



Chapter 9

Environmental Benefits and Considerations in India: Balancing Renewable Expansion and Ecological Stewardship in the Geothermal Sector

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Geothermal has one of the lowest land-use requirements of any energy type and can play a key role in reducing India's air pollution and greenhouse gas emissions. However, careful environmental oversight remains essential in geothermal development, with support from technical expertise, regular monitoring, data transparency, and safeguards to protect the country's precious resources.

With its vast and varied landscapes—from the Himalayas to the Thar Desert, the dense forests of the Western Ghats to the mangroves of the Sundarbans—India is home to extraordinary biodiversity. More than 100,000 documented species of animals, plants, and other organisms thrive in its ecosystems.¹ Safeguarding these landscapes and the ecosystems they support is one of the country's defining challenges.

As India seeks to meet its growing energy needs while decreasing its reliance on fossil fuels and improving air quality, geothermal energy offers resilient, always-on energy that also has the smallest surface footprint of any renewable energy source.

Given India's size and geological diversity, environmental factors will vary, as will surrounding communities' land and water needs. This chapter examines the environmental benefits and impacts—and some closely connected social and cultural factors—of geothermal development in India across all technology types (conventional, enhanced, and advanced geothermal systems) and stages of development. Key issues include wastewater handling, water use, induced seismicity, land changes, community disruption, and air quality.

The chapter also addresses best practices for geothermal development. When properly planned and managed, geothermal projects can be integrated into local



landscapes with minimal disruption—offering a pathway to sustainable growth that supports both economic development and environmental protection.

ENVIRONMENTAL BENEFITS OF GEOTHERMAL ENERGY

Reduced Carbon Dioxide Emissions

One of the most obvious environmental benefits of increasing geothermal energy for any nation is the significant decrease in carbon dioxide emissions. India’s continued dependence on coal, oil, and gas for energy and heating needs and the industrial sector’s heavy use of coal and oil and gas are major causes of emissions. In fact, about 25% of India’s total greenhouse gas emissions comes from burning coal for power.² Chapter 4, “Geothermal Cooling Opportunities,” shows that without action, cooling alone would produce an additional 810 million tonnes of carbon dioxide equivalent emissions annually by 2037, an increase so large that, on its own, it would place India among the world’s top 10 emitting countries, comparable to the total annual emissions of major emitters such as Canada or Saudi Arabia.

In September 2025, India’s government published a first-ever National Policy on Geothermal Energy, establishing a framework for geothermal development in the country. The policy noted that geothermal energy offers a significant additional renewable energy resource to help

India’s ambitious climate targets and the commitment to achieve net-zero emissions by 2070.³ These goals include achieving “50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030” and reaching the country’s “long-term goal of reaching net-zero by 2070.”⁴ Chapter 8 of this report, “Policy and Regulatory Pathways to Catalyse Geothermal in India,” outlines suggested geothermal development goals to help the Indian government achieve these targets.

In 2023 in the United Kingdom, scientists developed a meta-analysis of hundreds of studies comparing the climate change impacts of electricity-generating technologies.⁵ The results showed how developing geothermal energy can help countries reach their carbon emissions reduction goals. The analysis found that nuclear systems and wind are the technology with the lowest emissions, followed closely by geothermal, hydroelectric, photovoltaics, and concentrated solar power. Geothermal performs almost identically to photovoltaics—and it can have a much smaller surface footprint. The International Energy Agency’s recent report *The Future of Geothermal Energy* shared similar results, showing that geothermal has more potential than any other secure energy source except solar. The report also noted that there is enough geothermal energy potential to power the world 140 times over and that India has significant geothermal potential.⁶

LIFE CYCLE GHG EMISSIONS OF ENERGY RESOURCES

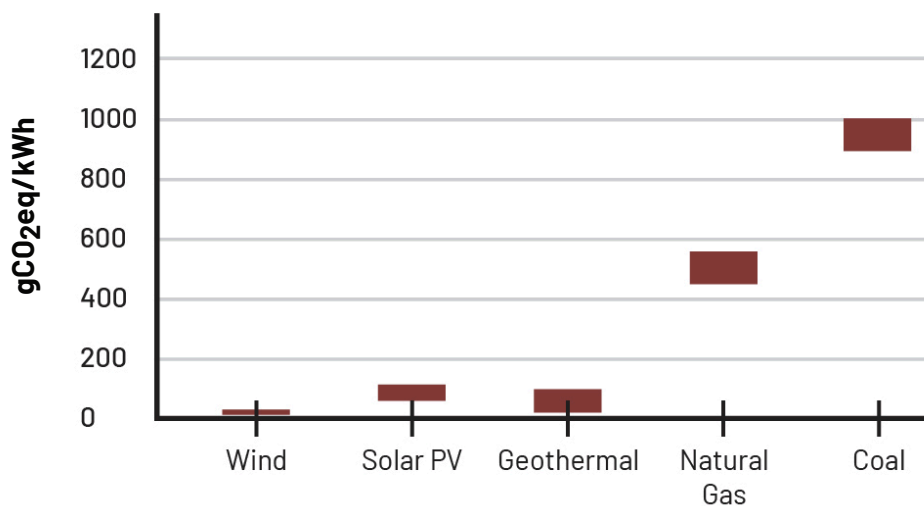


Figure 9.1: Life cycle greenhouse gas (GHG) emissions of different energy sources. gCO₂eq/kWh = grammes of carbon dioxide equivalent per kilowatt-hour; PV = photo voltaic. Source: Evans, A., Strezov, V., & Evans, T. J. (2009). [Assessment of sustainability indicators for renewable energy technologies](#). *Renewable and Sustainable Energy Reviews*, 13(5), 1082–88.



A 2010 life cycle assessment of conventional geothermal energy systems,⁷ which focused on the total greenhouse gas emissions generated across all phases of a geothermal project, found that geothermal still ranks among the lowest-emission technologies on a life cycle basis, especially when effective reinjection and gas-abatement systems are in place (**Figure 9.1**).⁸ This benefit is even higher for next-generation geothermal projects.

Though conventional geothermal power plants have slightly higher carbon dioxide emissions than solar and wind facilities, they offer a critical advantage: Geothermal plants have a much higher capacity factor. Conventional geothermal plants operate almost continuously, with capacity factors ranging from 70% to 90%, and next-generation geothermal is likely to have even greater capacity factors.⁹ Wind and solar power plants generate electricity only when the wind blows or the sun shines, so a 100 megawatt geothermal plant will deliver far more electricity over the course of a year than a wind or solar facility of the same size. Because this power is available at all times, its contribution to decarbonisation is more

valuable. As next-generation geothermal technologies continue to mature, improvements in drilling, reinjection, and plant design are likely, which will further reduce life cycle greenhouse gas emissions and increase geothermal's capacity factor, making it more favorable than wind and solar.

Reduced Air Pollutants

Expanding geothermal deployment in India would also cut emissions of fine particulates, sulfur dioxide, and nitrogen oxides that are by-products of fossil fuel combustion and major contributors to air pollution in the nation. A recent study found that one in eight deaths in India could be attributed to air pollution.¹⁰ Coal combustion, in particular, is identified as the largest anthropogenic source of air pollution-related health impacts in India.¹¹

Switching to geothermal, which emits virtually no on-site air pollutants, would significantly reduce local and regional pollution exposure and yield measurable public health benefits.

CLIMATE IMPACTS OF ELECTRICITY-GENERATION TECHNOLOGIES

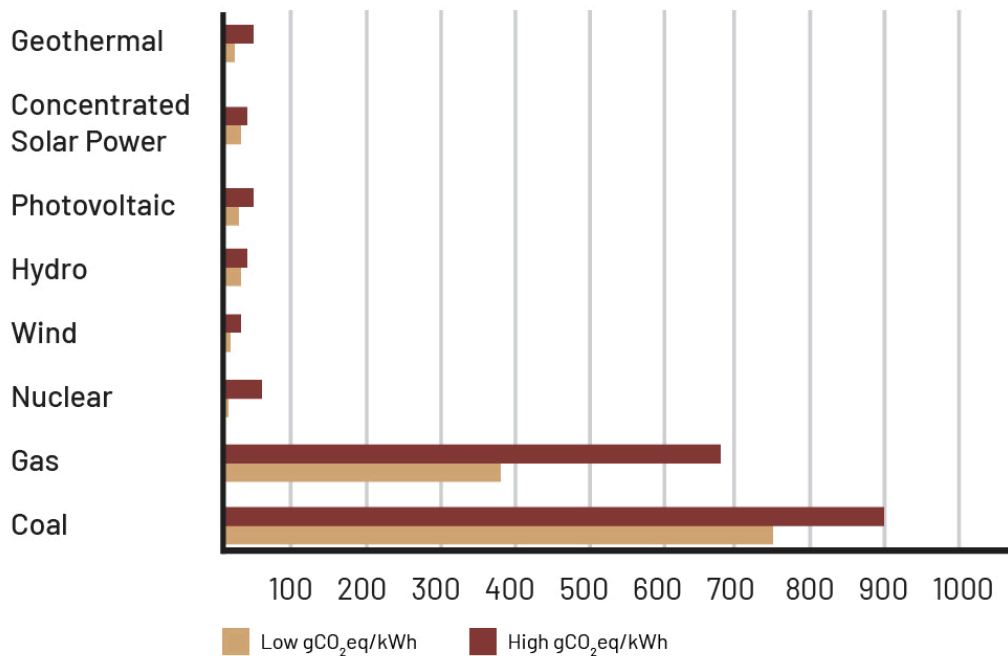


Figure 9.2: Climate impacts of various electricity-generation technologies. gCO₂eq/kWh = grammes of carbon dioxide equivalent per kilowatt-hour. Source: Graph created using figures from Guidi, G., Violante, A. C., & De Iuliis, S. (2023). [Environmental impact of electricity generation technologies: A comparison between conventional, nuclear, and renewable technologies](#). *Energies*, 16(23), 7847.



In the industrial sector, a large share of the combustion heat used for manufacturing and other processes is produced by burning coal or gas.¹² Replacing that share with direct geothermal heat would similarly slash emissions, especially in industrial clusters. With air pollutants often concentrated in industrial corridors, geothermal adoption would reduce localised pollution hot spots, mitigating exposure disparities.

Reducing coal-related emissions would improve air quality across India. One recent study showed that nitrogen oxide emissions from coal-fired plants depress crop yields by as much as 10% in nearby agricultural regions.¹³ Over time, the combined reductions in particulate and gaseous emissions would help India meet its ambient air-quality objectives more rapidly and reduce the costs of health care related to pollution.

Limited Land Use

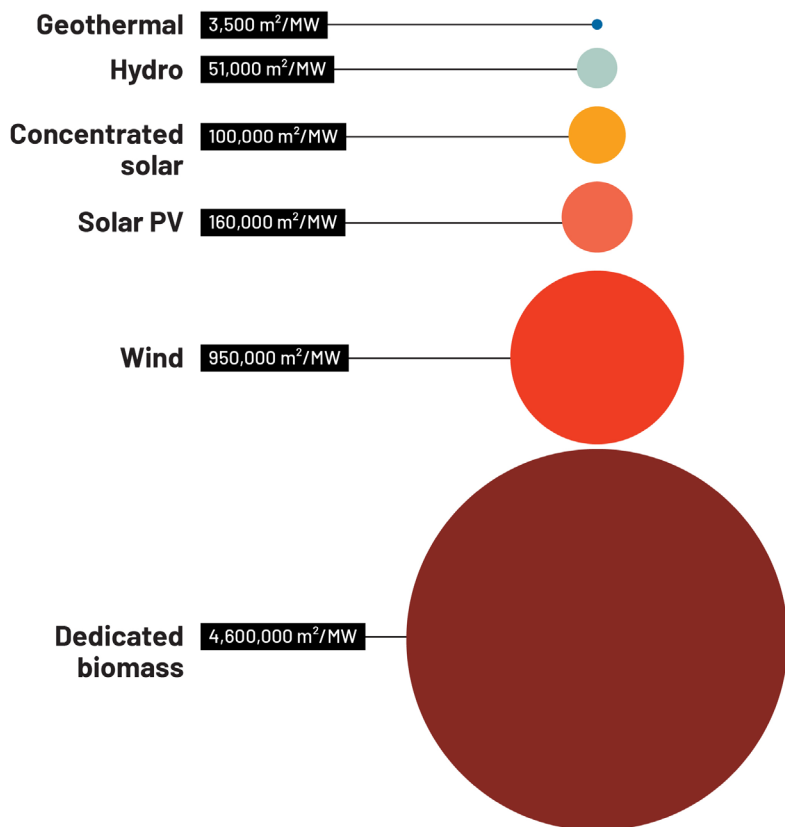
One of geothermal energy’s major advantages over other energy sources is that it typically uses the smallest

land area of any renewable energy source. Geothermal electricity plants typically use only 2.25% of the land that solar requires, 0.38% of the land needed for onshore wind, and 0.078% of the land needed by electricity plants that burn biomass for fuel (see **Figure 9.3**).^{14,15}

A typical geothermal energy power plant occupies just 3,500 square metres per megawatt (0.37 acres per megawatt), compared with 40,000 square metres per megawatt (9.9 acres per megawatt) for a coal-fired power plant.^{16,17} Novel next-generation geothermal designs may use multi-bench well configurations that could occupy even less space for future energy production.

When compared with solar and wind, geothermal power plants occupy between about 1 hectare and 2 hectares per megawatt of installed capacity.¹⁸ In contrast, solar photovoltaic facilities typically require between 4 hectares and 8 hectares per megawatt. Wind farms—although they have a smaller direct footprint (0.25 hectares to 0.5 hectares per megawatt at turbine

COMPARING SURFACE FOOTPRINT



Geothermal has the smallest footprint of any renewable energy source

Figure 9.3: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables. 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*. U.S. Department of Energy.



bases)—demand anywhere from 30 hectares to 50 hectares per megawatt when accounting for the total spread of the farm.^{19,20}

What’s more, deep geothermal heat-only projects for industrial or institutional use are even more land efficient and can be retrofitted into urban areas. Many complexes that are large enough to warrant deep geothermal heating already have access to the land area needed for development and drilling.

Importantly for India, however, is that most geothermal land-use estimates are derived from high-enthalpy regions such as Iceland or the western United States, where energy density is high and wells can be spaced more closely. In India, geothermal resources are largely low to medium enthalpy, which means they may require wider well spacing (or more land requirements), particularly for some next-generation geothermal such as engineered geothermal systems.²¹

Multi-Use Efficiency: Process Heat, District Cooling, Agro-Industrial Clusters, and More

In some cases around the world (for example, places with low- to medium-enthalpy resources in the Paris Basin, or in Klamath Falls, Oregon), a single geothermal resource has offered benefits for a number of applications. Because geothermal water remains warm even after its highest-temperature energy is extracted, it can be used sequentially—for electricity generation, industrial process heat, district heating or cooling, agriculture, and thermal storage. These cascading uses maximise energy recovery from each well, improve overall system efficiency, lower costs, and increase the economic and social value generated per unit of land.²² Geothermal systems can provide reliable, fuel-free thermal energy for industrial process heat, district cooling, and agro-industrial applications (see more in Chapter 3, “Direct-Use Geothermal for Manufacturing and Industrial Processes”).

While international experience demonstrates the viability of cascading geothermal systems, this model remains at an early stage in India, and additional pilot and demonstration projects will be necessary to validate their technical and economic feasibility under local conditions.

Reduced Ecosystem Pressure

Compared with large hydropower and biomass expansion, geothermal energy imposes significantly less pressure on ecosystems. In addition to having a small surface footprint, geothermal deployment mostly avoids the need to divert rivers. It also helps projects avert impacts such as displacement, sedimentation, and harm to biodiversity that are often associated with large hydropower projects. This benefit is particularly relevant in ecologically sensitive Himalayan and forested regions. Unlike biomass, geothermal energy does not compete for agricultural land, creates less strain on water resources, and is less likely to contribute to deforestation and air pollution from combustion.

As this chapter makes clear, the potential benefits of geothermal energy are plentiful. But scaling geothermal across India will also present environmental and community concerns. Next, we consider some of the potential challenges.

ENVIRONMENTAL CONSIDERATIONS

Impacts of Geothermal Technologies

Geothermal electricity generation falls into three main technological categories: conventional geothermal systems, engineered geothermal systems (EGS), and advanced geothermal systems (AGS). (See Chapter 1, “Geothermal 101.”) Each type can have different environmental footprints throughout the development cycle.

India’s potential for geothermal energy, however, extends well beyond electricity generation. Industries such as food processing, textiles, ceramics, and agriculture can directly tap into geothermal for low-cost, zero-emissions process heat (see more in Chapter 3, “Direct-Use Geothermal for Manufacturing and Industrial Processes”). Moreover, geothermal-based cooling systems can help reduce electricity use for air-conditioning in India’s rapidly growing cities (see more in Chapter 4, “Geothermal Cooling Opportunities”). Together, these applications offer a practical path to secure growth, industrial competitiveness, and climate resilience. These industrial heat and urban cooling projects may use any of the approaches outlined in the following sections.



Advanced Geothermal Systems (AGS)

Closed-loop systems are designed to maintain complete separation between the working fluid and natural geothermal reservoirs. Because no direct contact occurs between the fluid and subsurface formations, AGS significantly reduce the risk of groundwater contamination and chemical discharge.^{23,24} Because AGS have a small surface footprint, they can be deployed under buildings or within urban areas. Overall, AGS represent the least environmentally intrusive geothermal technology, with the smallest impact. Most geothermal heating and cooling systems are also closed-loop systems and have similar benefits to AGS.

Enhanced Geothermal Systems

The vast majority of geothermal projects in India will use low- to medium-enthalpy resources—ground source heat pumps, or closed-loop geothermal installations—for direct heating and cooling applications. These resources don't require hydraulic fracturing (also known as *fracking*). However, in select areas, and for a small number of electricity-generation projects that extract heat from hard granite, water-based hydraulic fracturing may be used to open microfractures in the rock. This technology has some environmental concerns that should be managed. The most prominent risk is induced seismicity, which results from fluid injection and fault activation.

While most induced seismic events are too minor to be felt (magnitudes less than 2.0), there have been exceptions. A well-known case occurred in Pohang, South Korea, in 2017, where an EGS project was linked to a 5.4 magnitude earthquake, causing injuries, damage to buildings, and long-term public opposition to geothermal energy.²⁵

Much next-generational geothermal development in India is still in the exploratory or pre-commercial stages, yet caution is warranted. India's Himalayan geothermal provinces (such as those in Uttarakhand, Himachal Pradesh, and Ladakh) lie in tectonically active zones with known fault lines and should be drilled carefully and continuously monitored to mitigate seismic risks (**Figure 9.4**). Land subsidence in Joshimath, Uttarakhand, is an important example of how construction and industrial activity in fragile ecosystems can significantly exacerbate the severity of geohazards.²⁶

Water consumption is another potential challenge, as EGS operations require substantial volumes for both drilling and circulation.²⁷ EGS can also mobilise trace elements from deep rock layers, leading to potential chemical contamination if reinjection is not managed effectively. Nonetheless, with appropriate controls, reinjection systems, transparent community engagement, communication of safety measures, and continuous monitoring of microseismic events, all of these impacts can be significantly mitigated. The effectiveness of these strategies will depend on proper state and national regulatory oversight and institutional capacity.

Additionally, because both AGS and EGS technologies only need hot rock, rather than hot water, there are more areas across India in which those projects can be developed. This feature is important because it doesn't just mean more opportunities for geothermal; it also means that projects in environmentally sensitive areas where only conventional geothermal would work can be avoided.

Conventional Geothermal Systems

While conventional systems have a smaller surface footprint than other renewable energy sources such as solar and wind, they often disturb surface manifestations such as geysers and hot springs that may be ecologically or culturally sensitive. Emissions of gases such as carbon dioxide, hydrogen sulfide, and trace elements can occur, though advanced gas-abatement technologies (including scrubbers and condensers) are capable of reducing these emissions by more than 95%.²⁸ Reinjection of used fluids is now a standard practice, not only to minimise surface discharge pollution but also to maintain reservoir pressure and ensure long-term sustainability.²⁹ While conventional systems present moderate environmental risks, as with EGS, those risks are manageable when best practices are implemented.

India's Geothermal Landscape: Geological and Environmental Features

Geothermal opportunities in India are found in a diverse range of geological formations and ecological zones, each with its own history, ecosystem, and sociocultural context.



EXAMPLE OF CONTINUOUS SEISMIC MONITORING SYSTEM

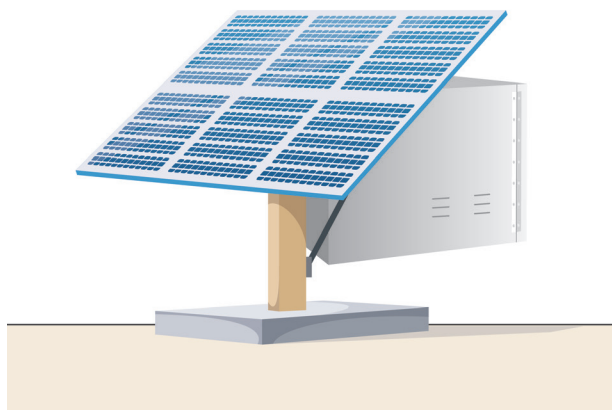


Figure 9.4: Example of a continuous seismic monitoring system.
Source: Project InnerSpace.

Himalayan Provinces

These regions stand out due to their ecological fragility, cultural significance, and tectonic sensitivity. Stretching over 1,500 kilometres from Ladakh to Assam, the Himalayan geothermal belt is home to key sites such as Puga Valley, Chumathang (Ladakh), and Manikaran (Himachal Pradesh). This region offers significant opportunities for geothermal development, provided certain factors are carefully considered and addressed:

- **Ecological fragility:** The sites fall within or near protected areas with rich biodiversity and fragile alpine ecosystems. Environmental clearances for geothermal projects in this belt must account for the impacts on flora, fauna, and hydrology.
- **Cultural significance:** Some of these locations, such as Manikaran, are considered sacred by local communities and attract large numbers of pilgrims. Development in such areas requires engagement with religious stakeholders and culturally sensitive planning.
- **Seismic vulnerability:** The Himalayas lie within Seismic Zones IV and V, the most seismically active zones in India.³⁰ Incorrect deep drilling and subsurface fluid injection, particularly in EGS, carry the risk of induced seismicity in these tectonically active zones.³¹

Cambay Graben, Gujarat, Western India

This region presents a different scenario. With a moderate geothermal gradient and a well-developed oil infrastructure, the basin has potential as a site for binary-cycle geothermal power generation using retrofitted oil wells.³² While the area overlaps with agricultural land, careful site selection, advanced drilling techniques, and closed-loop heat exchange systems can help minimise land acquisition needs and prevent groundwater contamination. Seismically, the region lies in Zone III,³³ indicating moderate seismic risk, but caution remains necessary given the induced seismicity observed in oil and gas operations in similar basins globally. A combination of strong resource potential and proactive environmental safeguards offers a pathway for sustainable geothermal expansion in the region.

Tattapani Field, Chhattisgarh, Eastern India

This geothermal field, along the Son-Narmada Lineament, lies in a mixed landscape of forest patches, agriculture, and rural settlements. The Tattapani site does not fall within a high seismic-risk zone, but the surrounding terrain may still require careful hydrological and ecological assessment to avoid unintended impacts on local water resources and habitats. While this area is not as culturally sensitive as the Himalayan sites, any energy development here must engage with rural communities to address land rights and livelihood concerns.

Regardless of the location, where land is ecologically fragile, densely populated, and often socially contested, it is critical to assess how geothermal development can alter land-use dynamics. A careful balance of energy extraction and environmental oversight will be required as these sites are developed—a balance that can be achieved with a combination of technical expertise, regular monitoring, data sharing, and transparency.

CULTURAL AND SOCIAL IMPACT

Geothermal development can contribute positively to regional energy security, job creation, and economic upliftment. However, these benefits often come with social and cultural trade-offs, particularly for local communities. In India, many geothermal provinces—



GEOHERMAL POTENTIAL IN INDIA

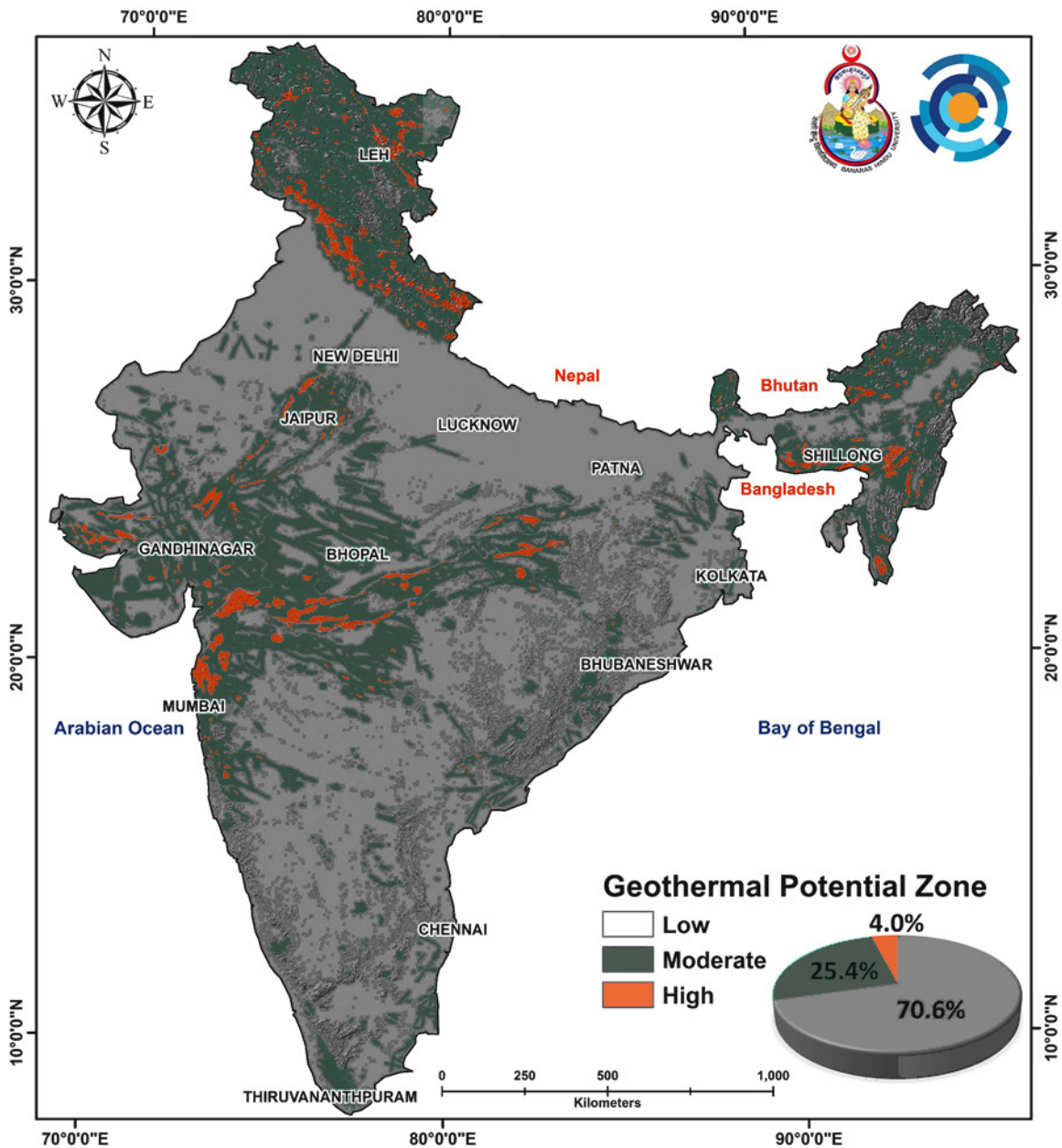


Figure 9.5: Map showing geothermal potential in India (without the Andaman and Nicobar islands and Lakshwadeep). Source: Project InnerSpace; Satya Prakash Maurya & Avinash Chouhan.

such as Puga (Ladakh), Tattapani (Chhattisgarh), Manikaran (Himachal Pradesh), and Bakreshwar (West Bengal)—are not only rich in geothermal potential but also deeply embedded in religious and cultural traditions. These sites host sacred hot springs, pilgrimage routes, and temples that are integral to local identity and spiritual practices.

The development of infrastructure such as roads, pipelines, and drilling facilities near these culturally sensitive areas can lead to land acquisition disputes, displacement, or the desecration of sacred landscapes. In some instances, geothermal surface manifestations themselves (for instance, steaming vents or hot water pools) are considered holy and worshipped by communities. Disrupting these features without due consideration can



erode community trust and lead to project opposition, as seen in past infrastructure projects in culturally significant zones. (For more information and details about solutions to community and stakeholder engagement, see Chapter 6, “India’s Stakeholders: Opportunities and Implications for Geothermal Growth and Development.”)

ENVIRONMENTAL IMPACT OF PROJECT PHASES

Geothermal development has three main phases: exploration, resource development, and operations and decommissioning. Of these phases, exploration and resource development are the most complex, while the operations and decommissioning phase has fewer environmental implications.

Exploration

Many geothermal exploration techniques are largely non-invasive and observational. For example, sampling methods occasionally involve the need to access sensitive areas, but environmental impacts from these activities are largely minimal. Some exploration methods, however, do have a larger effect.³⁴ Most exploration surveys use existing road and infrastructure networks to save costs, resulting in little habitat loss or vegetation removal. When there is a need to create new infrastructure, care must be taken to minimise environmental impacts.

During the exploration phase, seismic exploration involves generating seismic waves at the surface through rapid ground displacement. Active seismic surveys often compress soil or rock at the surface with an air gun or a seismic vibrator.³⁵ Though this method creates noise and disturbs soil and wildlife, it is temporary and usually doesn’t require excavation or result in any lasting impacts.

Exploration boreholes require drilling small-diameter holes, much like those used in exploration drilling typical of mining projects. In deep geothermal projects, these holes can range from hundreds of metres to a few thousand metres and are used to measure subsurface temperatures and collect rock cores. Land disturbance is confined to a drill site (or pad) of a few hundred square metres, a space in which vegetation may be cleared and temporary access tracks constructed. As with development drilling, the process generates rock fragments and mud (on a smaller scale than

with project drilling) that are managed on-site or removed per environmental regulations. 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.

Overall, the exploration phase has minimal impact on the environment.

Project Drilling and Construction

Most of the environmental impact of developing a geothermal plant in a region occurs during the drilling and construction phases, so it is vital to understand mitigation strategies for each potential hazard.

Surface Modifications

Although geothermal systems occupy less area in absolute terms, the associated infrastructure (drilling pads, pipelines, cooling towers, and access roads) requires earthworks and surface modification. These impacts, though concentrated, are ecologically significant in mountainous and high-altitude regions such as Puga Valley (Ladakh) or Tattapani (Chhattisgarh), where terrain instability, fragile ecosystems, and biodiversity sensitivity amplify the risks.

Water and Fluid Management

Drilling geothermal wells uses methods similar to those employed by the oil and gas industry, such as mud rotary-drilling techniques with water and additives rich with bentonite (an absorbent swelling clay consisting mostly of montmorillonite and used in drilling mud) to help carry rock cuttings to the surface. For these projects to be environmentally sound, developers first need to consider the impact of water use, as securing an adequate water source in remote or water-scarce regions such as Ladakh or parts of the Deccan Plateau can present logistical and ethical challenges.^{36,37} As a result, water extracted for drilling must be carefully managed to prevent the depletion of local sources that are vital to residents’ livelihoods, public health, agriculture, and ecosystems.

The wastewater generated by this process must also be carefully managed because it may be contaminated with heavy metals and other naturally occurring chemicals.



(The wastewater might also be so hot that direct disposal could damage the environment.) Mishandling, or a lack of adequate regulations, can cause these metals and chemicals to seep into the soil or leach into groundwater, threatening both environmental and human health.

In the Puga Valley geothermal project in Ladakh, an unexpected release of geothermal fluid into a local stream raised environmental concerns and led to significant project delays. Work on the site resumed in 2024 after changes in operational and drilling teams occurred. Multiple reports in the media point to this issue,^{38,39} though there doesn't seem to be a publicly available scientific report on the incident. For projects to succeed, developers should ensure that disposal strategies account for how to contain, treat, and manage wastewater. This can be challenging, as pollution levels can vary depending on complicated factors such as the underground flow of groundwater and the permeability of different barriers. Wetlands are especially vulnerable because groundwater and surface water interact, making spread of contamination more likely.⁴⁰ Broken pipes,⁴¹ casing failure and leakage,⁴² and leaks from both wastewater storage reservoirs and solid waste sites should be closely monitored.

Surface Emission

During drilling and initial well testing, geothermal reservoirs may release gases such as carbon dioxide, hydrogen sulfide, methane, and other trace compounds. These emissions are deeply tied to the geological nature of the resource.

For example, India's Himalayan geothermal zones, such as those in the Garhwal and Ladakh regions, exhibit natural carbon dioxide emissions from hot springs.⁴³ Although these emissions are often low compared with coal-fired plants, certain geothermal fields globally have shown carbon dioxide emission levels exceeding 500 grammes of carbon dioxide per kilowatt-hour, underscoring the need for proper site assessments and emission controls.⁴⁴ Moreover, hydrogen sulfide, even in small amounts, is toxic and must be monitored closely due to its pungent odor and potential health hazards.

Noise

During drilling and plant construction, noise from drill rigs, generators, and construction vehicles can push sound

levels up to 120 decibels.⁴⁵ For workers, residents, and wildlife, such levels can be distressing, particularly in tranquil rural areas or protected natural habitats. Moreover, conventional geothermal sites might be situated near communities and tourist locations (such as the hot springs of Manikaran or Tattapani) where noise pollution can disrupt daily life and diminish the area's spiritual or recreational value. While the noise is largely temporary, its effects on migratory birds, sensitive species, and local residents need mitigation through noise barriers, timing restrictions, and community coordination, so addressing the noise is important. The good news is that from 900 metres away, the noise produced by drilling and construction decreases to match ambient noise levels in urban areas (71 dBA–83 dBA). And during normal operations, noise levels drop to between 15 dBA and 28 dBA, which matches the average background noise in wilderness areas (20 dBA–30 dBA).⁴⁶

Many geothermal operations employ muffling techniques such as noise shields, exhaust mufflers, and acoustic insulation to reduce noise by up to 40%.⁴⁷

Impact on Biodiversity

The intensity and nature of risk to biodiversity from geothermal activity is generally lower than what are associated with oil and gas exploration and other resilient energy sources—thanks to the absence of hydrocarbons, a lower chemical load, and more stable flow patterns and smaller surface footprints—yet it is important to recognise that geothermal can still have a damaging effect if development is not managed carefully.^{48,49}

Biodiversity, which is often fragile in geothermal-rich ecosystems, can be at risk during development phases. The initial stages of geothermal projects (such as site clearance for access roads, drilling rigs, and heavy equipment) can lead to habitat fragmentation and species displacement.⁵⁰ These disruptions can be critical in ecologically sensitive or protected areas, where intrusions can cascade into broader ecosystem imbalances. Another major threat is the discharge of untreated geothermal fluids, which can contain toxic elements such as arsenic, boron, mercury, and lithium. This practice is carefully regulated and prohibited in most jurisdictions where geothermal development is more advanced, and India should ensure this global best practice is implemented.



If released into adjacent streams or wetlands, these pollutants may alter water chemistry and become catastrophic for aquatic and soil-dependent life forms.⁵¹ These fluids may significantly exceed safe levels for drinking water or ecological thresholds, depending on site-specific geology and fluid chemistry.

Figure 9.6 illustrates the concentration of naturally occurring major contaminants that have been found in conventional geothermal fluids from various global geothermal fields. These values are presented alongside average freshwater concentrations and regulatory thresholds established by the World Health Organization and the U.S. Environmental Protection Agency.^{52,53} The figure underscores that although geothermal energy is a secure energy source, development carries non-trivial risks to water quality

and aquatic ecosystems that need to be addressed through updated case-specific waste-management protocols.

That said, these embedded chemicals are less likely to be an issue for shallow geothermal systems such as ground source heat pumps and next-generation geothermal systems, which are more often designed as closed-loop or contained systems that circulate a working fluid through sealed pipes rather than producing formation fluids.

The Puga Valley in Ladakh exemplifies the biodiversity challenges in geothermal zones. Puga Valley is not only one of India's most promising high-temperature geothermal fields but also a designated wetland ecosystem and seasonal habitat for migratory birds such

CONCENTRATION OF MAJOR CONTAMINANTS IN FLUIDS IN CONVENTIONAL GEOTHERMAL POWER PLANTS

Contaminant	Concentration in Geothermal Fluids	Geothermal Fields	Avg. Freshwater Concentration	WHO Threshold	U.S. EPA Maximum Concentration Limit (MCL)	India's General Standard for Discharge into Inland Surface Water*
Arsenic (AS)	Up to 2.6 mg/L	West Java, Indonesia	0.001 mg/L	0.01 mg/L	0.01 mg/L	0.2 mg/L
Boron (B)	Up to 25 mg/L	El Salvador	0.01 mg/L	2.4 mg/L	NA	NA
Mercury (Hg)	Up to 6.5 µg/L	West Java, Indonesia	0.00004 mg/L	0.006 mg/L	0.02 mg/L	0.01 mg/L
Hydrogen Sulfide (H₂S)	Approximately 130 mg/L	Krafla, Iceland	<0.001 mg/L	NA	NA	NA
Ammonia (NH₃)	Up to 30 mg/L	Iceland, El Salvador and others	0.04 mg/L	NA	NA	5.0 mg/L

Figure 9.6: Naturally occurring contaminants that have been found in conventional geothermal fluids from various global geothermal fields. * = as provided in Schedule VI of The Environment (Protection) Rules 1986. EPA = Environmental Protection Agency; g = grammes; L = litre; mg = milligrams; WHO = World Health Organization. Source: World Health Organization (WHO). (2017). [Guidelines for drinking-water quality, fourth edition: Incorporating the first addendum](#); U.S. Environmental Protection Agency (EPA). (2025, December 1). [National primary drinking water regulations](#); Central Pollution Control Board (CPCB). (1986). [General standards for discharge of environmental pollutants](#); Stefánsson, A., Arnórsson, S., Gunnarsson, I., Kaasalainen, H., & Gunnlaugsson. (2011). [The geochemistry and sequestration of H₂S into the geothermal system at Hellisheidi, Iceland](#). *Journal of Volcanology and Geothermal Research*, 202(3-4), 179-88; Irnawati, I., et al. (2021). [Assessment of arsenic levels in water, sediment, and human hair around Je Seu'um geothermal manifestation area, Aceh, Indonesia](#). *Water*, 13(17), 2343; Herdianita, N. R., & Priadi, B. (2008). [Arsenic and mercury concentrations at several geothermal systems in West Java, Indonesia](#). *ITB Journal of Science*, 40(1), 1-14; Stefánsson, A. (2017). [Gas chemistry of Icelandic thermal fluids](#). *Journal of Volcanology and Geothermal Research*, 346, 81-94.



as bar-headed geese and ruddy shelducks. In such high-altitude ecosystems, noise from drilling operations, alterations in groundwater regimes, and increased human activity may disturb wildlife, particularly endemic

and sensitive species. Aquatic habitats, which rely on stable thermal and chemical conditions, are especially vulnerable to potential changes caused by accidental geothermal discharges or leaks.

ENVIRONMENTALLY PROTECTED AREAS AND GEOTHERMAL HOT SPOTS

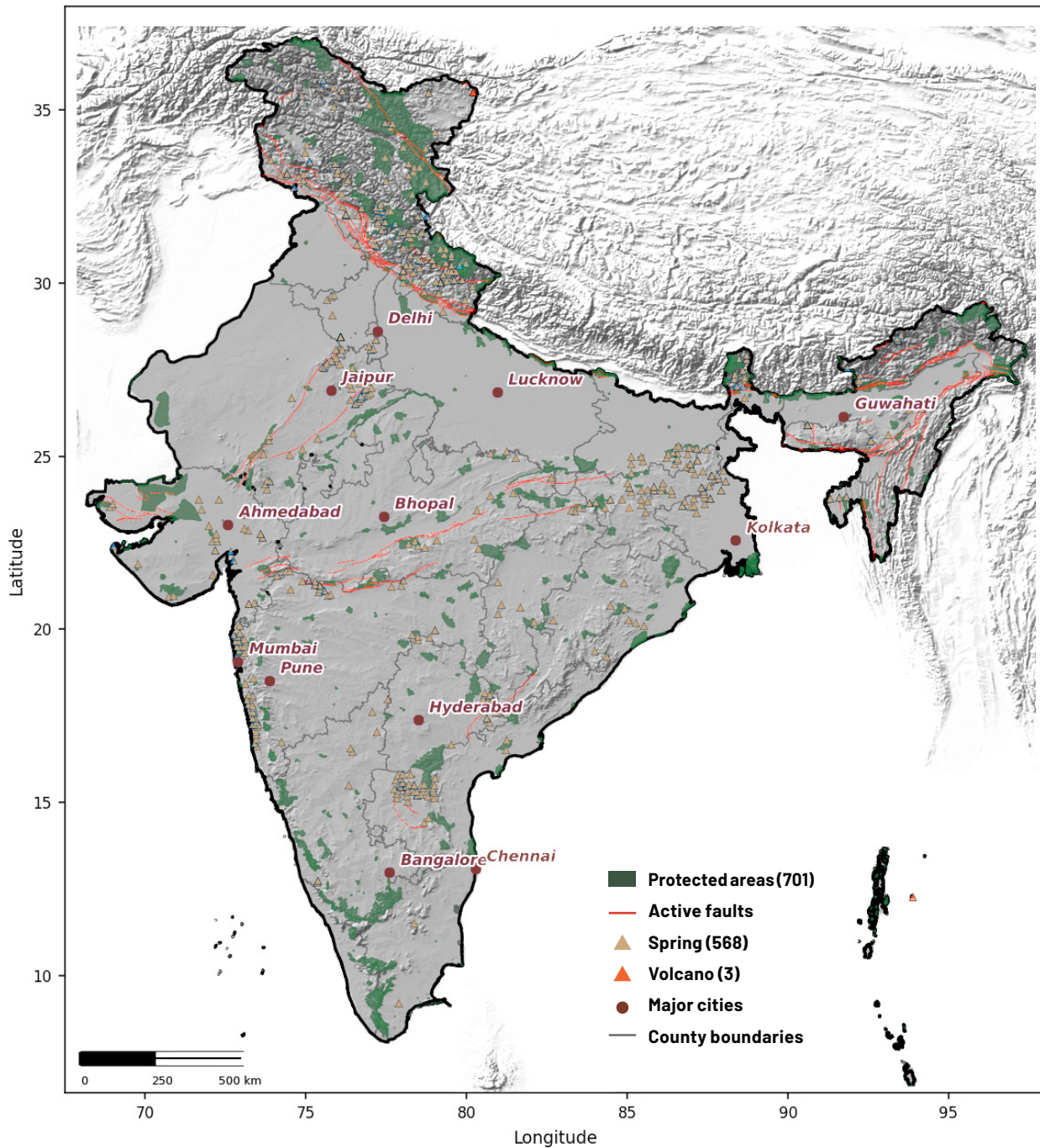


Figure 9.7: Geothermal potential overlaid with environmentally protected areas: Source: Project InnerSpace. (n.d.). [GeoMap](#).



To address biodiversity risks, Environmental Impact Assessments for geothermal projects should include a baseline biodiversity inventory, particularly in ecologically sensitive zones such as the Himalayas and northeast India. The inclusion of a project-specific biodiversity impact table that details species presence, conservation status, seasonal patterns, and potential impact pathways can be invaluable for regulatory decision-making and long-term monitoring.

To mitigate these impacts, early and meaningful community engagement is crucial. This engagement includes recognising customary land rights, involving local leaders and religious authorities in project planning, and developing a shared social and economic benefit framework. Preservation of religious structures and features must be prioritised not only as an act of compliance but also as a sign of respect for local traditions and an investment in long-term project viability. Read more about these strategies in Chapter 6, “India’s Stakeholders: Opportunities and Implications for Geothermal Growth and Development.”

Enhancing Biodiversity Through Geothermal Development: A Case Study from the Eden Project in the UK

In some areas, geothermal power plants have created additional habitats for wildlife. At the Eden Project in Cornwall in the United Kingdom, for example, project managers made improvements in species-rich grassland and wildflowers, as trenches there were sowed with a diverse seed mix. Ducks, geese, house martins, willow warblers, and grey wagtails all nest there, and foxes and deer are often present at the site. Staff also protected a woodland area in the centre of the drilling site with oak trees and willow carr and retained hedge lines to support biodiversity. Topsoil trenches were also reinstated and seeded with wildflower mix and topsoil bunds to be suitable habitats for insects and burrowing bees. Natural stone gabions—rather than concrete pillars—were used to support the above-ground sections of pipe. (During drilling, the site was monitored for noise, and the loudest sound recorded was the dawn chorus of birds in the hedge.^{55,56})

Project Operations and Decommissioning

Once a project becomes operational, environmental impacts stabilise and remain relatively low, particularly compared with other fossil fuel-based or even some renewable energy systems. Advanced gas-abatement systems reduce emissions by as much as 95%.⁵⁴ Abandoned boreholes and wells can be decommissioned, capped, or repurposed for monitoring throughout the lifespan of the project so there is minimal lasting impact on land use. The land surrounding a project can be repurposed for community benefits such as eco-tourism, educational facilities, or small-scale manufacturing units powered by resilient energy.

Land Subsidence

Extracting geothermal fluids from underground reservoirs alters the pressure and mechanical balance within subsurface rock formations. Over time, this pressure change can lead to land subsidence (the gradual sinking or compaction of the Earth’s surface).



Wildflower mix planted over the heat main at Eden Geothermal. Image provided by Eden Geothermal 2023.



Though often subtle at first, this phenomenon can accumulate to cause significant structural damage to geothermal wells, pipelines, roads, and surrounding infrastructure. In severe cases, subsidence may even disrupt the hydrology of an area by altering surface and subsurface drainage patterns.

A cautionary example comes from Mehsana, Gujarat, where extensive oil extraction combined with groundwater withdrawal led to observable subsidence that damaged buildings, pipelines, and roads over time.⁵⁸ Though the subsidence in this case was caused by fossil fuel development, the underlying mechanisms are similar to those used in geothermal operations,

REGULATORY SIMILARITIES BETWEEN OIL AND GAS AND GEOTHERMAL ENERGY SECTORS

As noted in Chapter 5, "Leveraging Oil, Gas, and Mining Technologies and Workforce to Advance Geothermal in India," oil, gas and mining industry expertise, supply chains, and data sets can support geothermal development. Enhanced geothermal system (EGS) technologies in particular have been adapted from the oil and gas industry.⁵⁷ The development process for new geothermal projects involves several phases that mirror upstream petroleum activities such as comprehensive subsurface assessment, computational modelling, specialised

drilling operations, and surface facility management. Consequently, the environmental considerations stemming from both sectors have some overlap.

From a regulatory perspective, a perusal of oil and gas sector regulations highlights the extent to which these can be applied to the geothermal sector. In some cases, these can be applied in pari materia, while others could be used to guide the development of geothermal specific regulations for India.

Laws Applicable to the Geothermal Sector and the Oil and Gas Sector	Analogous Regulations
Environment (Protection) Act, 1986, and rules and regulations under this act	Petroleum and Natural Gas Rules, 1959
Wildlife (Protection) Act, 1972; Forest (Conservation) Act, 1980	Oilfields (Regulation and Development) Act, 1948
Mines and Minerals (Development and Regulation) Act, 1957; Mines Act, 1952	Petroleum and Minerals Pipelines (Acquisition of Right of User in Land) Act, 1962
Water (Prevention and Control of Pollution) Act, 1974; Water (Prevention and Control of Pollution) Cess Act, 1977; relevant states groundwater acts, such as the Karnataka Ground Water (Regulation for Protection of Sources of Drinking Water) Act, 1999, and Maharashtra Ground Water (Regulation for Drinking Water Purposes) Act, 1993	Petroleum & Mineral Pipelines (Acquisition of Right of User in Land) Rules, 1963
Air (Prevention and Control of Pollution) Act, 1981	Oil Industry Safety Directorate standards
Public Liability Insurance Act, 1991	

Figure 9.8: Laws that are applicable to the geothermal and oil and gas sectors and analogous regulations. Source: Oil Industry Safety Directorate (OISD). (n.d.). [OISD standards list](#). Ministry of Petroleum and Natural Gas, Government of India.



where fluid withdrawal without adequate pressure management can result in ground compaction and structural instability. The risk of this happening with geothermal, however, is much smaller: Conventional geothermal reinjects most fluids, and next-generation geothermal does not depend on local water.

One of the most effective mitigation strategies for geothermal-induced subsidence is the reinjection of spent geothermal fluids back into the reservoir. Reinjection serves multiple purposes: It helps maintain reservoir pressure, supports thermal recovery, and minimises the risk of ground deformation. Global experience shows that systematic reinjection, which has been implemented in fields such as Wairakei (New Zealand) and The Geysers (United States), can significantly reduce or stabilise subsidence rates.⁵⁹ As

India expands next-generation geothermal development, especially in sensitive regions such as Puga Valley, project design must include early reinjection planning and regular geotechnical monitoring to prevent long-term damage.

Emissions

As mentioned, operational conventional geothermal plants emit significantly less carbon dioxide than fossil fuel-based power plants. On average, conventional geothermal plants release between 40 grammes and 120 grammes of carbon dioxide per kilowatt-hour, depending on the reservoir and technology used. (In some rare cases, particularly when development happens in high gas fields, carbon dioxide emissions can reach up to 500 grammes of carbon dioxide per kilowatt-

CONSIDERATIONS TO ENSURE RESPONSIBLE, ETHICAL GEOTHERMAL DEVELOPMENT IN INDIA

1	<p>Mitigate induced seismicity through continuous monitoring. Implement real-time seismic monitoring systems around geothermal project sites, particularly in tectonically sensitive zones. Monitoring pressure changes and microseismic events can help operators adjust fluid injection rates and prevent larger fault reactivations. Advanced monitoring can include deploying Advanced Traffic Light Systems (ATLS), as developed by the GEISER (Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs) consortium, to monitor and manage induced seismicity risks.</p>
2	<p>Ensure safe fluid and waste management. Promote reinjection as a mandatory procedure to prevent groundwater and surface contamination through used fluids. Ensure proper treatment and disposal of spent fluids and drilling muds containing toxic elements such as arsenic, mercury, and boron.</p>
3	<p>Promote low-emission technologies and life cycle planning. Encourage deployment of binary and advanced closed-loop systems, which minimise greenhouse gas emissions and surface disturbance. Projects should include life cycle assessments from the outset, with clear decommissioning and land restoration plans in place.</p>
4	<p>Implement noise control approaches. Install temporary noise barriers during drilling in ecologically sensitive areas. Use equipment with silencers, mufflers, and acoustic shielding to limit operational noise impacts on local communities and wildlife.</p>
5	<p>Apply reinjection strategies. Maintain balanced water extraction and reinjection rates to minimise subsidence risks. Differences and delays between water extraction and reinjection can cause land subsidence and hinder sustainable use of geothermal resources. Although these risks primarily pertain to EGS and conventional geothermal systems, they underscore the need for careful reservoir management practices across all geothermal developments.</p>
6	<p>Protect culturally and ecologically sensitive areas. Many geothermal zones in India overlap with sacred hot springs or ecologically fragile habitats. Prioritising Environmental Impact Assessments, buffer zones, and community engagement can reduce conflict and help preserve biodiversity and cultural heritage.</p>
7	<p>Design risk-mitigation strategies for early-stage development. The relatively higher risks and uncertainties of early-stage development could be mitigated to some extent through collaborations that bring expertise from countries and regions with more experience of geothermal development, including through scientific institutes, regional and national agencies, and international institutions.</p>

Figure 9.9: Considerations for ensuring responsible and ethical development of geothermal in India. Source: authors.



hour, approaching coal plant levels.) While hydrogen sulfide emissions are more significant, due to toxicity and odour, these are highly site specific (typically 0.1 grammes to 10 grammes per kilowatt-hour) and can also be managed with advanced gas-abatement systems such as scrubbers and condensers. Together, these tools can reduce emissions by 99%, making the plant much cleaner during the operational phase.⁶⁰

Noise and Vibrations

Turbine generators and associated machinery generate operational noise ranging from 60 dBA to 90 dBA at close range. While these numbers are lower than construction phase levels, continuous noise may still impact nearby communities or wildlife if not mitigated with acoustic enclosures and vegetative buffers.

Thermal and Chemical Discharge

If geothermal brine is not reinjected, it can contaminate surface waters with heavy metals and salts. This concern is particularly relevant in conventional geothermal systems and EGS, in which large volumes of fluid are extracted from and reintroduced into deep reservoirs. Common constituents include arsenic (up to 2 milligrams per litre), boron (up to 10 milligrams per litre), mercury (trace to 0.1 milligrams per litre), and lithium, depending on reservoir chemistry. However, reinjection techniques, now standard practice, drastically reduce these risks by returning spent fluids underground to maintain reservoir balance and avoid surface pollution.⁶¹

CONCLUSION AND RECOMMENDATIONS

Geothermal energy offers India significant environmental benefits by cutting air pollution, greenhouse gas emissions, and associated health impacts and minimising surface impacts given its small footprint. Although risks such as induced seismicity, water use, and subsurface contamination exist, they are well understood, readily managed through established best practices, and much less impactful than the environmental and social risks posed by fossil fuels or even large-scale hydropower.

As with all technologies, geothermal's success hinges on creating robust environmental safeguards and

meaningful community engagement. Enforcement, mitigation, and consensus should be key in proliferating geothermal energy in India. Establishing a regulatory framework that can accommodate different types of risks and mitigation strategies—by geography and context and by stage of project and types of technology deployed—is also essential. These steps could be fostered through scientific and technical collaborations with other countries where geothermal energy is more advanced.

Some key elements for this framework are set out in **Figure 9.9**, some of which are explored in more detail in Chapter 8, "Policy and Regulatory Pathways to Catalyse Geothermal in India." With careful planning and management, nearly all of the potential challenges—including water resource use, groundwater protection during drilling, induced seismicity, and land subsidence—can be effectively mitigated, allowing for sustainable and responsible development.

Geothermal represents one of the few always-on, renewable energy options available to India. Its success, however, will depend as much on strong governance, robust environmental oversight, transparent data, and meaningful community engagement as on drilling technology itself.





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