IMPROVING DECISION-MAKING FOR THE ENERGY TRANSITION

Guidance for using Strategic Environmental Assessment

CHAPTER 9

GEOTHERMAL POWER

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Links to the complete guidance document and to individual chapters are also available.

CHAPTER 9

GEOTHERMAL POWER

9.1 WHY SEA IS IMPORTANT TO GEOTHERMAL POWER

An overall rationale for why it is important to use Strategic Environmental Assessment (SEA) to support the energy transition is provided in the preface to this guidance.

SEA can provide critical information to support better decision-making for geothermal power planning and development, including identifying where there may be implications for policies, plans, and programs (PPPs) to adequately address significant environmental and/or socioeconomic risks and impacts. This information can be particularly important to identify and assess the scale and significance of possible cumulative impacts of multiple geothermal power schemes/developments, whether alone or in combination with other renewable energy technologies (e.g., solar, wind).

The SEA process will:

- Identify and focus on key environmental and socioeconomic issues and the concerns of likely affected stakeholders, including local communities, marginalized groups and Indigenous peoples. Major issues are discussed in detail in Section 9.5 and summarized in Table 9.3.

- Identify/recommend if there are areas that should be avoided for geothermal energy development ("no-go" areas) because of particularly high risks to the environment, habitats/biodiversity, and/or people.

- Identify what changes or additions are required to PPPs governing geothermal power development to address these risks.

- Make subsequent project-level Environmental Impact Assessments (EIAs) more efficient and cheaper by addressing the big picture and cumulative potential impacts, identifying the particular issues that individual project EIAs should focus on in more (site-specific) detail.

- Engage stakeholders (particularly in areas where geothermal power potential has been identified), including communities, marginalized groups, and Indigenous peoples, which can be particularly affected by geothermal energy developments. SEA enables them to be informed early of proposed or possible policy options or plans and to provide their perspectives and present their concerns as early as possible. This will enable key issues to be identified and verified, help build understanding and support for geothermal energy development, and avoid future misunderstanding and possible conflicts.

The steps and methodologies available for use in SEA are common to all SEAs, whatever they are focused on, and reflect internationally accepted standards of good practice. They are discussed in detail in Chapters 1 and 2 and are therefore are not repeated in this chapter.

9.2 EXISTING SEA GUIDANCE/GUIDELINES FOR THE GEOTHERMAL ENERGY SUB-SECTOR

An international survey of existing SEA guidelines conducted for IAIA was unable to identify any that are specifically focused on the geothermal power sub-sector. Several recent guidelines specific to EIA for geothermal energy development projects have been identified in Australia and Europe.[1]

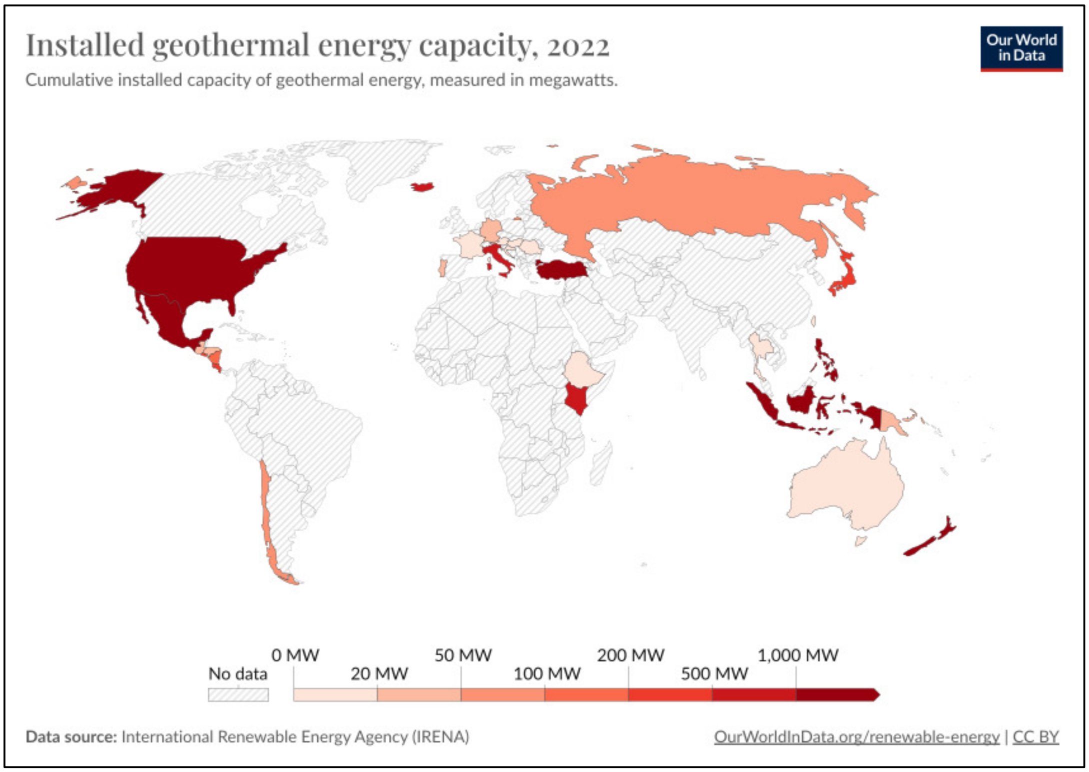
[1] e.g., For Australia, see "Guideline for the Development of Petroleum, Geothermal and Pipeline Environment Plans in e.g., Western Australia" (https://www.dmp.wa.gov.au/Documents/Geological-Survey/Guideline-for-Development-Petroleum-Geotherman-Pipeline-Environment-Plans.pdf). For Europe, see "Proposal for a harmonised procedure on the Environmental Impact Assessment and licensing guidelines for geothermal

Some international agencies have produced guidance on environmental and social issues related to geothermal energy generation,[2] and various sources discuss the environmental impacts of geothermal energy.[3] While not a guideline, the World Bank has completed a rapid environmental and social impact assessment of geothermal energy development in Indonesia which identifies key risks and impacts typically associated with geothermal power development in forest areas.[4]

9.3 GEOTHERMAL ENERGY INSTALLED CAPACITY

The installed capacity of geothermal energy has gradually increased worldwide over the last decade, reaching 14,877 megawatts (MW) in 2022[5] (see Table 9.1). Figure 9.1 shows the global distribution of installed capacity in 2022. The top 10 countries in 2020 are listed in Table 9.2.

Figure 9.1: Installed geothermal energy capacity, 2022
Source: Our World in Data (2023b) based on BP (2021)



development in Europe" (geoenvi.eu/publications/proposal-for-a-harmonised-procedure-on-the-environmental-impact-assessment-and-licensing-guidelines-for-geothermal-development-in-europe/)

[2] e.g., IFC (2007)

[3] e.g., CEI (2019); Energysage (2019); UCS (2013b); Bošnjaković *et al*. (2019)

[4] Meijaard et al. (2019)

[5] Fernández (2024)

Table 9.1: Installed geothermal energy capacity by region, 2022
Source: IRENA (2023)

Region	Installed capacity (MW)
Asia	4,711
North America	3,712
Eurasia	1,765
Europe	1,635
European Union	892
Oceania	1,323
Africa	956
Central America & Caribbean	724
South America	51
World	14,877

Note: These figures cannot be summed, as some areas may have been considered as part of at least two different regions (e.g., components of Oceania may have been included in other regions).

Table 9.2: Top 10 geothermal countries, 2022
Source: IRENA (2023)

Country	Installed capacity (MW)
USA	2.653
Indonesia	2,343
Philippines	1,932
Turkey	1,691
New Zealand	1,273
Mexico	1.059
Kenya	949
Italy	772
Iceland	757
Japan	431
Other	1,017
Total	14,877

9.4 BACKGROUND TO GEOTHERMAL ENERGY GENERATION

Geothermal energy is generated in countries located on or near seismically and volcanically active tectonic plate boundaries. There are four main types of geothermal power plants:

- Dry-steam plants use steam directly from a geothermal reservoir to turn generator turbines.
- Flash-steam plants take high-pressure hot water from deep inside the earth and convert it to steam that drives generator turbines.
- Binary-cycle power plants transfer the heat from geothermal hot water to another liquid.
- A hybrid system.

Geothermal power plants operate by extracting the Earth's heat in the form of steam or hot water, which, in turn, is used to drive a steam turbine and generate electricity. There are two basic systems: open-loop systems, which can require a large amount of cooling water; and closed-loop systems, which return the water to the underground source.

The geothermal energy is captured through drilling production wells into deep groundwater reservoirs and then extracting and piping the hot water and steam to a power plant where it drives a turbine.

In dry-steam and flash-steam plants, a part of the steam is released to the atmosphere. Wastewater effluents and gases are typically reinjected into the reservoir or its periphery to minimize the potential for groundwater contamination.[6]

[6] IFC (2007)

An example of a geothermal power plant is the 330 MW Sarulla plant geothermal power plant in Sumatra, Indonesia[7] (see Figure 9.2 and Box 9.1).

Figure 9.2: Sarulla Geothermal Plant, Indonesia

Photo: Courtesy of Sarulla Operations Limited

Unlike solar and wind energy, geothermal energy is constantly available. Hence, it provides both baseload power and firming power[8] for when variable renewable energies (e.g., wind or solar) are unavailable.

The environmental and social effects of geothermal energy are dependent on how and where geothermal energy is extracted. Access roads, pipelines, and transmission lines must be constructed, often in areas that have had little or no previous development. Other infrastructure, such as workers camps, may also be required.

During operation, freshwater may be required to cool exhaust gases (before they are passed through amine scrubbers to reclaim the amine solvents) and for cooling towers. Projects may have a wastewater treatment plant located within the production complex. Processed wastewater from exhaust gas washing and reverse osmosis plants and cooling tower wastewater are directed to a wastewater treatment plant prior to discharge to a public sewage system, where this exists.[9] Storm water from handling areas in the production complex needs to be drained through a sedimentation trap drain to an oil and grease separator, after which it might be discharged to natural waterways.[10]

[7] For more information, see Sarulla Operations Ltd (https://www.sarullaoperations.com/company/overview).
[8] Matek and Gawell (2015)
[9] Englande *et al*. (2015)
[10] Meland (2016)

9.5 IMPACTS OF GEOTHERMAL ENERGY DEVELOPMENT

During scoping for an SEA, key issues regarding geothermal energy development should be identified. They will be used to focus the SEA on the most important issues and to help develop environmental and social quality objectives (ESQOs), which address these issues and will be used during the main assessment stage (see Chapter 1, Section 1.5; and Chapter 2, section 2.5.1). The key issues will be identified by reviewing relevant documents (e.g., EIA and special subject reports, environmental/social profiles, sector and inter-sector strategies, donor documents, academic papers, other geothermal energy development applications, etc.), interviewing key informants, and holding stakeholder consultations at national to local levels. Many of the issues will be well known as a result of implementing existing geothermal energy development projects.

At the individual project level, these issues will be the focus of an EIA, which should recommend how to manage or mitigate project impacts that might be likely to arise. Ideally, before individual geothermal projects are approved, a PPP for the geothermal energy sub-sector should be completed and be subjected to an SEA. This should assess the risks and impacts of multiple projects, schemes, and activities likely to arise from implementing the PPP—some directly concerned with the construction and operation of sites and facilities, others linked to associated infrastructure (e.g., transmission lines and access roads). Thus, there is a risk that the impacts of individual geothermal energy developments/projects may become highly significant as they become cumulative. An SEA should focus on the potential for such cumulative impacts and make recommendations for addressing them. This may include recommending thresholds for particular factors that should not be breached by an individual project (and which should be addressed by a project-level EIA). Where the risks of cumulative impacts are extremely high, this might provide the basis for the SEA report to recommend an alternative to the PPP or components of it. Often, the timing of individual geothermal energy project applications and overarching SEA planning is not synchronized, and SEA may have to “catch-up” to the pace of individual projects rather than providing upstream (pre-project) guidance as to how they should proceed.

Table 9.3 summarizes the range of environmental and socioeconomic issues associated with geothermal energy development.

During scoping, a key task is to determine which issues the SEA should focus on.

Table 9.3: Environmental and socioeconomic issues associated with geothermal energy development

ISSUE	COMMENT
Environmental	
Air quality	• Geothermal power plant emissions are negligible in comparison to fossil fuel-based power plants. • Some small amounts of carbon dioxide are found in plant steam, and site vents can also produce very small levels of hydrogen sulphide emissions. • Well emissions in open-loop systems include sulphur dioxide, hydrogen sulphide, carbon dioxide, ammonia, methane, and boron. • Some geothermal plants also produce small amounts of mercury emissions, which must be mitigated using mercury filter technology. Scrubbers can reduce air emissions, but they produce a watery sludge composed of the captured materials, including sulphur, vanadium, silica compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge often must be disposed of at hazardous waste sites.
Greenhouse gases	• Geothermal energy can reduce GHG emissions where it displaces coal as a fuel source.
Noise	• Noise from well exploration (e.g., installation, testing), construction machinery and vehicles, and maintenance activities during operation.
Soil erosion	• From clearing of vegetation and construction of access roads.
Water quality	• Chemical pollution of surface water and groundwaters. Hot water pumped from underground reservoirs often contains high levels of sulphur, salt, and other minerals, which can affect local water quality if not a closed-loop system (i.e., water is pumped directly back to geothermal reservoir after it has been used for heat or electricity production). Surface water used by geothermal plants is normally returned to the original source (e.g., a river) with some increase in heat. • Fluids used during drilling activities may be water- or oil-based and may contain chemical additives. Cuttings from oil-based mud may have high oil-related contaminants in effluent. • Rejected water from geothermal separators may contain heavy metals. • Well blowouts can result in the release of toxic drilling additives and fluids, as well as hydrogen sulphide from underground. • Pipeline failures can result in the surface release of geothermal fluids and steam containing heavy metals, acids, mineral deposits, and other pollutants.
Water use	• Geothermal plants can require between 1,700 and 4,000 gallons of water per MW-hour. • Open-loop systems can require a large amount of water (with over exploitation of available resources); closed-loop systems return the water to the underground source.
Habitats and biodiversity	• Land clearing for well pads, pipelines, and access roads. • Fragmentation of habitat from access roads, pipelines, and transmission lines. • Increased poaching and hunting due to increased access to areas and introduction of workforce into an area. • Risks to birds/bats from collision with overhead power lines.
Protected areas	• Geothermal sites may be close to or within protected areas. • Many geothermal sites are in remote and sensitive ecological areas. • Improved access, roads, and transmission lines increase vulnerability of protected areas.
Waste	• Geothermal power plants produce a relatively minimal amount of waste, but there is potential for leaching of silica compounds, chlorides, arsenic, mercury, vanadium, nickel, and other heavy metals, which may be classified as hazardous.

ISSUE	COMMENT
Earthquake risk	• Hydrothermal plants are sited on geological "hot spots," which tend to have higher levels of earthquake risk.
Visual and aesthetic value	• The visual amenity of the landscape will change. This may reduce appeal of the area to tourists, but may create opportunities for industrial tourism (e.g., visits to facility).
Land and ecosystem restoration	• The average lifespan for geothermal power plant is 20-25 years for the indoor components and 50 years of more for the ground loop. If and when decommissioning takes place, restoration of the site to its former status/condition will be required.
Socioeconomic	
Local economy and livelihoods	• Relocation of people and their structures. • Increased pressure on the host communities' public services. • People displaced from their economic activities, such as crop cultivation. • Loss of income from fishing activities, crop cultivation, and other farming activities; damage to crops from discharges. • Loss of income from small business and enterprise activities due to acquisition of land by energy companies. • Conflict between communities and geothermal energy companies over land ownership. • Negative impact on Indigenous communities and their traditional or customary land and resources. • Benefits to local economy from jobs created (see section on employment and labor conditions).
Employment and labor conditions	• Employment in the construction and operation phases of projects and associated businesses and activities. • Substandard working conditions. • Worker safety. • Workers have the opportunity to learn new skills.
Gender and vulnerability	• Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and Indigenous communities) may be disadvantaged and at particular risk. • Gender-based violence and human trafficking resulting from an influx of predominantly male construction workers. • Employment opportunities within new projects. • Opportunities for vulnerable groups to acquire new skills and learn new technologies.
Cultural heritage	• Loss of religious, historical, and archaeological sites and properties. • Cultural heritage may be destroyed or damaged due to transmission lines, pipelines, and access roads. • Limited access to cultural heritage sites.
Health and safety	• Nearby communities may be exposed to air pollution, including hydrogen sulphide gas. • General hazards for local communities may include contact with hot components, equipment failures, and presence of active or abandoned wells. • Short-term disruptions, such as traffic, road, influx of population, noise, vibration, odor, and steam.
Public services and infrastructure	• Infrastructure (e.g., roads, bridges, schools, health centers, and administrative buildings) may be improved due to community investment by geothermal energy companies. • Pressure on public services and infrastructure will increase as a result of in-migration. • Heavy vehicles and transportation can damage existing roads and bridges. • Increased vehicle traffic during construction.

9.5.1 Environmental issues

Habitats and biodiversity [11]

The location of geothermal power projects is predominantly selected based on geological conditions that are suitable for the highest yield of geothermal energy. Such locations may occur in natural habitats (which can sometimes be critical habitats), such as the dense forests of Sumatra in Indonesia. Alternatively, they could be within modified habitats, such as plantations or rice fields, which may still harbor significant biodiversity value. It is common that forests and vegetation need to be cleared by heavy machinery to allow for the construction of the required infrastructure, such as well pads, power plants, cooling towers, pipes and pipelines, access roads, transmission lines, and other associated facilities.

Clearing results in direct loss of habitat and displaces fauna—which can include protected and threatened species—that depend on it. Animals are forced to seek alternative suitable habitats in other areas of the forest, if available. This can have a knock-on effect, as the displaced individuals may cause an increase in competition for resources or out-compete other less dominant species in such areas. There can also be road kills due to collisions with construction vehicles on access roads.

Significant long-term impacts on biodiversity typically arise from the development of access roads and transmission line easements due to habitat fragmentation. This occurs when an area of habitat that was originally “whole” before the development becomes divided into multiple areas due to partitioning. For fauna species, fragmentation creates a barrier effect by limiting or preventing their movements to areas of the habitat that they would have previously accessed for food, shelter, or breeding grounds. Arboreal species (i.e., species that almost exclusively move in the tree canopy), small mammals, and slow-moving species are particularly vulnerable to habitat fragmentation.

In the long term, once forests have been permanently fragmented, the gene pool of both flora and fauna species tends to be less diverse and more vulnerable to unpredictable and chance events, such as lightning strikes and floods. The creation of access roads through a forest also introduces an “edge effect,” where micro-climates become permanently modified and plant species struggle to survive when exposed to an increased amount of sunlight. Access roads also increase the risk of introducing invasive species.

Access roads constructed through a once undeveloped and relatively inaccessible area can also lead to an increase in illegal hunting or trade and poaching of wildlife, as well as an increase in illegal harvesting of timber and other forest products.

Wildlife can also be displaced from their habitat near a geothermal development due to construction noise (e.g., vehicles and drill rigs) and noise from operations (e.g., vehicles and plant).[12] Similarly, floodlights at a geothermal power plant site can also cause the displacement of wildlife species that are not able to tolerate such changes in their environment. It can force them to seek other habitats, potentially displacing less-dominant species and increasing competition for resources and shelter.

Sulphur emissions from geothermal plants can hinder the growth of vegetation around the site.

Once a geothermal well pad has been established, it is usually tested for its viability and yield. More often than not, some well pads will be unviable, and more drilling than initially planned will be required. In some cases, a well pad is decommissioned or abandoned altogether. Typically, the original planned footprint of a geothermal power project will be subject to change and may increase in area with greater loss of habitat than originally envisaged.

The development of multiple geothermal projects across a region would amplify the negative effects on habitats and biodiversity, potentially resulting in a significant cumulative displacement or loss of biodiversity, even though the impacts of the individual projects may be limited.

[11] Ng *et al.* (2021)
[12] ADB (2017)

The loss of biodiversity and habitat, or the alteration of the ways in which species can utilize the habitat, can disrupt and unbalance the overall function of the original ecosystem and can result in additional loss of some species and ecosystem services.[13]

These issues need to be assessed and mitigation measures identified (see Box 9.1).

Box 9.1: Risks to habitats and biodiversity at Sarulla geothermal power plant, Indonesia
Source: ADB (2019); ADB (2020)

The Sarulla Geothermal Project in Indonesia (Figure 9.2) was developed in an area of high biodiversity value. It was found to pose several risks to high value habitats and biodiversity, including:

- Loss of connectivity between habitats due to the creation of access roads through them.
- Mortality of fauna species from collisions with vehicles.
- Increase in hunting or poaching of threatened species.
- Clearing of habitat for project components, including well pads.

A Critical Habitat Assessment and Biodiversity Action Plan (BAP) was developed for the project to mitigate the risks. The BAP recommended actions to be undertaken by the project company, including designing road crossings for primates, raising community and workforce awareness about the value of the habitats and species in the area, and implementing speed limits to avoid collisions with fauna species.

Protected areas

There is a risk that geothermal developments could be in or near protected areas such as national parks when there is a drive to make the most of the available geothermal resource. In some areas, it is difficult to avoid encroaching on protected areas to create wells for a development, construct an access road, or construct a transmission line to export the energy to the electricity grid. The terrain on fault lines is generally steep, and, in some instances, the only feasible access route to get to the geothermal resource may be to traverse a portion of a protected area. Similarly, in some instances, routing a transmission line through a portion of a protected area may be the most cost-effective or only feasible technological solution open to a development’s design.

Encroachment into protected areas results in direct habitat loss and fragmentation of habitat (see previous section). However, the impacts can be even more significant, as protected areas are intended for conservation purposes. As such, they may host a range of protected flora and fauna species that may not exist in significant numbers elsewhere, and these species may be particularly sensitive to disturbance and human presence. Thus, encroachment into protected areas can lead to a loss of high-value biodiversity. This is particularly true if these habitats are also critical habitats.

A geothermal energy development may inadvertently increase access to protected areas, even if the development or its associated infrastructure is not actually located within the protected area. This can lead to degradation of the protected area by enabling illegal take of wood or other resources from the protected area as well as increasing the opportunity for illegal poaching.

Air quality

In closed-loop geothermal energy systems, gases removed from a well are not released to the atmosphere but are injected back into the ground after giving up their heat, so air emissions are

[13] IFC (2012d); ADB (2019 and 2020)

minimal. In contrast, open-loop systems emit hydrogen sulphide (H_2S), carbon dioxide (CO_2), ammonia, methane, and boron.**[14]**

Once in the atmosphere, H_2S changes into sulphur dioxide (SO_2), which can have a strong odor when emitted in high concentrations. This contributes to the formation of small acidic particulates that can be absorbed by the bloodstream and cause heart and lung disease. At high enough levels (1,000 parts per million by volume), SO_2 can cause death.**[15]** SO_2 also causes acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. However, SO_2 emissions from geothermal plants are approximately 30 times lower per MW-hour than from coal-fired power plants (CFPPs) and in some cases can be null.**[16]**

Emissions of H_2S from geothermal power plants can cause odor annoyances among members of the exposed public, some of whom can detect this gas at concentrations as low as 0.002 parts per million by volume.[17]

Some geothermal plants also emit small amounts of mercury, which must be mitigated using mercury filter technology such as "scrubbers" or air filters. This is generally due to the nature of the local environment (i.e., thermal waters can naturally contain mercury and arsenic). For instance, a study in West Java showed that thermal waters can naturally contain up to 2.6 ppm arsenic and 6.5 ppb mercury, and the surface hydrothermal alteration can contribute up to 50 ppm arsenic and 800 ppb mercury.

However, geothermal power plant emissions are negligible compared to those of fossil fuel combustion-based power plants or bioenergy. For example, geothermal power plants emit approximately 1% of the sulphur oxide (SO_x) and nitrogen oxide (NO_x) and 5% of the CO_2 emissions of a coal-fired thermal power plant of similar power generation capacity.**[18]**

Scrubbers can reduce air emissions of mercury, but they produce a watery sludge composed of the captured materials, including sulphur, vanadium, silica compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge must be disposed at hazardous waste sites.

Local air quality can also be affected during construction due to emissions from construction vehicles and by the creation of dust. Occupational exposure to geothermal gases (mainly hydrogen sulphide) may occur during non-routine release of geothermal fluids (e.g., due to pipeline failures) and maintenance work in confined spaces, such as pipelines, turbines, and condensers. The significance of the H_2S hazard may vary depending on the location and geological formation particular to the facility.

Water quality

Closed-loop geothermal systems have few impacts on water quality, as most of the extracted water is returned to the underground source via a second well, resulting in little or no discharges to the environment. However, in open-loop systems, there can be risks associated with the discharge of geothermal water to receiving water bodies. Such water (i.e., brine) extracted from underground reservoirs often contains high levels of sulphur, salt, and other minerals that can negatively affect water quality of the water body or waterway that it is discharged to and/or if there is runoff downstream. In turn, this can lead to a deterioration, alteration, or even loss of aquatic habitat, as well as effects on downstream users of the water. There have also been instances when steam emissions from the geothermal energy process have corroded building roofs and damaged habitats and crops of nearby communities.[19] [20]

[14] Kagel *et al*. (2005)
[15] Layton *et al.* (1981)
[16] UCS (2013b)
[17] Layton *et al.* (1981)
[18] Duffield and Sass (2003)
[19] UCS (2013b)
[20] Treece (2021)

Under both open- and closed-loop systems, there are risks that construction and operation activities will have a negative impact on water quality because of soil erosion and subsequent sedimentation of waterways (see section on soil erosion) or may result in accidental hazardous waste discharges (see next section).

Accidental spills of contaminants and geothermal fluids can occur during the drilling and construction stages, which can have a negative impact on surface water quality.[21]

If not well managed, polluted runoff from well pads and ponds, especially during rainy season floods, can also affect water quality.

Waste

The biggest source of solid waste on a geothermal project is the earthen drill cuttings material (e.g., soil, rock, mud) extracted during the drilling process. This material is temporarily stored in drill pits, (e.g., mud from the drilling process is stored in temporary mud pits).[22] The material then needs to be transported to a landfill if an option for reuse is not available.

Other construction waste streams would include:

- Material from packaging
- Building materials
- Scrap metals
- Excess soil material
- Plastic and masonry products
- Cleared vegetation
- Sanitary wastes
- Empty chemical storage containers
- Concrete wash out water.

These wastes can pose a risk to water and soil quality and put pressure on landfills if not managed appropriately.

Water use

Closed-loop systems recapture the steam of the geothermal water after it has driven the steam turbine, condense it back to water via a cooling process, and then return the water to the ground via a second well. This means that almost all the water is returned to the underground source. Nevertheless, there are some water losses (approximately 2%) from evaporation and "blow down."[23] However, in the less common open-loop systems, the geothermal water is not returned to the source. Some is lost as steam through the cooling process, but the remainder is condensed and transferred to large-scale cooling ponds and subsequently discharged (e.g., to a marine or freshwater environment).

In the drilling stage of geothermal power plants, high volumes of surface water are required and are usually taken from nearby rivers or lakes, if accessible. In some regions of the world (e.g., Southeast Asia), there is often sufficient surface water availability in the wet season but not in the summer dry season.[24] In drier areas of the world, the high demand for water may put pressure on available water resources.

Like thermal power plants, open-loop geothermal plants also require a source of cooling water that is separate to the geothermal resource. This water could come from either a freshwater or groundwater

[21] World Bank (2017)
[22] ADB (2019)
[23] Blow down refers to a process where some water from the cooling system is purposely released, and new cooling water is added to the system to avoid a build-up of corrosion-causing minerals such as salts in the cooling system.
[24] Alamsyah *et al*. (2020)

source and typically would draw approximately 9,000 liters per MW-hour.[25] Depending on the availability of water resources in an area, this can lead to excess demand on local water resources, which reduces freshwater available to local communities and for livestock and crops. This can be a particular problem for communities in the dry season.

The condensate from the steam cycle is used in the cooling system. Approximately 70% of the water is evaporated by the cooling tower.[25] Alternatively, air-cooled condensers may be used. These use large-scale fans to generate a flow of cool air to condense the steam to water. Such condensers do not require a water source to operate, but they create noise (see section on noise).

Soil erosion

Soil erosion can occur when land is cleared for geothermal project components, pipelines, access roads, and transmission lines. Large volumes of soil can be excavated for leveling well pads and creating access roads.[26] This removal of vegetation, particularly roots, decreases soil stability.

In regions where high rainfall is common, this can cause exposed soils to wash away, leading to sedimentation of nearby waterways. This can reduce water quality and result in the alteration or loss of habitat for aquatic species. Soil erosion can also lead to localized landslips, a health and safety risk for communities (see section on health and safety).

Noise and vibration

The development of a geothermal energy facility involves several construction and commissioning phases that may produce adverse levels of noise and vibration:

- Steam field development involves drilling geothermal wells, which produces noise and vibration from drilling and well-testing activities, mud pumps, compressors, hydraulic pumps, and generators.

- Purging geothermal wells to remove debris involves a vertical discharge, generating a very high noise level. However, this typically lasts only a few hours. Few mitigation options are available, apart from shielding the well outlet and scheduling the activity in periods with a lower risk of intrusion (such as during a weekday).

- General construction noise and vibration impacts come from construction of the power plant, support infrastructure, and site office buildings. The equipment transported to the site can be very large, causing temporary nuisance noise and vibration in the communities through which it is transported.

- During operation of a facility, the main sources of noise will likely include high flow steam pipelines, traps installed in supply lines, steam vents, well maintenance, and electricity generation plants.

Earthquake risk

Geothermal plants are in seismically active areas where earthquakes are likely to occur. In general, geothermal projects themselves are not considered to generate any significant seismic risk. However, there have been some examples of geothermal projects inducing micro-seismic events (by drilling in rock creating “shearing” or fractures) at a localized level that may be perceptible by and impact nearby communities (see Box 9.2).[27] This risk is subject to ongoing research.

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[25] USDE (2006)
[26] World Bank (2017)
[27] USDE (2007)

Box 9.2: Earthquake in Switzerland caused by a geothermal system
Source: Choi (2009)

In 2006, a geothermal system in Switzerland caused a magnitude 3.4 earthquake in Basel, an area prone to natural earthquakes. No expert assessment had been conducted of how much the seismicity induced by the project would connect with the natural seismicity under the Basel area.

A court case seeking compensation for property damage was brought against the head of the company, Geothermal Explorer, which subsequently shut down the system.

Visual impacts

In some cases, for safety reasons, a geothermal project will undertake a ground flare to dispose of methane gas should the operation of engines be disrupted. Best practice is to use an enclosed ground flare. Flares would normally only be of short duration. Providing suitable technology choices are made, impacts on air quality are not expected to be significant. However, the visual amenity of the landscape will change. This may reduce the appeal of the area to tourists and local populations and could, depending on location, impact property prices.

The development of a geothermal energy project and its associated pipelines can cause negative visual and spatial effects on the landscape (e.g., by altering vegetation and wildlife habitat).[28] In some countries, geothermal energy is located in protected areas, where the construction of the power plants, access road, transmission lines, and other facilities tends to change the natural visual landscape and, ultimately, can undermine the attractiveness of the area for tourism.[29] [30]

However, geothermal resources often coincide with natural hot springs, presenting opportunities to develop tourism. Iceland is a prime example.

Land and ecosystem restoration

As discussed above, there are significant risks associated with geothermal power development with regard to potential environmental harm and degradation (e.g., unnecessary or excessive deforestation when preparing land for geothermal plant sites and constructing new access roads, pipelines, and transmission lines; destruction of habitats and loss of biodiversity and ecosystem services; soil erosion and pollution). This will particularly arise where mitigation measures proposed by an SEA (and by subsequent project-level EIAs) are inadequate, ineffective, or not undertaken. The significance and seriousness of such degradation can be compounded where the impacts are cumulative and extensive. Such cumulative impacts will be highly likely to occur where there are multiple geothermal power developments across landscapes.

Environmental impacts will usually lead to demand for, and need for, land and ecosystem restoration (see Chapter 2, Section 2.6.6), particularly at sites of projects that have come to the end of their useful operational life. The average lifespan for a geothermal power plant is 20–25 years for the indoor components, and 50 years of more for the ground loop. If and when decommissioning takes place, restoration of the site to its former status/condition will be required. At a minimum, this should involve revegetation of the plant area to its original state, including replanting and reseeding using a mix species that were naturally part of the ecosystem/land prior to development of the geothermal power project.

[28] Manzella *et al*. (2018).
[29] Nepal has over 100 facilities within protected areas, while India has 74 under development in important conservation zones. Read more in this 2020 BBC News article (https://www.bbc.co.uk/news/science-environment-52023881).
[30] Soltani *et al.* (2021)

9.5.2 Socioeconomic issues

Local economy and livelihoods

As with many other renewable energy developments, geothermal energy projects provide opportunities for local communities, as well as a range of risks and possible impacts, such as those associated with access to land for drill rigs, well pads, access roads, pipelines, transmission lines, and other associated facilities.

The acquisition of land can create physical and economic displacement. The average area of land required for geothermal projects is smaller than for most other types of renewable energy (see Box 9.3). The most land-intensive stage is the construction of well pads, power plants, and associated infrastructure. The building of access roads and storage facilities during earlier drilling stages may also cause short-term disturbances to the livelihood activities of affected communities and open up areas with natural resources which previously were less accessible.

Box 9.3: Land required for geothermal energy projects

Source: Geothermal Technologies Office (undated); ADB (2019b)

Geothermal projects have a small footprint. The US Geothermal Technologies Office estimates that an entire geothermal field uses 1-8 acres (0.4–3.2 hectares) per megawatt (MW) compared to 19 acres (7.7 hectares) per MW for coal power plants.

The Asian Development Bank-financed 110MW Dieng (2) geothermal expansion project in Java, Indonesia, estimated the need for about 30.8 hectares in total in various locations, mainly for the new pipelines and access road but also for the power plant and five well pads. According to the project's resettlement plan, the project will require 30.8 hectares for five well pads and the power plant site. As the site is in a fertile and intensively farmed area (Figure 9.3), the acquisition of land for the project will directly impact the livelihoods of 106 persons (29 households) and indirectly affect four lease coordinators (21 persons), particularly smallholders, tenants\, and sharecroppers in the area.

Figure 9.3: Location of Dieng geothermal expansion project in Java, Indonesia

Image: Courtesy of ADB (2019b)

Because well pads generally have a small footprint, and associated infrastructure is linear or underground, careful siting and design can often help avoid or minimize physical displacement.

Land acquisition for geothermal exploration and exploitation is different to other renewable energy projects. An area for exploration may be acquired, but exploration—usually involving the drilling of several wells—may not actually confirm the presence of the resource (geothermal energy) or it may not be economically worth exploiting. By comparison, modeling of wind and solar energy to determine sufficient yield can be undertaken through desktop work. The specific location of geothermal resources can therefore lead to more potential for disputes within communities over land ownership and sometimes over land compensation arrangements. Disputes about land ownership can cause community tension.

Conversely, geothermal projects can be built in harmony with other land uses and deliver livelihood benefits (see Box 9.4).

Box 9.4: Livelihood benefits from geothermal energy

Source: Geothermal Technologies Office (Undated)

The website of the US Geothermal Technologies Office mentions 15 geothermal plants that are producing more than 400MW in one of the most productive agricultural areas, where land around the geothermal infrastructure is used for livestock grazing and agriculture and is adjacent to a national wildlife refuge. See more at https://www.energy.gov/eere/geothermal/geothermal-technologies-office.

Other than the adverse impacts, geothermal projects can induce local business opportunities. As with other renewable technologies, local communities could provide services for the geothermal companies and contractors, such as accommodation for workers, retailing, and other services. In 2000, the Gunung Salak geothermal project in Indonesia, located in the middle of a protected forest, won a prestigious environmental award for its well-planned community development program and responsible environmental management.[31] In Iceland, the geothermal sub-sector provides a multitude of stakeholder benefits, such as participation in decision-making, job creation, and infrastructure upgrades, along with sustainable energy development. But there are trade-offs between pursuing an economically efficient energy system and nature conservation.[32] Iceland has been able to stimulate new unforeseen industries alongside geothermal plants (see Box 9.5).

Box 9.5: New industries connected to geothermal energy in Iceland

Source: McMahon (2016)

Iceland has leveraged geothermal energy production to stimulate new industries, including data storage, greenhouse agriculture, and ecotourism. Prior to recent volcanic eruptions, visitors to Iceland were drawn to the famous Blue Lagoon geothermal spa located in a lava field near Gridavik.

Engineers have begun to design power plants to accommodate tourists and have established geothermal-powered greenhouses where local farmers produce tomatoes, cucumbers, and other crops that once had to be imported.

[31] Slamat and Moelyono (2000)
[32] Cook *et al*. (2022)

Occupational health and safety

As with other types of renewable energy projects, geothermal energy presents occupational risks and hazards, including:[33]

- Hazards from working in a confined space, where entry by workers and the potential for accidents may vary among geothermal facilities depending on design, on-site equipment, and the presence of groundwater or geothermal fluids.

- Exposure to geothermal gases, mainly hydrogen sulphide, during the non-routine release of geothermal fluids (e.g., well blowout and pipeline failures) and during maintenance work in confined spaces like pipelines, turbines, and condensers.

- Exposure to heat during construction activities and the operation and maintenance of pipes, wells, and related hot equipment.

In the case of large-scale geothermal plants, many projects will be subject to the environmental and social safeguards of multilateral development banks (MDBs) and to the environmental and social risk management guidelines and procedures of MDB standards and the Equator Principles. These may provide a higher standard of (and oversight of) labor and occupational health and safety management procedures than the prevailing national standard.

Community health and safety

Geothermal projects bring health and safety issues for local communities. These can be induced by the exploration, construction, and operational phases of a project. During the construction phase, communities close to the project infrastructure sites will be exposed to short-term nuisances, such as increased truck and vehicle movements, noise, vibration, dust, odor, and influx of skilled workers. Geothermal wastewater and gaseous emissions typically contain hydrogen sulphide and other non-condensable gases and may contain mercury, which can be emitted during geothermal well drilling and testing processes.[34] These emissions are typically not significant, though this is dependent on the concentration of gases and the proximity of wells to sensitive receptors. Nearby communities may be exposed to air pollution, including hydrogen sulphide gas, which has an odor and can be toxic.[35] Geothermal wells need to have cement casings to prevent pollution of groundwater.

The health risks to communities include exposure to air pollution (e.g., hydrogen sulphide gas), infrastructure safety issues, and impacts on water resources.[36] Without proper management, the release of wastewater from the plants can cause adverse impacts on community health (e.g., skin and respiratory diseases), sanitation, and noxious odors.

Noise from gas engines, drilling, construction vehicles, and power plant operation can cause disturbance and damage to local communities and property (e.g., noise and traffic congestion can affect community tourism and homestays) and nearby infrastructure.

Gender and vulnerability

One of the social risk factors associated with geothermal energy development is the degradation of water quality and supply (discussed in Section 9.3.1). This may have a disproportionate impact on women and girls, where they tend to be the primary collectors of water for household use, and may increase “time poverty” [37] if longer travel to clean water sources is required. Other risks are associated with potential land acquisition and displacement, plus resettlement planning and compensation procedures for geothermal projects. In addition, the development of geothermal

[33] IFC (2007)
[34] Finster (2015)
[35] Bastaffa *et al*. (2019)
[36] IFC (2007)
[37] Time poverty is the experience or feeling of having too much to do and not enough time to do it.

projects may cause potential damage to, or restrict access to, areas of spiritual and cultural significance.[38] This can have disproportionate impacts on women and vulnerable groups, particularly those from Indigenous communities, and sometimes more so than other renewable energy technologies (see section on Indigenous communities).

Other risks include the potential for an increase in gender-based violence (GBV) against women, plus sexual harassment, exploitation, and abuse, resulting from an influx of predominantly male construction workers[39] and other male presence, such as private security forces or the military (see Box 9.6). Concerns around an increased risk of GBV during renewable energy projects have also been discussed in other technologies (see discussion of gender and vulnerability in Chapters 5 and 6).

Box 9.6: Community opposition to the Chevron Geothermal Project, Philippines
Source: World Bank (2019)

In Kalinga, Philippines, Indigenous women in Western Uma blocked the development of a Chevron geothermal energy project, causing the company to abandon the site. The women's grievances included disregard for cultural beliefs linked to the resource, loss of tiger grass (an important cash crop for women), fear of gender-based violence (GBV) from an anticipated increase in military presence to protect assets at the project site, and unequal compensation and benefits for women, including scholarships and employment opportunities.

Furthermore, women who pursue professional careers in geothermal energy often face several barriers, such as social expectations about their roles and abilities and a lack of an inclusive workplace environment.[40] As with other technologies, factors such as a skills gap among women due to their limited access to and uptake of education and training in STEM subjects[41] (see discussion of gender and vulnerability in Chapter 5) can also limit their employment opportunities in the geothermal industry.

Indigenous communities

Geothermal development may have a negative impact on Indigenous communities and land under traditional or customary use. Geothermal plants are often located near volcanoes or hot water—sites that frequently have cultural, sacred, and spiritual value for local communities of Indigenous people. The healing properties of the warm and sulphur-rich water are often the subject of community lore.

Potential geothermal energy development sites tend to be located in remote areas where Indigenous communities often reside
Chapters. They may be disproportionately affected by land acquisition and by opening up access to the natural areas and resources they depend on. Novel approaches to co-developing equitable communication models between Indigenous peoples and geothermal developers have been proposed in Alberta, Canada.[42] It is intended to allow for a more appropriate, community-centered approach to consultation, honoring Indigenous rights to free, prior, and informed consent as per the United Nations Declaration on the Rights of Indigenous Peoples and treaties signed with the Government of Canada.

Chapters addressing other types of renewable energy have highlighted the potential for local Indigenous communities near renewable energy projects to benefit from employment opportunities with the project, during construction and/or operations. There is a risk that such employment

[38] World Bank (2019)
[39] World Bank (2019)
[40] World Bank (2019)
[41] Science, technology, engineering, and mathematics.
[42] Giang, et al. 2021

opportunities will not be accessible to local Indigenous people (e.g. because they may lack qualifications or required skills and experience).

In British Columbia, Canada, the Clarke Lake Geothermal Development Project is a CAD $40.5 million, wholly-owned and Indigenous-led project that will provide jobs and economic opportunities for local community members and provide capacity building and training to workers to help them transition into the renewable energy sector. Waste heat may also be sold to nearby timber and greenhouse industries.[43] Other Indigenous-owned geothermal projects are also scheduled for development in the Pacific Ocean "Ring of Fire".[44]

Cultural heritage

New geothermal developments can take place in or near sites that are protected or prized for cultural significance or aesthetic aspects, threatening or compromising the physical or visual status of sites.[45] Such risks may be more pronounced among Indigenous communities who frequent geothermal sites for the sacred and healing properties they are believed to have. Such sites may also be in, or contain, fragile or protected ecosystems with endangered species.[46]

Research carried out at Olkaria geothermal fields in Kenya found that the development of geothermal projects led to a reduction in family size. This was linked to the gradual loss of community land to the project, which greatly impacted the preservation of local cultural heritage sites. Also, the local community complained about foreign cultural attitudes penetrating their culture and causing cultural conflicts because of the interaction with outsiders.[47] The preservation of cultural sites can help to increase their potential to attract tourism.

Employment and labor conditions

Geothermal energy development has the potential to offer some employment during both the construction and operations phases, providing the local community with the opportunity to acquire new skills. For instance, the ESIA for the 35 MW Casita geothermal project in Nicaragua estimated that the exploration phase (intended to be 2.5 years) would create 100 jobs for site preparation and 100 for drilling.[48] Specialist skills are required for drilling. Skills gained in fossil fuel industries are transferable to geothermal development (e.g., drilling experts and construction-related roles). Figure 9.4 shows that, in 2021, there were almost 200,000 jobs in the geothermal energy sub-sector, significantly fewer than in the other renewable energy sectors discussed elsewhere in this guidance.

Public services and infrastructure

As for other renewable energy types, geothermal energy projects can bring both opportunities and risks for public services and infrastructure under the remit of local public authorities. Heavy construction vehicles and transportation may damage existing roads or buildings adjacent to roads, especially bridges. Normally, energy projects will contribute to the development, improvement, upkeep, and access to overall community facilities and services in an area. This may be because the project simply requires certain infrastructure and will put this in place, or, alternately, will do so through its wider corporate social responsibility (CSR) programs. The potential for community investment has been discussed previously for other renewable energy technologies.

Geothermal energy could create alternative employment opportunities for those who may have lost jobs or are at risk of unemployment due to the transition away from non-renewable energy.

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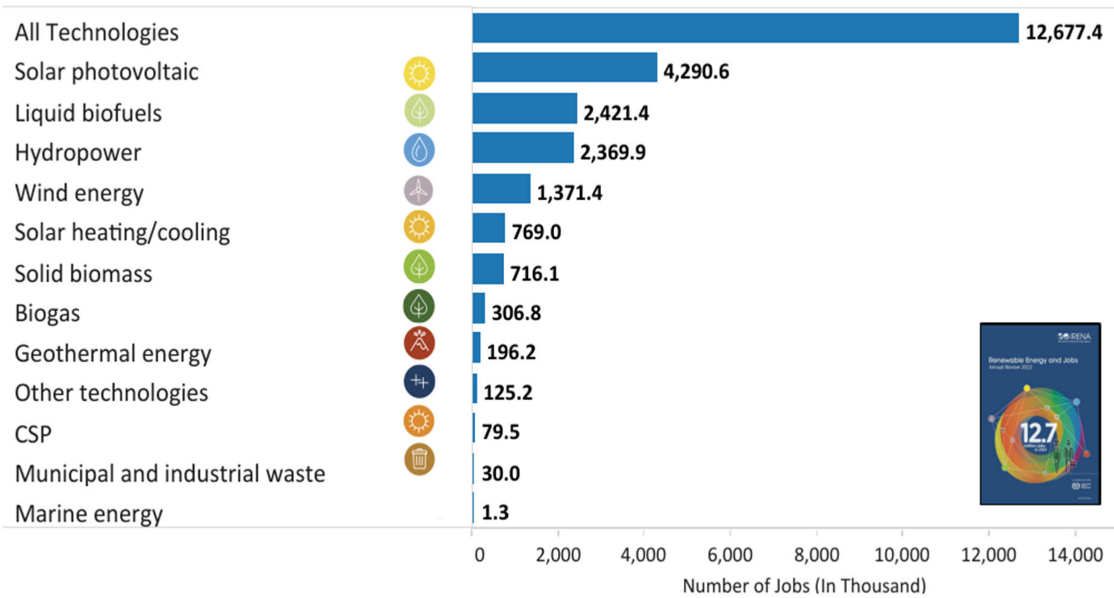
[43] Natural Resources Canada (2021)
[44] For more information, see the 2021 Forbes article "Asia's Ring Of Fire Is A Hot Spot For Net Zero Energy" (https://www.forbes.com/sites/mitsubishiheavyindustries/2021/11/15/asias-ring-of-fire-is-a-hot-spot-for-net-zero-energy/).
[45] The World Bank (2019b)
[46] World Bank (2019)
[47] Kabeyi and Olanweraju (2022)
[48] World Bank (2017)

Figure 9.4: Renewable energy employment by technology in 2021
Source: IRENA (2022d)



Source IRENA and ILO (2022), Renewable energy and jobs: Annual review 2022, International Renewable Energy Agency, Abu Dhabi and Internationa Labour Organization, Geneva. Data are principally for 2021, with some dates for 2020 and a few instances in which only earlier information is available. The data for hydropower include direct employment only and for other technologies include both direct and indirect employment whereve possible. 'Other Technologies' include jobs not broken down by individual renewable energy technologies.