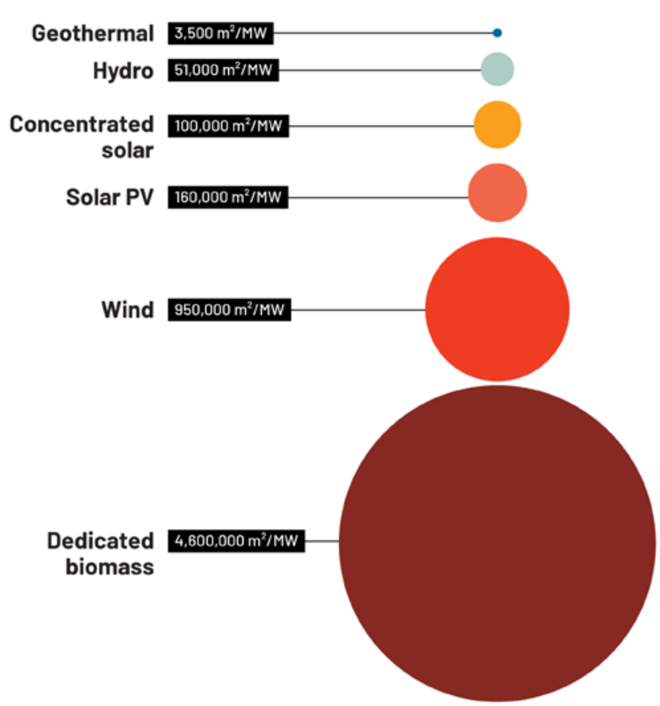

Figure 8.3: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. m^2/MW = square meters per megawatt; PV = photovoltaic. Source: Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS ONE*, *17*(7), e0270155; National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology*.

CONVENTIONAL GEOTHERMAL SITES AND CAPACITY BASED ON LAND USE STATUS IN INDONESIA

Land Use Status	Number of Geothermal Potential Points	Potential Capacity (MW)
Conservation areas	48	4,873
Protection forest	54	5,736
Production forest	46	2,416
Non-forest use	182	8,056
Total	**330**	**21,081**

Figure 8.4: Conventional geothermal sites and potential capacity based on land use status in Indonesia. MW = megawatts. Source: Meijaard, E., Dennis, R. A., Saputra, B. K., Draugelis, G. J., Qadir, M. C. A., & Garnier, S. (2019). *Rapid environmental and social assessment of geothermal power development in conservation forest areas of Indonesia*. PROFOR & World Bank.

In other countries, geothermal projects have actually helped create ecosystems for plants and species. In the United Kingdom, managers of the Eden Project have sown trenches with diverse seed mixes, creating new, lush habitat for an array of birds and pollinators. They also protected a stand of oak trees, a field of willow carr, and long lines of hedge to retain existing biodiversity.

Emerging next-generation geothermal technologies require even less space, such as a single, shallow groundwater circulation well for direct use or a geothermal doublet well for electricity production.

Even better to note is that as Indonesia expands the development of its abundant geothermal resources, next-generation technologies will allow developers to focus on regions that have fewer of the major risks inherent with flooding and unstable earth that are commonly found in Ring of Fire regions.

POTENTIAL ENVIRONMENTAL IMPACTS OF GEOTHERMAL DEVELOPMENT

As mentioned, one of geothermal energy's major advantages over other energy sources is that it uses the smallest land area. Geothermal electricity plants require one-fifth as much land as solar and one-tenth the amount as onshore wind—and a miniscule amount (1/70th) compared with electricity plants that burn biomass for fuel. Facilities generally require far less infrastructure than other energy sources, with a typical geothermal energy power plant occupying just 1,500 square meters per megawatt-hour (0.37 acres per megawatt-hour) compared with 40,000 square meters per megawatt-hour (9.9 acres megawatt-hour) for a coal-fired power plant.[15]

Deep geothermal heat-only projects for industrial or institutional use are even more efficient and can be retrofitted for use in urban areas. Many complexes large enough to warrant deep geothermal heating already have access to the land needed for development and drilling. This is one clear benefit of the technology compared with other energy sources: It disrupts less land and disturbs less habitat.

TYPES OF GEOTHERMAL SYSTEMS

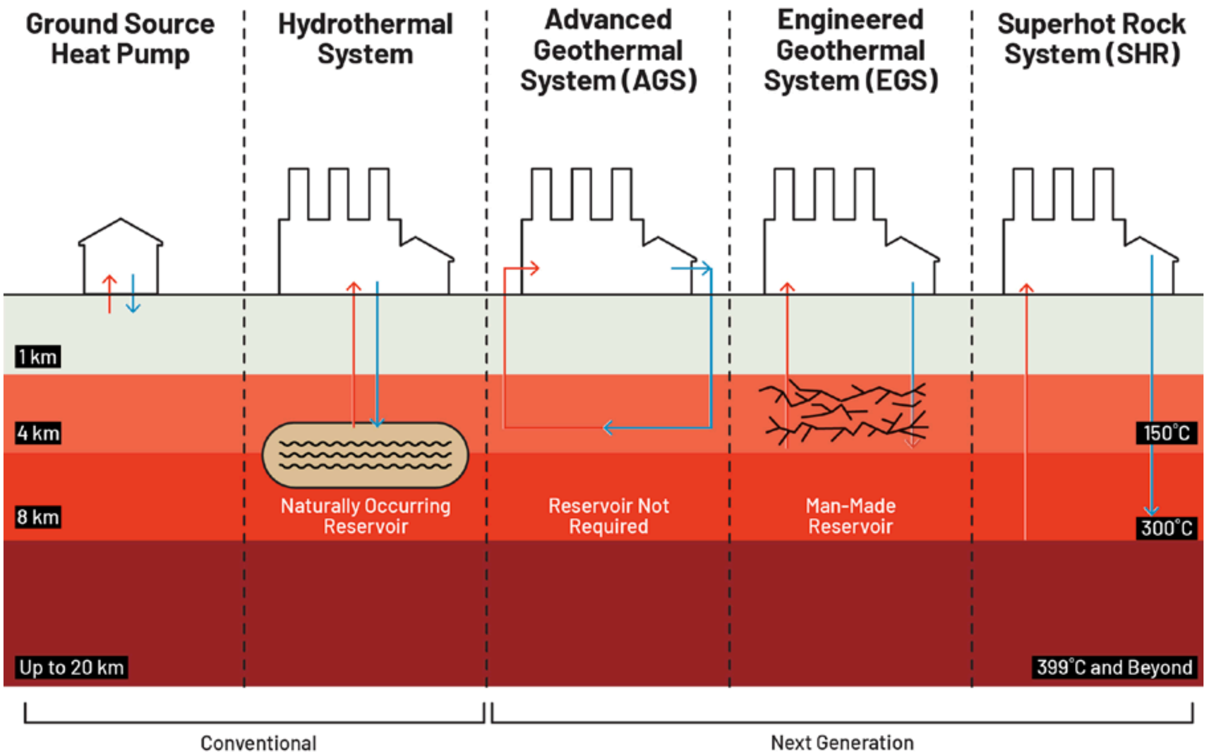

Figure 8.5: Comparison of key geothermal power generation technologies illustrating variations in resource type and heat extraction method for electricity production and industrial direct use. Ground source heat pumps (GSHP) are also shown, illustrating a building heating scenario. In the GSHP scenario, fluid flow can be reversed to provide cooling. Source: Adapted from D'avack, F., & Omar, M. (2024). *Infographic: Next-generation technologies set the scene for accelerated geothermal growth*. S&P Global.

A COMMERCIAL-SCALE GEOTHERMAL HEAT PUMP PROJECT IN SWITZERLAND

Figure 8.6: Well services teams prepare to drill a series of shallow geothermal boreholes to provide commercial-scale heating and cooling in the urban area of Lausanne, Switzerland. Photo courtesy of Groupe Grisoni.

As explained in Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Geothermal Direct Use Potential," Indonesia has significant potential to deploy geothermal for urban cooling, as is already done in Europe on a fairly widespread basis. Many cities either deploy geothermal district heating or use geothermal to heat and cool individual buildings. In a geothermal installation in Lausanne, Switzerland, a total of 150 boreholes—each plunging 300 meters deep and fitted with high-efficiency double-U probes—now power the site's heating and cooling systems. Urban drilling, a common practice, has a small footprint. When done, the system provides secure heat and cooling for the lifetime of the building.[16]

GLOBAL GHG EMISSIONS BY POWER SOURCE

Technology	Typical Life Cycle GHG Emission Range (gCO_2/kWh)	Notes
Conventional Geothermal (hydrothermal, flash/binary)	10–120	Highly site-dependent due to non-condensable gas (NCG) content; Indonesian fields like Dieng (higher, ~100+) vs. Lahendong (lower, <50). Reinjection lowers emissions.
Engineered Geothermal Systems (EGS)	5–40	Still pilot-scale; most emissions from drilling and construction. No NCG release since reservoirs are engineered.
Advanced Geothermal Systems (AGS, closed-loop)	<5–15	Projected values (no commercial-scale yet); emissions only from materials and construction.
Coal (subcritical to supercritical, no CCS)	820–1050	Among the highest; Indonesia's coal-dominated grid averages ~900.
Natural Gas (CCGT)	400–500	Lower than coal, but methane leakage can push higher.
Solar PV	20–60	Most emissions from panel manufacturing.
Onshore Wind	8–20	Very low; mostly from steel and concrete in turbines.
Hydropower (large reservoir)	1–250	Wide range; tropical reservoirs (like Indonesia) can emit more methane.

Figure 8.7: Global greenhouse gas (GHG) emissions by power source. CCS = carbon capture and storage; CCGT = combined-cycle gas turbine; gCO_2/kWh = grams of carbon dioxide per kilowatt-hour. Source: Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate change 2021: The physical science basis*. Cambridge University Press; International Energy Agency (IEA). (2022). *Renewables 2022*; International Energy Agency (IEA). (2023). *Net zero roadmap: A global pathway to keep the 1.5°C goal in reach*; O'Sullivan, M., Gravatt, M., Popineau, J., O'Sullivan, J., Mannington, W., & McDowell, J. (2021). Carbon dioxide emissions from geothermal power plants. *Renewable Energy, 175*, 990–1000; Geothermal Technologies Office. (2019). *GeoVision: Harnessing the heat beneath our feet*. U.S. Department of Energy.

That said, care must be taken at each stage of development and during plant operations to mitigate any environmental hazards. Broadly, geothermal projects have three stages: site exploration, drilling and construction of a plant, and ongoing operations. The following sections explain the environmental considerations at each stage.

IMPACTS OF EXPLORATION AND CONSTRUCTION

Exploration

Most geothermal exploration techniques are largely non-invasive and observational. For example, sampling methods occasionally involve the need to access sensitive areas, but these activities largely have minimal environmental impacts. Certain exploration methods, however, do have a larger effect. Some surveys need to build roads and some infrastructure networks, resulting in some habitat loss or vegetation removal. When there is a need to create new infrastructure, developers must take care to minimize environmental impacts.

The case of Baturraden in Central Java highlights these concerns. During the 2016–17 exploration phase, the clear waters of the Prukut River, which runs from the slopes of Mount Slamet, turned brown. Monitoring confirmed that geothermal developer PT Sejahtera Alam Energi was responsible. Local reports also mentioned people had a harder time accessing clean water.

Some projects also require exploration boreholes to confirm the subsurface properties of a proposed geothermal project. Exploration boreholes require the drilling of small-diameter holes, much like those used in exploration drilling that is typical for mining projects. For boreholes, land disturbance is confined to a drill site (or pad) of a few hundred square meters, a space in which vegetation may be cleared and temporary access tracks constructed. Although noise, vehicle traffic, and soil displacement occur during drilling, the level of sound generated is small and the duration short-lived, and sites can be reinstated once the borehole is complete. Any abandoned boreholes should be safely capped.

The government of Indonesia takes environmental concerns related to project development seriously. For every project, the Ministry of Environment and Forestry requires a mandatory Environmental Impact Assessment (EIA). The EIA is a regulatory requirement for both conventional and unconventional geothermal developments; it ensures that potential environmental and social impacts are thoroughly assessed and that public consultations are conducted before project approval and permitting. (See Chapter 6, "Common Ground: Building Trust and Transparency in Indonesia's Energy Transition," for more information.)

Construction

The plant construction phase is the most impactful phase, as well as the one with the most risks. Plants can require extensive surface infrastructure, such as drilling pads, production and injection wells, pipelines, and the power plants themselves. While geothermal plants have the smallest surface footprint of any power source (see **Figure 8.3**),[17] the dispersed nature of wells means that large tracts of land can still be affected in some instances. In Indonesia, many high-potential conventional geothermal sites overlap with conservation forest areas, creating risks of deforestation, habitat fragmentation, and ecosystem disruption.[18] These concerns are particularly acute in biodiversity-rich montane forests where ecological integrity is already under pressure.

As mentioned, though, next-generation technologies such as an EGS and an AGS may reduce surface damage even more (see Chapter 1, "Geothermal 101: Overview of Technologies and Applications"). The smaller footprints of AGS and EGS installations minimize disturbance to topsoil and allow development away from high-value farmland and protected volcanoes, further minimizing soil-degradation risks and damage to culturally sensitive lands. In Indonesia, several lands hold sacred or cultural value to local communities; these lands require a specific protocol for development beyond just ecological protection.

According to Project InnerSpace's GeoMap analysis, Indonesia holds immense untapped geothermal potential even when protected areas are excluded. Within just the first 5 kilometers of subsurface depth, the country could harness an estimated 2,160 gigawatts of geothermal electricity—equivalent to more than 21 times its total installed power capacity in 2024 (see the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities"). This analysis shows that major expansion is possible outside protected lands and that with today's improved drilling and plant design practices, next-generation geothermal development can be carried out with far less environmental impact than the conventional projects of past decades (see **Figure 8.8**).

TOTAL GEOTHERMAL HEAT-IN-PLACE FOR INDONESIA'S PROTECTED AREAS

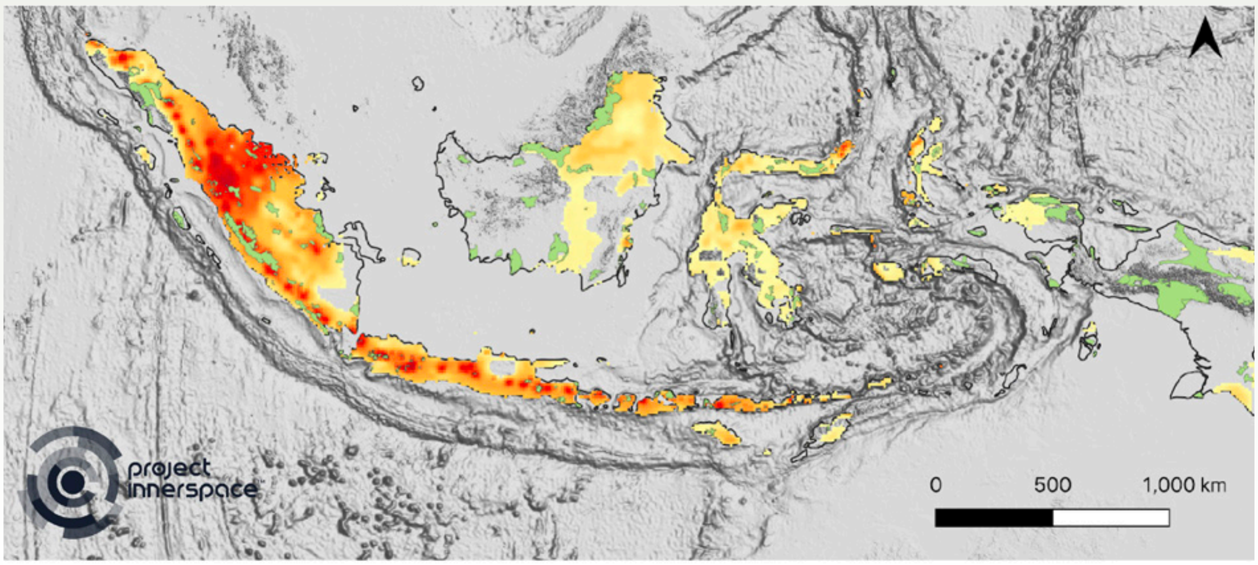

Figure 8.8: Indonesia's total geothermal heat-in-place from GeoMap and Indonesia's protected areas. The purpose of this map is to highlight the regions with the greatest geothermal potential in Indonesia. It represents the cumulative potential up to a depth of 3 kilometers to ensure clear differentiation between areas. Extending the analysis to 5 kilometers would result in almost the entire map appearing red, eliminating meaningful contrasts and insights. Source: Protected Planet. (2025). *World database on protected areas*; Project InnerSpace. (2025). *GeoMap*.

LESSONS LEARNED

During development of the Gunung Salak conventional geothermal plant in Mount Halimun Salak National Park in West Java, plant construction created forest clearance and habitat loss, soil erosion, alterations in stream water quality, elevated hydrogen sulphide levels in ambient air, and traffic congestion and accidents on narrow roads. Developers implemented several mitigation measures, including reforestation and efforts to avoid forest fragmentation.[19]

Moreover, surface infrastructure in volcanic and hilly terrain may disrupt watershed functions, reduce soil stability, and increase erosion and sedimentation in rivers. With hydrothermal development, care must also be taken to avoid degrading surface features such as fumaroles and hot springs, which are often seen as ecologically and culturally significant landmarks.[20]

Costa Rica provides important lessons on how to mitigate these impacts. Its geothermal projects—Las Pailas I and II power plants and the planned Borinquen plant—sit on volcanic flanks outside national park boundaries to avoid damaging critical ecosystems.[21]

The country uses directional drilling and multi-well pads to reduce surface disturbances, and compact designs link each production pad directly to separation and reinjection units, limiting the spread of roads and pipelines. Reinjection practices help stabilize reservoirs, reducing the need for new drilling areas, and repowering existing plants extends operational lifespans without creating a need to develop more land.[22]

These best practices are relevant for Indonesia, where leaders can reduce the ecological footprint of geothermal development by mandating clustered well pads, directional drilling from outside conservation zones, and compact field layouts.

Greenhouse Gas Emissions

Geothermal is widely recognized as a low-emission renewable energy source, which is particularly attractive for countries like Indonesia that have abundant geothermal potential.[23,24] However, geothermal systems are not entirely free of greenhouse gas emissions, particularly during the construction phase.[25,26,27] When building a geothermal operation, 95% of the emissions generally come during construction. The drilling process can release gases into the atmosphere, including carbon dioxide, methane, and hydrogen sulfide, among others.

Where possible, grid electricity can be used to power drilling, which reduces sulfur dioxide and volatile organic compound (VOC) impacts to negligible levels, or hydrogenated vegetable oil can be used in place of diesel to run the generators, greatly reducing the impacts of

NON-CONDENSABLE GAS (NCG) COMPOSITION AND HARM THRESHOLDS IN GEOTHERMAL SYSTEMS

Gas	Typical Share of NCGs	Key Concerns	Harmful Levels
Carbon dioxide	90%–99%	Main GHG, asphyxiant in confined spaces, vegetation die-off near vents	>0.5% (5,000 ppm, OSHA 8-hr limit), >4% harmful to humans
Hydrogen sulfide	0.1%–3%	Acute human toxicity, corrosive, toxic to flora and aquatic life	>10 ppm irritation, >100 ppm dangerous, >500 ppm fatal
Methane	0.1%–1%	Potent GHG (GWP ~28–34), explosive hazard	5%–15% explosive in air
Ammonia	<0.1%	Irritant to humans (lungs/eyes), toxic to plants	>25 ppm harmful (OSHA limit)
Others (Nitrogen, Hydrogen, Radon)	Trace	Mostly inert, except radon (radioactive risk)	Varies

Figure 8.9: Non-condensable gas (NCG) composition and harm thresholds in geothermal systems. GHG = greenhouse gas; GWP = global warming potential; OSHA = Occupational Safety and Health Administration. Source: DiPippo, R. (2012). *Geothermal power plants: Principles, applications, case studies and environmental impact* (3rd ed.). Elsevier; Fridriksson, T., Mateos, A., Audinet, P., & Orucu, Y. (2016). *Greenhouse gases from geothermal power production*. World Bank; Intergovernmental Panel on Climate Change (IPCC). (2022). *AR6 climate change 2022: Mitigation of climate change*. IPCC; OSHA. (2006). *Occupational safety and health standards–Air contaminants*. U.S. Department of Labor.

carbon dioxide by up to 90%; nearly eliminating sulfur dioxide; and greatly reducing nitrogen oxide, particulate matter, and VOC emissions.

The main emissions from geothermal energy production come from non-condensable gases (NCGs) that are naturally present in geothermal reservoirs, particularly carbon dioxide and, to a lesser extent, hydrogen sulfide, methane, and other trace gases (see **Figure 8.9**).[28,29] These gases are released into the atmosphere during drilling and well testing.[30,31]

Water Consumption, Fluid Management, and Soil Disturbance

Geothermal development is water-intensive, particularly during well drilling. Depending on geological conditions and drilling technology, a single well may require between 1,000 cubic meters and 3,000 cubic meters of water.[32,33] In Indonesia, these projects are often located in volcanic highland regions that overlap with conservation forests and watersheds, areas that are critical for biodiversity and water catchment.[34,35] Early in development, improper management of drilling muds and geothermal fluids may contaminate nearby surface and groundwater sources.[36]

Globally, several mitigation strategies have been applied to balance geothermal development with water and environmental security, including reinjecting geothermal fluids to prevent contamination, sourcing drilling water from reservoirs specifically designated for industrial use, and adopting advanced waste treatment before disposal.[37,38] Next-generation geothermal technologies, such as AGS closed-loop systems and EGS, offer alternative approaches that reduce water and contamination risks even further. Advances in water recycling and the use of non-potable water have also helped mitigate impacts.[39]

For Indonesia, given the country's highly volcanic setting, EGS may not be a practical option, but AGS could shape the future of geothermal development nationally, particularly in areas where water availability or environmental sensitivities limit conventional hydrothermal projects.

In agricultural regions, geothermal development can also undermine soil fertility by introducing contaminants such as heavy metals and boron into irrigation waters and soils, leading to crop toxicity and reduced yields. In some areas of Indonesia, geothermal expansion has also reportedly led to water contamination, soil destabilization, and declining crop performance. These findings highlight that unmanaged solid waste not only threatens soil fertility but also directly affects food security in surrounding communities.

The waste disposal regulations in Indonesia, particularly Waste Management Law No. 18 of 2008,[40] emphasize the importance of reducing reliance on landfills and safeguarding the environment, highlighting the necessity for a strong and flexible waste management framework. By incorporating advanced waste management practices and leveraging AGS technology, geothermal developers can minimize solid waste impacts, protect soil quality, and ensure that geothermal energy remains a sustainable resource.

Induced Seismicity

An EGS, which often requires hydraulic fracturing, can reactivate existing fault lines, reducing rock cohesion and leading to seismic events. The seismic events are usually relatively minor, but sometimes injection can generate migrating swarms. In tectonically active regions, this result can raise concerns that repeated small quakes could trigger a larger slip on nearby faults.[41,42,43]

Indonesia's Geothermal Law No. 21 of 2014 enables the government to supervise every project phase to ensure compliance with safety, environmental, and operational standards.[44] Recent global practice emphasizes a modular risk management framework.[45] This approach integrates (i) pre-screening of sites for geological suitability and fault stability; (ii) hazard and risk assessment using geomechanical and seismic models; (iii) adaptive traffic-light systems linked to operational thresholds; (iv) deployment of dense, real-time seismic monitoring networks; and (v) transparent communication with regulators and local communities. Several geothermal projects worldwide have successfully applied these measures.

For example, at Soultz-sous-Forêts in France, pressure-controlled stimulation protocols kept seismic events below damaging levels.[46] In Helsinki, Finland, the St1 Deep Heat project used near-real-time seismic monitoring to adjust injection rates and avoid escalation to higher-magnitude events.[47] And in the United States, the Blue Mountain plant in Nevada combined pre-operational risk modelling with a responsive traffic-light system to maintain low seismicity,[48,49] while the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) research site has demonstrated that comprehensive site screening and staged injection can limit seismic hazards, even in complex tectonic settings.[50]

These cases show that with proactive learning, adaptive operational controls, and continuous monitoring, geothermal projects can significantly reduce the likelihood and impact of induced seismicity while maintaining safe and reliable operations.

For Indonesia, adopting these lessons will require real-time seismic monitoring, enforcement of traffic-light systems as part of project permits, the establishment of a centralized seismicity database, and stronger site-approval procedures.

Noise Pollution

The construction of a geothermal plant can cause a lot of noise that may disturb local communities and wildlife. Most noise pollution is ignored during environmental assessments, but in many situations it can have strong effects on human health and animal behaviors—the latter of which is particularly concerning because geothermal plants are usually built in remote, ecologically sensitive areas. Noise pollution in these environments can disrupt the feeding, mating, and migration patterns of wildlife. Research on geothermal noise impacts on wildlife remains limited.

Take, for example, the Wae Sano project on Flores (West Manggarai, East Nusa Tenggara), a World Bank–supported Geothermal Energy Upstream Development Program project to establish a plant that could initially produce between 10 megawatts and 32 megawatts. In this rural setting, heavy machinery, well pad construction, and drilling generate constant sounds that stand out against the low background noise levels (daytime = 44 dBA–49 dBA, nighttime = 39 dBA–44 dBA). Modeled construction noise is about 65 dBA at approximately 100 meters and about 43 dBA at around 500 meters; around the nearest residence (approximately 80 meters), daytime maximums can reach around 70 dBA, exceeding the residential limit of 55 dBA if the noise is unmitigated (see **Figure 8.10**).[51] Short well-testing phases can briefly produce levels up to approximately 110 dBA at the source, though these events are episodic and usually mitigated with silencers, mufflers, and temporary barriers.

The good news is that almost all of this noise goes away when construction is finished and plant operations begin.

OPERATIONAL PHASE

The lifespan of a geothermal plant is often long, which is good news. Once a plant is up and running, there are fewer issues to monitor. The following issues should be monitored once a plant is in operation.

Surface Emissions

The emissions of conventional geothermal plants in Indonesia are a fraction of the amount created from burning coal. If Indonesia can transition from coal to geothermal power, the country could cut its carbon dioxide emissions by more than 90% and also reduce local air pollutants such as sulfur dioxide, nitrogen oxides, and total suspended particulates. That said, conventional geothermal plants in Indonesia have some emissions, typically through steam containing NCGs, primarily carbon dioxide and hydrogen sulfide.

For example, the 230.5 megawatt Wayang Windu hydrothermal field emits about 65.9 grams of carbon dioxide equivalent per kilowatt-hour and roughly 2,067 tons of hydrogen sulfide per year.[52] Other gases, such as methane and ammonia, and trace elements such as mercury, arsenic, and radon are present in minor concentrations and generally reinjected into the reservoir as per national environmental regulations.[53]

The primary environmental and health concern is hydrogen sulfide, which has a characteristic "rotten egg" smell and can be harmful at high concentrations. Chronic exposure limits are low, with the World Health Organization recommending no more than 150 micrograms per cubic meter over a 24-hour period. Acute danger occurs only at very high concentrations (approximately 500 ppm–

NOISE LEVELS ACROSS GEOTHERMAL DEVELOPMENT PHASES COMPARED TO ANTHROPOGENIC SOURCES

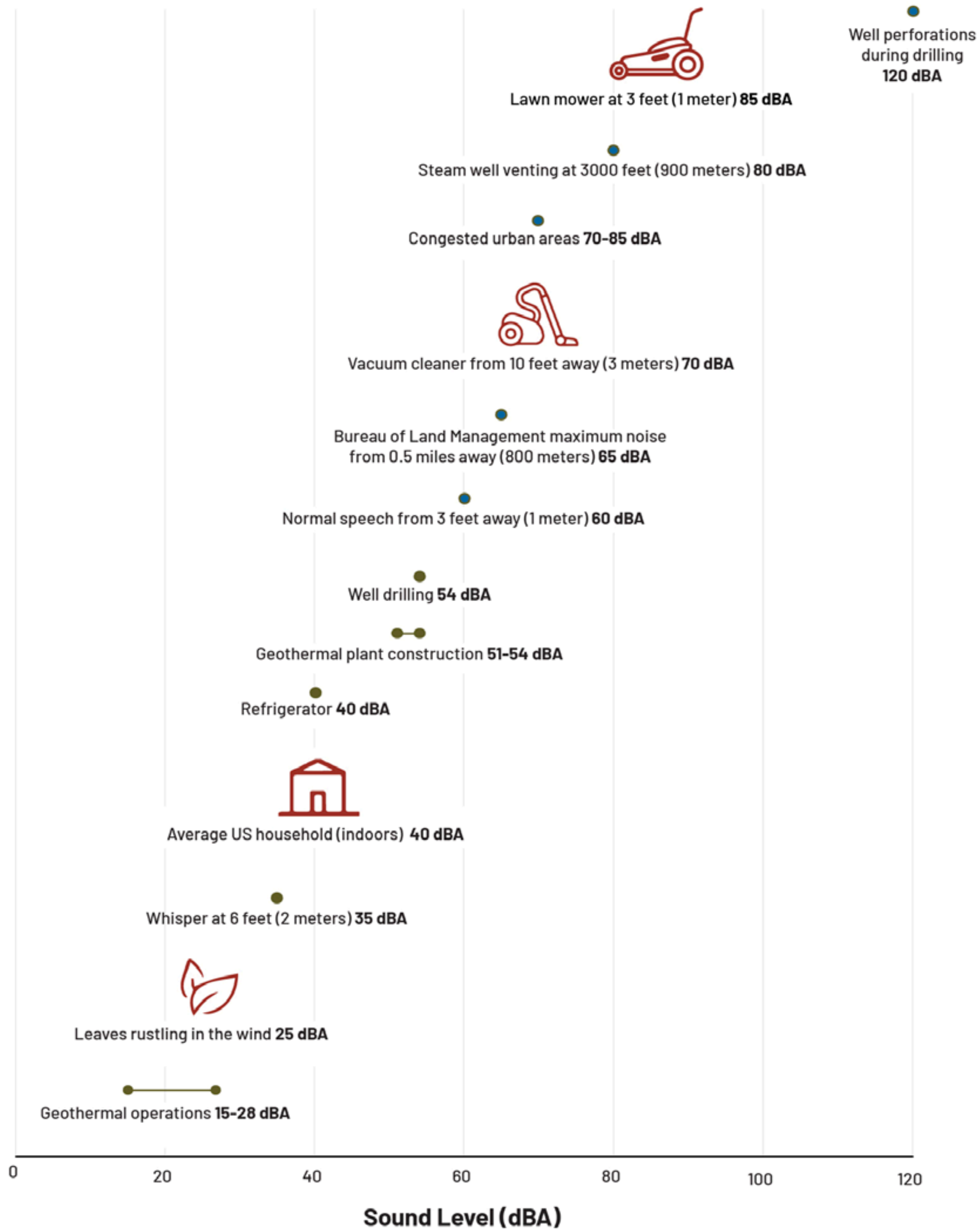

Figure 8.10: Noise levels across geothermal development phases compared with anthropogenic sources. Sources: Kagel, A., Bates, D., & Gawell, K. (2005). *A guide to geothermal energy and the environment*. Geothermal Energy Association; Massachusetts Institute of Technology (MIT). (2006). Environmental impacts, attributes, and feasibility criteria. In MIT (Ed.), *The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century* (pp. 8-1–8-20). MIT; Bryant, M., Starkey, A. H., & Dick-Peddie, W. A. (1980). *Environmental overview for the development of geothermal resources in the State of New Mexico*. New Mexico Department of Energy; Birkle, P., & Merkel, B. (2000). Environmental impact by spill of geothermal fluids at the geothermal field of Los Azufres, Michoacán, Mexico. *Water, Air, and Soil Pollution, 124*, 371–410.

700 ppm) and can be lethal within an hour. Field monitoring, such as at the Lumut Balai geothermal site, has recorded maximum hydrogen sulfide levels at around 0.54 ppm—well below acute toxicity thresholds.[54]

In one case, modeling at the Dieng geothermal field showed that bleeding NCGs through a hydrogen sulfide abatement tank would cut near-source hydrogen sulfide from between around 2 ppm and 5 ppm down to between around 0.4 ppm and 1.0 ppm, safely under the 5 ppm threshold.[55] While this modeling demonstrates a viable mitigation pathway, it is not universally required for all geothermal power plants. Fields with low hydrogen sulfide reservoirs, such as Sarulla, have been reported to exhibit minimal surface emissions, with measured concentrations typically fewer than 0.1 ppm, suggesting that continuous abatement may be unnecessary.[56] However, for "sour" fields such as Dieng and Lahendong—where elevated hydrogen sulfide levels are common and surrounding communities are directly exposed—abatement technologies should be considered standard practice.[57,58] This aligns with Indonesian air quality regulations,[59] which set ambient hydrogen sulfide limits at 30 micrograms per cubic meter (24-hour average) and occupational thresholds at 5 ppm.[60]

In the longer term, next-generation technologies (see Chapter 1, "Geothermal 101: Overview of Technologies and Applications") represent a strategic solution to address surface emission risks and strengthen the environmental performance of Indonesia's geothermal sector. Studies completed on next-generation pilot projects have reported surface emissions at 32 grams of CO_2-equivalent per kilowatt-hour for EGS facilities[61] and 11.6 grams of CO_2-equivalent per kilowatt-hour for AGS.[62]

Greenhouse Gas Emissions

Plants tend to release much lower volumes of NCGs during operation than during exploration or construction. In Indonesia, carbon dioxide emissions from current conventional geothermal plants range between 42 grams and 73 grams of carbon dioxide–equivalent per kilowatt-hour, with an average of 63 grams of carbon dioxide–equivalent per kilowatt-hour (see **Figure 8.11**).[63]

Next-generation systems such as a closed-loop AGS offer a pathway to fewer operational emissions. Most potential reservoir-derived gases remain dissolved or

GHG EMISSIONS OF GEOTHERMAL PROJECTS IN INDONESIA

Project Name	Location	Installed Capacity (MW)	Technology Type	Estimated GHG Emissions (gCO_2e/kWh)	Developer / Operator
Wayang Windu	West Java	227	Flash steam	73	Star Energy Geothermal
Sarulla	North Sumatra	330	Binary cycle & flash steam	100	Medco Power, Itochu, Ormat, INPEX
Lahendong	North Sulawesi	120	Flash steam	60–80	PT Pertamina Geothermal Energy
Ulubelu	Lampung, Sumatra	220	Flash steam	63	PT Pertamina Geothermal Energy
Kamojang	West Java	235	Flash steam	73	PT Pertamina Geothermal Energy
Dieng & Patuha	Central & West Java	120	Flash steam	65-75	Geo Dipa Energi

Figure 8.11: Greenhouse gas (GHG) emissions of geothermal projects in Indonesia. gCO_2e/kWh = grams of carbon dioxide–equivalent per kilowatt-hour; MW = megawatts. Source: Ea Energy Analyses. (2024). *Technology data for the Indonesian power sector: Catalogue for generation and storage of electricity*.

trapped in the closed circuit of an AGS, and under normal operations, they do not vent to the surface.

Solid Waste

Geothermal development creates drill cuttings, spent drilling mud, silica sludge, materials from maintenance activities, and other solid waste (**Figure 8.12**) that threaten soil, water, and agricultural health if not properly managed, particularly in the rural and ecologically sensitive areas of Indonesia.[64,65,66]

At the same time, if managed well, geothermal solid waste presents opportunities for reuse. Silica sludge can be used as a supplementary cementitious material in concrete, improving strength and reducing reliance on raw materials.[67,68] Drill cuttings may serve as aggregates for road base construction or landfill cover, and bentonite-based drilling mud has potential as a soil amendment if contaminants are controlled.[69]

Emerging technologies also enable the recovery of commercial-grade silica and other valuable minerals from geothermal waste streams, linking geothermal development with circular economy strategies.[70] To support this aspect, common waste management practices such as composting organic waste, recycling non-hazardous materials, and implementing secure disposal of hazardous waste remain essential to Indonesian geothermal operations.[71]

SUMMARY OF THE SOURCE AND THE TYPE OF GEOTHERMAL FIELD SOLID WASTE

No.	Activity	Source	Type of Solid Waste
1	Exploration and production	Drilling	Drill cutting
		Steam field	Silica
		Condensation	Scale Sludge
		Office	Paper Paper box Plastics Woods Battery Food waste Mixed waste Used fluorescent lamp Used PPE (personal protective equipment)
2	Maintenance	Washing	Scale
		Spare parts replacement and workshop activity	Used spare parts Scrap metal Used paint cans Used toner Used lubricants can
		Gardening	Leaves Grass
3	Laboratory analysis	Water treatment	Sludge
		Analysis using chemical	Contaminated rag Expired chemical substances Biocyte cans
4	Power generation	Cooling tower	Scale

Figure 8.12: Summary of the source and type of geothermal field solid waste. Source: Utami, A., Aji, N., Fadyah, A., Ghifari, A., Anam, M. B., Ramadhani, S., Rasyid, F. H., & Maulana, R. R. (2020). Geothermal energy solid waste management: Source, type of waste, and the management. *AIP Conference Proceedings, 2245*(1), 060001.

Looking forward, next-generation technologies offer pathways to mitigate many of these risks. Because an AGS uses closed-loop systems that circulate working fluids through sealed wells (see Chapter 1, "Geothermal 101: Overview of Technologies and Applications"), these systems do not need the large volumes of drilling mud required for conventional hydrothermal plants. An AGS also creates less contaminated sludge.

Land Subsidence

In Indonesia, with its high tectonic activity, geothermal energy extraction raises serious concerns about land subsidence, especially when fluid-removal rates are higher than reinjection rates, as in conventional geothermal.[72,73] Excessive overdrawing can consolidate subsurface reservoirs so much that the surface above visibly sinks. Subsidence can diminish the efficiency and sustainability of geothermal systems because it reduces pore spaces and fracture pathways, impairing fluid storage and movement.[74] The type of geothermal technology matters here. Conventional systems, which involve large-scale fluid extraction and reinjection, are more likely to cause the ground to sink. But newer technologies, such as AGS closed-loop systems, are designed to maintain reservoir pressure, reducing or eliminating the risk of subsidence.

Several geothermal fields in Indonesia have experienced notable subsidence because of surface loading, geological faults, altered rock compaction, and other factors.[75] Land in Muara Laboh, for instance, sinks up to 30 millimeters per year,[76] and Ulubelu averages 3.3 millimeters per year.

To mitigate land subsidence caused by geothermal development, countries around the world inject geothermal fluids back into the reservoir to maintain underground pressure and prevent compaction, a method proven effective in stabilizing fields such as Wairakei in New Zealand and areas within California's Basin and Range region.[77,78] Regulators and developers can also deploy comprehensive monitoring programs using techniques such as levelling and gravity surveys to measure ground deformation and remote-sensing technologies to detect subtle surface movements across large areas. These combined practices help prevent or minimize subsidence impacts while ensuring long-term reservoir sustainability.[79,80]

Water Consumption and Fluid Management

The types of plant and technology used determine how much water is needed during operations. An EGS requires the most water to maintain reservoir pressure and keep fractures open, whereas an AGS requires the least. An AGS eliminates the need for direct interaction with subsurface fluids by circulating a working fluid through sealed wells, and this design greatly reduces the risk of groundwater contamination and minimizes water consumption. Pilot projects in Germany by Eavor Technologies and in New Mexico by XGS Energy show that an AGS can operate with near-zero water withdrawal, addressing one of the key concerns in water-scarce regions and water-sensitive geologies.

Noise Pollution

In the operation phase, geothermal plants continue to produce noise from steam flow, turbines, and cooling systems, though at lower and more stable levels than construction. The Wae Sano project, for example, creates noises of only 55 dBA that cannot be heard beyond 500 meters. Plants can mitigate operational noise by deploying measures such as acoustic enclosures, low-noise fans, vegetation buffers, and earth berms.[81]

Geothermal noise is usually fairly moderate, but long-term exposure can still bother nearby communities.[82] To minimize risks, projects should apply noise-reduction technologies across both phases and comply with Indonesia's ambient noise limits (55 dBA for housing; 70 dBA for industrial zones).[83] Such measures are also important for protecting sensitive ecosystems where wildlife may be vulnerable to prolonged disturbance.

ONGOING CONCERNS

Injecting or extracting fluids from geothermal reservoirs can cause earthquakes, and Indonesia's location on the Pacific Ring of Fire makes it especially vulnerable. Earthquakes have been documented in active zones such as the Muara Laboh geothermal field in Sumatra, where minor induced seismic events range from moment magnitudes of −0.5 to 2.0.[84] Similar concerns have been reported near the Gunung Salak and Dieng geothermal plants. Residents living close to Gunung Salak have reported frequent tremors since operations began, despite limited scientific evidence confirming a direct link. In Kepakisan, near the Dieng plant, communities have also associated increased earthquake activity with geothermal drilling, citing instances of property damage.[85]

AGS and superhot rock (SHR) systems are more suitable options for Indonesia considering the country's high volcanic activity and frequent eruptions. Unlike conventional hydrothermal systems, an AGS—which operates through a closed-loop design and does not rely on underground reservoirs or fluid permeability—allows geothermal heat extraction in non-volcanic or seismically safer zones.[86] And SHR systems, which harness heat from extremely deep, supercritical rock formations, offer the potential for significantly higher energy output per well. Given Indonesia's abundant volcanic heat sources and delicate geology, these next-generation technologies provide a safer and more flexible alternative for expanding geothermal energy across a broader and more stable range of locations.[87] To further mitigate the risks of seismic events, developers should conduct comprehensive geological and fault mapping studies before starting exploration, prioritize low-risk sites, carefully manage fluid injection pressures, and set up ongoing seismic monitoring.

CONCLUSION AND RECOMMENDATIONS

The geothermal energy sector in Indonesia holds significant promise for achieving the nation's resilient energy and carbon reduction targets, particularly with the advancement of new geothermal technologies. Realizing its full potential, however, requires a careful approach to environmental hazards. Environmental impacts such as groundwater contamination, greenhouse gas emissions, biodiversity loss, induced seismicity, and land subsidence can be concerns, depending on location, and must be managed carefully. These risks can be amplified in Indonesia if development is pursued within conservation forests, protected ecosystems, and volcanic zones.

To guard against these hazards, policymakers and developers should prioritize smart resource siting, strong regulation, and resilient technologies. (For more on this topic, see Recommendation #9 in Chapter 7, "Turning Potential into Power: A Policy Blueprint for Indonesia's Geothermal Transformation.") By implementing careful strategies and proper safeguards, developers can scale up geothermal energy without sacrificing the forests, waters, and communities that make Indonesia unique. The following ideas—some of which are explored in more detail in Chapter 7—highlight ways to mitigate potential geothermal risks:

- Promote the adoption of next-generation geothermal systems for additional power generation as well as for cooling and industrial uses. Next-generation geothermal could be of particular value in opening up areas with limited permeability outside of High Conservation Value Areas to reduce surface disruption, water use, and subsurface and ecological risks.
- Prioritize geothermal development in lower-risk zones outside forest areas, where more than 2,160 gigawatts of potential have been identified (see the Chapter 3 supplement, "Expanding the Scope: Next-Generation Geothermal Opportunities"), while strengthening land use regulations to enforce strict "no-go" protections for high-biodiversity and conservation forests. Next-generation geothermal could significantly expand the potential for geothermal in Indonesia.
- All geothermal development should include requirements for post-operation land rehabilitation, including reforestation, slope stabilization, and ecological restoration, especially in forested or mountainous areas.
- Developers should be required to install real-time monitoring systems at all sites to track seismic activity, subsidence, emissions, and groundwater quality, with transparent public reporting.
- A circular approach to geothermal waste should be implemented by encouraging the reuse of silica sludge, drilling muds, and other byproducts in construction, agriculture, or industrial applications.
- Develop a national geothermal environmental database that is accessible to developers, investors, and communities for tracking land use, emissions, seismicity, and biodiversity impacts.
- Clear guidelines should be developed for inclusive community engagement, ensuring that local residents and Indigenous groups are consulted meaningfully and that environmental data are made publicly accessible.

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