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Review Article

Geothermal Energy Potential in Sedimentary Basins: An Overview of Exploration and Development Strategies

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Abstract

Geothermal energy is increasingly recognized as a reliable, low-carbon energy source capable of supporting global decarbonization while providing continuous baseload power and direct heat. Although volcanic regions have traditionally dominated geothermal development, sedimentary basins are emerging as attractive alternatives because of their broad geographic distribution, favorable reservoir properties, and extensive subsurface data acquired through decades of hydrocarbon exploration. Their significant thermal resources present opportunities for sustainable electricity generation, district heating, industrial processes, and integration with existing energy infrastructure. This review provides a comprehensive overview of the geothermal potential of sedimentary basins, with particular emphasis on exploration and development strategies. It examines the geological framework governing heat accumulation, fluid circulation, and reservoir quality, followed by an evaluation of contemporary exploration approaches, including geological, geophysical, geochemical, and borehole-based investigations for resource characterization and risk reduction. The review further discusses development strategies encompassing drilling technologies, reservoir engineering, energy extraction systems, and sustainable reservoir management practices that enhance long-term productivity. Technical, economic, environmental, and regulatory challenges affecting large-scale deployment are critically assessed alongside recent technological advances that improve exploration efficiency and project viability. Representative case studies from established and emerging geothermal regions are synthesized to highlight successful practices and transferable lessons for future developments. By integrating geological understanding with advances in exploration, engineering, and resource management, this review provides a concise yet comprehensive reference that identifies current knowledge, emerging opportunities, and strategic directions for accelerating the sustainable development of geothermal resources in sedimentary basins.

Keywords: Geothermal energy, Sedimentary basins, Geothermal exploration, Reservoir characterization, Reservoir engineering, and Sustainable geothermal development.

Introduction

The increasing demand for clean, secure, and sustainable energy has accelerated the global transition toward low-carbon energy systems, placing renewable energy resources at the forefront of climate change mitigation and energy security strategies. Among these resources, geothermal energy has gained considerable attention because it provides continuous baseload power and thermal energy with high-capacity factors, low greenhouse gas emissions, and minimal dependence on

weather conditions (Kumar *et al.*, 2022). Unlike intermittent renewable sources such as solar and wind, geothermal energy offers reliable year-round energy production, making it an essential component of diversified energy portfolios. Although commercial geothermal exploitation has traditionally focused on volcanic and tectonically active regions, advances in exploration technologies and subsurface characterization have expanded interest in geothermal resources hosted within sedimentary basins (Procesi *et al.*, 2019). These basins are widely distributed across the globe and represent an

underutilized geothermal resource capable of supporting electricity generation, direct heat applications, and industrial decarbonization (Beardsmore, 2025).

Sedimentary basins possess favorable geological and hydrogeological conditions that make them attractive targets for geothermal development. Thick sedimentary successions promote heat accumulation, while permeable aquifers and naturally circulating formation fluids facilitate efficient heat transport and extraction (Procesi *et al.*, 2019). Furthermore, decades of hydrocarbon exploration have generated extensive subsurface datasets, including seismic surveys, well logs, drilling records, and reservoir characterization data, significantly reducing geological uncertainty and exploration costs (Birdsell *et al.*, 2024). Advances in basin-scale thermal modeling, numerical simulation, and integrated geological, geophysical, and geochemical investigations have further improved the identification and evaluation of economically viable geothermal reservoirs (Lu *et al.*, 2023; Beardsmore, 2025). These developments have also encouraged the repurposing of depleted oil and gas infrastructure for geothermal applications, thereby improving project feasibility while supporting the transition toward sustainable energy systems (Beardsmore, 2025).

Despite their considerable resource potential, geothermal developments in sedimentary basins continue to encounter technical, economic, and regulatory challenges that influence commercial deployment and long-term sustainability. Reservoir heterogeneity, uncertainties in subsurface temperature distribution, high drilling costs, complex fluid chemistry, and reservoir management remain major constraints throughout the exploration and production lifecycle (Kumar *et al.*, 2022). Consequently, successful project implementation depends on integrated exploration strategies that combine geological mapping, geophysical surveys, geochemical analyses, borehole investigations, and numerical reservoir modeling to improve resource characterization and reduce exploration risk (Birdsell *et al.*, 2024; Rasheed *et al.*, 2026). At the same time, advances in drilling technologies, reservoir engineering, digital monitoring, and sustainable reinjection practices continue to improve energy recovery, operational efficiency, and long-term reservoir performance, reinforcing the growing role of sedimentary basin geothermal systems in achieving global decarbonization and energy resilience (Beardsmore, 2025; Rasheed *et al.*, 2026).

Although significant progress has been made in understanding geothermal resources within sedimentary basins, existing studies have primarily focused on individual aspects such as geothermal system characterization, resource mapping, reservoir evaluation, or technological innovations rather than providing an integrated perspective across the entire project lifecycle (Procesi *et al.*, 2019; Kumar *et al.*, 2022). Advances in geological modeling, geophysical imaging, and numerical reservoir simulation have substantially improved the identification and characterization of geothermal reservoirs (Lu *et al.*, 2023; Birdsell *et al.*, 2024). Likewise, growing

interest in utilizing hot sedimentary aquifers and repurposing existing oil and gas infrastructure has expanded the feasibility of geothermal development in sedimentary basins (Beardsmore, 2025). More recently, the integration of geospatial analysis, geochemistry, and geophysical datasets has enhanced resource targeting and reduced exploration uncertainty, particularly in emerging geothermal provinces (Rasheed *et al.*, 2026). Despite these advances, information on geological controls, exploration methods, reservoir engineering, sustainability, and development practices remains dispersed across the literature, limiting the translation of scientific knowledge into practical implementation. A comprehensive synthesis that integrates these complementary aspects is therefore needed to support effective resource evaluation, optimize development strategies, identify current knowledge gaps, and guide future research, industrial applications, and policy development.

The present review provides a comprehensive overview of the geothermal energy potential of sedimentary basins, with particular emphasis on the exploration and development strategies that enable their sustainable utilization. It examines the geological framework governing heat accumulation, fluid circulation, reservoir characteristics, and the distribution of geothermal resources within sedimentary basins to establish the scientific basis for resource evaluation. The review further synthesizes the principal exploration approaches, including geological, geophysical, geochemical, and borehole-based methods, highlighting their contributions to resource identification, reservoir characterization, and uncertainty reduction. It also discusses contemporary development strategies, encompassing drilling technologies, reservoir engineering, energy conversion systems, and reservoir management practices that improve energy recovery, operational efficiency, and long-term sustainability. In addition, the review evaluates the major technical, economic, environmental, and regulatory factors influencing geothermal project implementation and examines emerging technological innovations that enhance exploration accuracy, development performance, and resource management. By integrating current scientific knowledge with engineering practices and recent technological advances, this review offers a coherent and up-to-date reference for researchers, engineers, industry practitioners, investors, and policymakers. Ultimately, it aims to facilitate informed decision-making, promote the sustainable development of geothermal resources in sedimentary basins, identify opportunities for future research and technological innovation, and support the broader transition toward resilient, low-carbon, and secure energy systems.

Geothermal Systems in Sedimentary Basins

Sedimentary basins represent one of the most promising non-volcanic geothermal settings because they combine favorable geological conditions with widespread distribution and substantial subsurface data acquired through decades of hydrocarbon exploration. Their geothermal potential is

governed by the interaction of basin architecture, heat flow, lithological composition, groundwater circulation, and reservoir properties, which collectively determine heat accumulation, storage, and recoverability (Grant and Bixley, 2011; Banks, 2012; Dickson and Fanelli, 2013). Advances in basin-scale thermal modeling, geothermal play characterization, and reservoir evaluation have significantly improved the understanding of these systems, enabling more reliable assessment of geothermal resources and supporting their sustainable utilization (Moeck, 2014; Limberger *et al.*, 2018; Kolawole and Evenick, 2023; Gardner and Birdwell, 2023; Zayed *et al.*, 2023). Consequently, understanding the geological framework, heat transfer processes, reservoir characteristics, and resource classification of sedimentary basin geothermal systems provides the scientific foundation for effective exploration, resource assessment, and subsequent development.

Geological Framework and Basin Evolution

Sedimentary basins are long-lived tectonic depressions formed through extensional, compressional, strike-slip, or intracratonic processes that create accommodation space for the accumulation of sedimentary sequences over geological time (Grant and Bixley, 2011; Banks, 2012). Their structural evolution governs basin geometry, stratigraphic architecture, fault distribution, and lithological heterogeneity, all of which influence geothermal resource occurrence and productivity. Basin type, tectonic history, burial depth, and sedimentation rates collectively determine the thermal regime and the spatial distribution of geothermal reservoirs (Moeck, 2014). Consequently, understanding basin evolution is fundamental to identifying favorable geothermal settings and predicting reservoir continuity. The geothermal potential of sedimentary basins is largely controlled by the interplay between regional heat flow and the physical properties of sedimentary rocks. Heat originates primarily from the Earth's interior through mantle heat input and the radiogenic decay of heat-producing elements within the crust before being transferred upward by conduction through rocks and, where permeable pathways exist, by convection through circulating formation fluids (Banks, 2012; Dickson and Fanelli, 2013). Thick sedimentary successions act as effective thermal insulators, allowing heat to accumulate at economically exploitable depths, while variations in lithology and structural complexity produce spatial differences in temperature distribution and geothermal gradients (Limberger *et al.*, 2018; Kolawole and Evenick, 2023). These thermal characteristics determine the quantity and accessibility of geothermal energy stored within sedimentary formations.

Reservoir quality is strongly influenced by the geological evolution of the basin. Progressive burial, compaction, cementation, diagenesis, and tectonic deformation continuously modify porosity, permeability, and fracture networks, thereby affecting fluid storage and circulation (Grant and Bixley, 2011). Sandstones, carbonate formations, and naturally fractured reservoirs commonly provide the most

favorable conditions for geothermal exploitation because they combine sufficient permeability with adequate thickness and lateral continuity (Dickson and Fanelli, 2013; Limberger *et al.*, 2018). Structural features such as faults and fractures may further enhance permeability by creating preferential pathways for deep fluid migration, although they can also compartmentalize reservoirs depending on their sealing characteristics (Moeck, 2014). These geological controls govern reservoir connectivity, thermal recharge, and long-term production performance. Recent advances in basin-scale geological modeling have substantially improved the characterization of sedimentary geothermal systems by integrating stratigraphic, structural, thermal, petrophysical, and hydrogeological datasets into unified subsurface models (Gardner and Birdwell, 2023). Coupled thermo-fluid numerical simulations further enable prediction of heat distribution, fluid circulation, and reservoir behavior under different production scenarios, thereby reducing uncertainty in geothermal resource evaluation and supporting sustainable reservoir management (Zayed *et al.*, 2023). Such integrated geological frameworks provide a robust basis for identifying prospective geothermal reservoirs and optimizing subsequent exploration and development strategies.

Heat Generation and Heat Transport Mechanisms

The geothermal potential of sedimentary basins is fundamentally controlled by the generation, storage, and transfer of subsurface heat. Heat is supplied primarily through mantle heat flow and the radiogenic decay of uranium, thorium, and potassium within the continental crust, creating a regional geothermal gradient that generally increases with depth (Banks, 2012; Dickson & Fanelli, 2013). The magnitude of this gradient varies among sedimentary basins depending on tectonic setting, crustal thickness, lithospheric structure, and regional heat flow, resulting in significant spatial variability in geothermal resource potential (Kolawole and Evenick, 2023). Consequently, accurate characterization of the thermal regime is essential for estimating reservoir temperatures and identifying economically viable geothermal resources. Heat is transferred through sedimentary formations by conduction and convection, with their relative contributions determined by rock properties and fluid dynamics. Conductive heat transfer dominates in low-permeability formations where thermal energy moves through the rock matrix along temperature gradients (Banks, 2012). In contrast, convective heat transport becomes increasingly important in permeable aquifers and fractured reservoirs, where circulating groundwater redistributes heat and enhances thermal recovery (Grant and Bixley, 2011; Dickson and Fanelli, 2013). The interaction between these mechanisms governs subsurface temperature distribution, influences reservoir recharge, and determines the efficiency of geothermal energy extraction.

Geological discontinuities such as faults and fracture systems may further modify heat transport by acting as preferential pathways or hydraulic barriers, thereby creating localized thermal anomalies within sedimentary basins (Moeck, 2014).

Lithological variability also exerts a strong influence on basin thermal behavior because different rock types possess distinct thermal conductivities, heat capacities, and hydraulic characteristics. Fine-grained shale formations generally have lower thermal conductivity than sandstone or carbonate rocks, allowing greater heat retention, whereas highly permeable sandstones and fractured carbonates facilitate fluid circulation and convective heat transfer (Limberger *et al.*, 2018). The vertical and lateral arrangement of these lithologies therefore controls both heat storage and accessibility, emphasizing the importance of integrated geological and petrophysical characterization during geothermal resource assessment. Recent advances in thermal basin modeling have significantly

improved the understanding of heat generation and transport within sedimentary geothermal systems. Modern numerical models integrate geological architecture, heat flow, rock thermal properties, groundwater movement, and reservoir dynamics to reconstruct basin thermal evolution and predict subsurface temperature distributions with greater accuracy (Gardner and Birdwell, 2023; Zayed *et al.*, 2023). These integrated approaches enhance geothermal resource assessment by reducing uncertainty, identifying high-potential thermal reservoirs, and providing a scientific basis for sustainable reservoir development and long-term energy production.

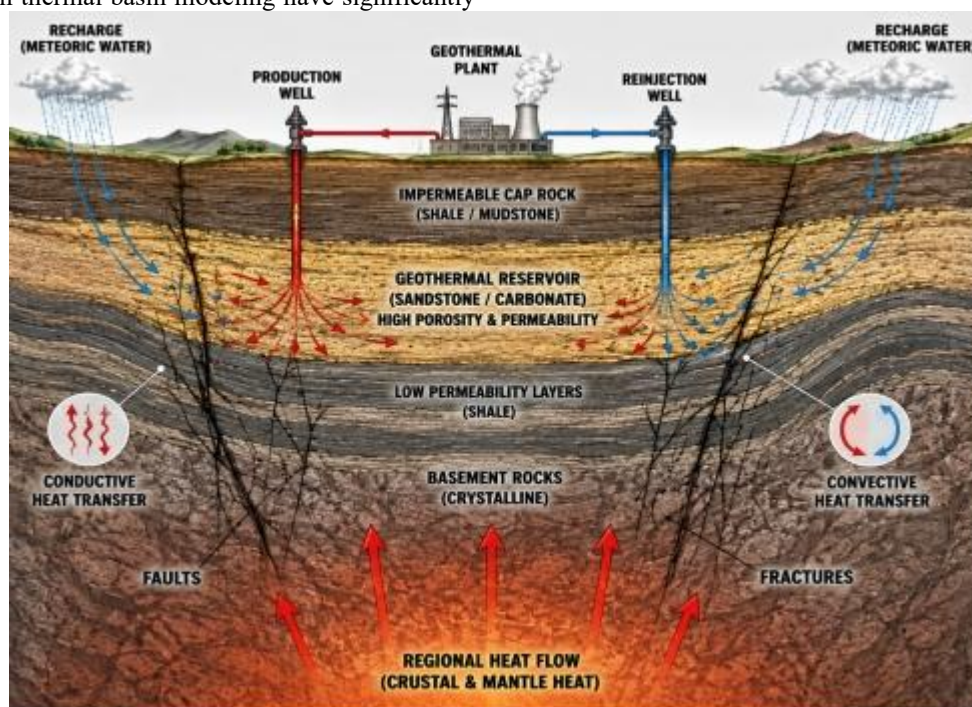


Figure 1. Conceptual geological model of a sedimentary basin geothermal system. This Schematic illustrate the geological framework, regional heat flow, groundwater circulation, geothermal reservoir, and production–reinjection system controlling geothermal energy occurrence and extraction in sedimentary basins

Source: Modified from Limberger *et al.* (2018)

Reservoir Characteristics and Geothermal Fluid Systems

The performance of a sedimentary geothermal system depends primarily on reservoir properties that control heat storage, fluid circulation, and sustainable energy extraction. An effective geothermal reservoir requires adequate temperature, sufficient thickness, lateral continuity, favorable porosity and permeability, and an active fluid system capable of transporting thermal energy (Grant and Bixley, 2011; Dickson

and Fanelli, 2013). These characteristics are governed by the basin's depositional environment, burial history, diagenetic evolution, and tectonic deformation, which collectively determine reservoir quality and long-term productivity (Moeck, 2014). Consequently, comprehensive reservoir

characterization is essential for accurately evaluating geothermal resources and minimizing development uncertainty. Porosity and permeability are the principal petrophysical properties controlling geothermal reservoir performance. Porosity determines the volume available for fluid storage, whereas permeability governs fluid flow and heat transfer within the reservoir (Grant and Bixley, 2011). Although burial and cementation generally reduce these properties with increasing depth, secondary porosity generated through dissolution, fracturing, and fault reactivation can significantly enhance reservoir productivity (Banks, 2012). Sandstone aquifers commonly provide favorable combinations of storage capacity and permeability, while fractured carbonate reservoirs may sustain high production rates through interconnected fracture networks despite relatively low matrix permeability (Limberger *et al.*, 2018). The spatial distribution

of these properties therefore influences reservoir connectivity, production efficiency, and thermal recovery.

Geothermal fluids constitute the primary medium for transporting heat from the subsurface to production wells. These fluids are predominantly groundwater or formation water that has been heated during deep circulation through sedimentary formations under regional geothermal gradients (Dickson and Fanelli, 2013). Their temperature, pressure, salinity, and chemical composition influence reservoir behavior, scaling potential, corrosion, and the selection of suitable energy conversion technologies. Fluid movement is controlled by hydraulic gradients, aquifer connectivity, permeability distribution, and structural features such as faults and fractures, which may either facilitate or restrict circulation depending on their hydraulic properties (Moeck, 2014; Lu *et al.*, 2023). Understanding geothermal fluid systems is therefore critical for predicting reservoir performance and designing sustainable production strategies. Recent advances in reservoir characterization have substantially improved the evaluation of geothermal systems in sedimentary basins. The integration of geological, petrophysical, geophysical, hydrogeological, and thermal datasets enables more accurate delineation of reservoir geometry, fluid pathways, and temperature distribution (Gardner and Birdwell, 2023; Birdsell *et al.*, 2024). Furthermore, coupled thermo-fluid reservoir models simulate fluid flow, heat transport, and pressure evolution under different production scenarios, providing valuable insights into reservoir behavior, production sustainability, and reinjection efficiency (Zayed *et al.*, 2023). These integrated approaches enhance resource estimation, reduce exploration uncertainty, and support the long-term management of geothermal reservoirs.

Classification of Sedimentary Basin Geothermal Resources

The classification of geothermal resources provides a systematic framework for evaluating reservoir characteristics, resource quality, and potential utilization pathways. In sedimentary basins, geothermal resources are commonly classified according to geological setting, reservoir temperature, depth, heat transfer mechanism, and intended application, enabling consistent resource assessment and supporting appropriate exploration and development strategies (Dickson and Fanelli, 2013; Moeck, 2014). Such classification also facilitates comparison among geothermal systems across different basin settings and improves the selection of suitable extraction technologies. From a geological perspective, sedimentary basin geothermal resources are predominantly associated with hot sedimentary aquifers, where permeable and laterally extensive formations contain naturally circulating thermal fluids capable of supporting direct heat applications and, in favorable conditions, electricity generation (Limberger *et al.*, 2018; Beardsmore, 2025). Depending on structural and hydrogeological conditions, geothermal systems may also occur within fractured sedimentary rocks or hybrid systems in which conductive heat flow is supplemented by convective fluid circulation along faults and fracture networks (Moeck,

2014). These geological variations strongly influence reservoir productivity, sustainability, and development potential.

Resource temperature remains one of the most widely applied classification criteria because it determines the most suitable utilization pathway. Low-temperature resources are generally used for space heating, greenhouse agriculture, aquaculture, and ground-source heat pump systems, whereas medium- and high-temperature reservoirs are increasingly exploited for industrial heating and electricity generation using binary-cycle technologies (Banks, 2012; Dickson and Fanelli, 2013). Advances in power conversion systems have expanded the economic utilization of moderate-temperature sedimentary geothermal resources that were previously considered unsuitable for electricity production (Kumar *et al.*, 2022; Beardsmore, 2025). Recent advances in geothermal assessment have promoted integrated classification approaches that combine geological architecture, thermal characteristics, hydrogeological conditions, reservoir properties, and numerical modeling to provide more realistic estimates of geothermal potential (Kolawole and Evenick, 2023; Birdsell *et al.*, 2024). Basin-scale geological modeling and coupled thermo-fluid simulations further improve the delineation of prospective geothermal plays and quantify recoverable thermal resources under different production scenarios (Gardner and Birdwell, 2023; Zayed *et al.*, 2023). These integrated classification frameworks provide a robust scientific basis for resource evaluation, reduce uncertainty in geothermal prospecting, and support sustainable exploration and development of sedimentary basin geothermal systems.

Exploration Strategies

Effective exploration strategies are fundamental to the successful development of geothermal resources in sedimentary basins because they reduce geological uncertainty, improve resource characterization, and enhance investment confidence. Unlike conventional hydrocarbon exploration, geothermal exploration prioritizes the identification of subsurface heat, permeable reservoirs, fluid pathways, and sustainable production conditions through the integration of multidisciplinary datasets (Moeck, 2014; Limberger *et al.*, 2018). Modern exploration workflows combine geological, structural, geophysical, geochemical, and borehole investigations with basin-scale numerical modelling and digital decision-support tools to accurately delineate geothermal systems and estimate recoverable resources (Nwaiwu *et al.*, 2023; AlGaier *et al.*, 2024; Birdsell *et al.*, 2024; Llanos and Blessent, 2025). Recent advances in artificial intelligence, integrated reservoir modelling, electromagnetic imaging, and geomechanical characterization have further improved exploration accuracy by enabling the efficient interpretation of large and diverse datasets, reducing exploration risk, and optimizing drilling targets (Castillo-Reyes *et al.*, 2024; Kolo *et al.*, 2024; Redouane, 2025; Cao *et al.*, 2026). Consequently, successful geothermal exploration in sedimentary basins increasingly depends on integrated, data-driven strategies that provide a reliable foundation for resource assessment, reservoir development, and sustainable geothermal utilization.

Table 1. Key geological controls on geothermal potential in sedimentary basins

Control	Primary influence on geothermal systems	Significance
Basin architecture	Determines thermal evolution, reservoir distribution, and structural framework	High
Heat flow and geothermal gradient	Control subsurface temperature and heat availability	High
Lithology	Regulates thermal conductivity, heat storage, and reservoir quality	High
Porosity and permeability	Govern fluid storage, circulation, and heat recovery	High
Faults and fractures	Modify permeability and provide pathways for fluid migration	High
Groundwater circulation	Enhances convective heat transport and reservoir recharge	High
Reservoir thickness and depth	Influence heat storage capacity and economic recoverability	Moderate–High
Cap rock integrity	Preserves reservoir pressure and thermal retention	High

Modified from Moeck (2014); Limberger *et al.* (2018); Beardsmore (2025)

Geological and Structural Characterization

Geological and structural characterization provides the foundation for geothermal exploration by defining the basin

architecture, stratigraphic framework, structural evolution, and reservoir distribution that collectively control geothermal resource occurrence. Basin geometry, depositional history, burial evolution, and tectonic setting determine subsurface temperature distribution, reservoir continuity, and the spatial relationship between heat sources, permeable formations, and sealing units (Grant and Bixley, 2011; Moeck, 2014; Limberger *et al.*, 2018). Consequently, detailed geological characterization is essential for identifying prospective geothermal plays and reducing uncertainty during exploration. Structural analysis complements geological investigations by evaluating faults, fractures, folds, and regional stress fields that influence geothermal fluid migration and reservoir permeability. Fault systems commonly serve as preferential pathways for deep fluid circulation and heat transport, whereas sealing faults may compartmentalize reservoirs and restrict fluid connectivity (Banks, 2012; Lu *et al.*, 2023). Their geometry, orientation, and reactivation history therefore play a critical role in controlling reservoir productivity and long-term sustainability. Integrated structural interpretation also improves the prediction of permeable zones and supports optimal well placement within sedimentary geothermal systems (Redouane, 2025).

Modern geological characterization increasingly integrates surface mapping, borehole information, well logs, core analyses, remote sensing, and three-dimensional geological modelling to construct comprehensive subsurface models (Birdsell *et al.*, 2024). These datasets are further enhanced through geographic information systems, machine learning,

and artificial intelligence, which enable rapid integration of geological, structural, thermal, and hydrogeological information for identifying high-potential geothermal targets and prioritizing exploration areas (Nwaiwu *et al.*, 2023; AlGaier *et al.*, 2024). Such multidisciplinary workflows improve exploration efficiency while reducing uncertainty associated with conventional geological interpretation. Recent developments emphasize basin-scale integrated characterization rather than isolated geological investigations. Coupling geological models with structural analysis, thermal history reconstruction, and numerical reservoir simulations provides a more reliable representation of geothermal systems and supports the prediction of reservoir quality before drilling (Llanos and Blessent, 2025). This integrated approach enhances resource evaluation, improves exploration success rates, and establishes the geological framework required for subsequent geophysical investigations, reservoir characterization, and sustainable geothermal development (Meryem *et al.*, 2024; Cao *et al.*, 2026).

Geophysical and Geochemical Exploration

Geophysical and geochemical investigations are indispensable components of geothermal exploration because they provide indirect evidence of subsurface heat sources, reservoir geometry, fluid pathways, and hydrothermal processes before drilling. Their integration significantly reduces exploration uncertainty by identifying favorable geothermal targets and refining geological interpretations derived from basin characterization (Dickson and Fanelli, 2013; Moeck, 2014). Modern exploration therefore combines multiple complementary techniques to improve the accuracy and reliability of geothermal resource evaluation. Geophysical exploration employs seismic, gravity, magnetic, electrical, electromagnetic, magnetotelluric (MT), and passive seismic methods to delineate subsurface structures and characterize reservoir properties. Seismic surveys define stratigraphic architecture and fault networks, while gravity and magnetic data reveal basement configuration and lithological variations.

Electrical and electromagnetic techniques, particularly MT, are widely applied to identify conductive geothermal reservoirs, fracture-controlled fluid pathways, and alteration zones associated with hydrothermal circulation (Castillo-Reyes *et al.*, 2024). Recent advances in integrated geophysical inversion, geomechanical analysis, and three-dimensional imaging have further improved reservoir delineation and drilling target selection by providing higher-resolution representations of subsurface thermal systems (Birdsell *et al.*, 2024; Cao *et al.*, 2026).

Geochemical exploration complements geophysical methods by evaluating the composition of geothermal fluids and gases to infer reservoir temperature, fluid origin, water–rock interaction, mixing processes, and circulation pathways. Hydrochemical analyses, stable isotopes, dissolved gases, and geothermometry are widely used to estimate subsurface temperatures and assess reservoir connectivity where direct temperature measurements are unavailable (Banks, 2012; Lu *et al.*, 2023). These techniques also help identify scaling and corrosion risks, thereby supporting both exploration and subsequent reservoir development. Recent exploration strategies increasingly integrate geological, geophysical, geochemical, and computational approaches within unified exploration frameworks. Artificial intelligence, machine learning, and spatial decision-support systems enable rapid interpretation of large multidisciplinary datasets, improve anomaly detection, and enhance geothermal prospect ranking (Nwaiwu *et al.*, 2023; AlGaier *et al.*, 2024). Combined with regional exploration experiences and basin-specific datasets, these integrated workflows improve exploration efficiency, reduce drilling uncertainty, and increase the probability of successful geothermal resource discovery (Redouane, 2025; Meryem *et al.*, 2024).

Borehole Rvaluation and Reservoir Characterization

Borehole evaluation provides the most direct and reliable means of confirming geothermal resources by validating geological interpretations, measuring reservoir temperature, and determining the hydraulic and thermal properties governing energy production. Following surface exploration, exploratory wells generate critical information on lithology, stratigraphy, fracture distribution, fluid chemistry, temperature gradients, pressure regimes, and permeability, thereby reducing uncertainty in resource estimation and field development (Grant and Bixley, 2011; Dickson and Fanelli, 2013). These datasets establish the basis for assessing reservoir productivity and long-term operational feasibility. Reservoir characterization integrates borehole observations with well logging, core analysis, hydraulic testing, and petrophysical evaluation to define reservoir geometry, fluid pathways, storage capacity, and flow behavior. Temperature logs identify productive geothermal intervals, while pressure tests, injection tests, and flow tests quantify reservoir transmissivity, permeability, and hydraulic connectivity. Core samples and geophysical logs further constrain lithology, porosity, fracture density, and mineral alteration, enabling a

comprehensive assessment of reservoir quality and production potential (Banks, 2012; Limberger *et al.*, 2018). This multidisciplinary characterization supports optimal well placement and efficient reservoir management.

Recent advances have significantly enhanced borehole evaluation through high-resolution logging technologies, fiber-optic distributed temperature sensing, digital well monitoring, and coupled thermo-hydraulic simulations that provide continuous assessment of reservoir conditions during exploration and production (Kolo *et al.*, 2024). Numerical reservoir models calibrated with borehole data improve predictions of fluid flow, pressure evolution, heat extraction, and reinjection performance under different production scenarios, thereby supporting sustainable reservoir development and minimizing thermal decline (Birdsell *et al.*, 2024; Llanos and Blessent, 2025). These approaches also facilitate adaptive reservoir management as new field data become available. Increasingly, borehole evaluation is integrated with geological, geophysical, and geochemical datasets to develop dynamic reservoir models that capture the complexity of sedimentary geothermal systems. Artificial intelligence and advanced data analytics further improve the interpretation of well logs, identification of productive intervals, and prediction of reservoir performance by extracting patterns from large multidisciplinary datasets (AlGaier *et al.*, 2024). This integrated characterization framework reduces exploration risk, improves drilling success, and provides the technical foundation for reliable resource assessment and sustainable geothermal field development (Redouane, 2025; Cao *et al.*, 2026).

Resource Assessment and Exploration Risk Analysis

Resource assessment integrates geological, geophysical, geochemical, and borehole data to estimate the quantity, quality, and recoverability of geothermal resources within sedimentary basins. Reliable assessment requires accurate characterization of reservoir temperature, thickness, lateral extent, permeability, fluid availability, and recharge potential, as these parameters determine the technical and economic feasibility of geothermal development (Grant and Bixley, 2011; Limberger *et al.*, 2018). Contemporary assessment frameworks increasingly combine deterministic and probabilistic approaches with basin-scale numerical modelling to improve estimates of recoverable thermal energy and long-term production performance (Birdsell *et al.*, 2024; Llanos and Blessent, 2025). Exploration risk analysis evaluates the uncertainties that may compromise geothermal project success before commercial development. Major risks include inadequate reservoir temperature, low permeability, insufficient fluid productivity, geological complexity, drilling uncertainty, reservoir heterogeneity, and economic constraints (Moeck, 2014; Redouane, 2025). Quantifying these uncertainties during exploration supports informed decision-making, optimizes exploration investments, and minimizes the likelihood of unsuccessful drilling campaigns.

Recent advances in digital technologies have substantially improved resource assessment and risk evaluation. Artificial intelligence, machine learning, geographic information systems, and multi-criteria decision-support tools enable rapid integration of multidisciplinary datasets, objective prospect ranking, and prediction of favorable drilling targets (Nwaiwu *et al.*, 2023; AlGaier *et al.*, 2024). In parallel, coupled thermo-hydraulic and geomechanical models simulate reservoir behavior under different production scenarios, providing more reliable estimates of resource sustainability and operational risks while supporting adaptive field management (Zayed *et*

al., 2023; Cao *et al.*, 2026). An effective exploration strategy therefore relies on the integration of robust resource assessment with systematic risk analysis rather than treating them as independent processes. Combining multidisciplinary data, advanced modelling, and uncertainty analysis improves exploration success, strengthens investment confidence, and supports sustainable geothermal development by ensuring that technical, geological, and economic risks are identified and managed before large-scale field implementation (Llanos and Blessent, 2025; Redouane, 2025).

Table 2. Major exploration methods and their applications in sedimentary basin geothermal systems

Exploration method	Primary objective	Key information obtained
Geological mapping	Define basin framework	Lithology, stratigraphy, structures
Structural analysis	Identify fluid pathways	Faults, fractures, stress regime
Seismic survey	Image subsurface geometry	Reservoir architecture
Gravity and magnetic survey	Delineate deep structures	Basement configuration
Magnetotelluric (MT) survey	Detect conductive zones	Reservoirs, fluid pathways
Geochemical analysis	Evaluate geothermal fluids	Reservoir temperature, fluid origin
Exploratory drilling	Confirm geothermal resource	Temperature, pressure, lithology
Well logging and testing	Characterize reservoir	Porosity, permeability, productivity
Numerical modelling	Predict reservoir behaviour	Heat extraction, sustainability
Risk assessment	Quantify exploration uncertainty	Exploration and development risk

Development Strategies

Successful geothermal development in sedimentary basins depends on engineering strategies that maximize heat recovery while preserving long-term reservoir performance and economic viability. Following resource confirmation, development focuses on optimizing well design, reservoir engineering, energy extraction technologies, and operational management to achieve efficient and sustainable heat production (Grant and Bixley, 2011; Zhu, 2023; Khan *et al.*, 2025). Recent advances in enhanced geothermal systems, coupled thermo-hydraulic modelling, low-energy extraction technologies, digital reservoir management, and energy system integration have significantly improved production efficiency, operational flexibility, and resource sustainability (Horne *et al.*, 2025; Ma *et al.*, 2025; Vatanpour *et al.*, 2026).

Consequently, modern development strategies increasingly emphasize integrated engineering solutions that enhance geothermal utilization while minimizing environmental impacts, operational risks, and long-term reservoir degradation.

Reservoir Engineering and Well Design

Reservoir engineering and well design are fundamental to efficient geothermal development because they determine heat recovery, fluid productivity, reservoir longevity, and overall project performance. Reservoir engineering integrates geological, hydrogeological, and thermo-hydraulic information to optimize well placement, production strategies,

and reinjection schemes while maintaining reservoir pressure and thermal sustainability (Grant and Bixley, 2011; Zhu, 2023; Khan *et al.*, 2025). These engineering decisions directly influence the technical and economic viability of geothermal projects throughout their operational lifespan. Well design is tailored to reservoir depth, temperature, lithology, stress conditions, and fluid characteristics to ensure reliable production under high-temperature and high-pressure environments. Appropriate well trajectory, casing design, cementing, completion techniques, and production–reinjection configurations improve fluid circulation, minimize thermal losses, and reduce operational challenges such as scaling, corrosion, and wellbore instability (Kumar *et al.*, 2022; Birdsell *et al.*, 2024). In sedimentary basin systems, doublet and multi-well configurations are commonly adopted to enhance heat extraction while maintaining long-term reservoir productivity. Recent advances in reservoir engineering increasingly combine coupled thermo-hydraulic–mechanical modelling, real-time monitoring, and digital optimization to predict reservoir behaviour under different production scenarios and support adaptive field management (Llanos and Blessent, 2025; Vatanpour *et al.*, 2026). Enhanced geothermal system technologies, advanced drilling techniques, and improved well completion designs have further expanded the development potential of low-permeability and deep geothermal reservoirs by increasing reservoir connectivity and heat recovery efficiency (Horne *et al.*, 2025; Yuan *et al.*, 2025). Collectively, these innovations improve production reliability, extend reservoir life, and provide the engineering foundation for sustainable geothermal energy development.

Energy Extraction Technologies

Energy extraction technologies determine how efficiently geothermal heat is converted into usable energy and therefore play a central role in the commercial development of sedimentary basin resources. The choice of extraction technology depends primarily on reservoir temperature, fluid characteristics, permeability, and intended end use, with systems designed to maximize thermal recovery while minimizing energy losses and operational costs (Dickson and Fanelli, 2013; Kumar *et al.*, 2022). Appropriate technology selection enhances resource utilization across both high- and moderate-temperature geothermal systems. Hydrothermal systems remain the most widely deployed technology where naturally permeable reservoirs and sufficient geothermal fluids are available. Depending on reservoir conditions, extracted heat may be utilized for electricity generation through flash steam or binary cycle power plants, or directly for district heating, industrial processes, agriculture, and other thermal applications (Grant and Bixley, 2011; Vatanpour *et al.*, 2026). Binary Organic Rankine Cycle (ORC) systems are particularly suitable for sedimentary basins because they efficiently exploit moderate-temperature resources that are unsuitable for conventional steam-based technologies (IEA, 2024). Recent technological advances have expanded geothermal utilization beyond conventional hydrothermal production. Enhanced geothermal systems, advanced heat exchanger technologies, closed-loop geothermal systems, and low-energy extraction processes have improved heat recovery from low-permeability and deep geothermal reservoirs while reducing dependence on naturally productive formations (Horne *et al.*, 2025; Zhu, 2025). In addition, co-production strategies that recover geothermal energy from abandoned mines, depleted hydrocarbon reservoirs, and other subsurface infrastructure improve resource efficiency and reduce development costs by utilizing existing wells and facilities (Ma *et al.*, 2025). These innovations, supported by advances in reservoir modelling and thermal optimization, continue to improve energy conversion efficiency, operational flexibility, and the long-term economic competitiveness of geothermal energy (Khan *et al.*, 2025; Yuan *et al.*, 2025).

Reservoir Management and Sustainability

Effective reservoir management is essential for sustaining geothermal production by maintaining reservoir pressure, thermal performance, and fluid availability throughout the operational life of a project. Sustainable management integrates continuous monitoring with adaptive production strategies to balance heat extraction and natural reservoir recharge, thereby minimizing thermal decline and preserving long-term resource productivity (Grant and Bixley, 2011; Zhu, 2023; Khan *et al.*, 2025). This approach ensures that geothermal development remains technically reliable and economically viable over extended production periods. Production optimization is commonly achieved through controlled extraction rates, strategic reinjection, and continuous surveillance of reservoir temperature, pressure, and

fluid chemistry. Reinjection not only sustains reservoir pressure but also supports fluid circulation and improves long-term heat recovery when appropriately designed and managed (Kumar *et al.*, 2022; Birdsell *et al.*, 2024). Coupled thermo-hydraulic modelling, digital reservoir simulation, and real-time monitoring further enhance decision-making by predicting reservoir responses under different production scenarios and enabling timely operational adjustments (Llanos and Blessent, 2025; Vatanpour *et al.*, 2026). Long-term sustainability also requires effective management of operational and environmental challenges, including scaling, corrosion, fluid depletion, and induced seismicity. Advances in reservoir engineering, low-energy production technologies, and enhanced geothermal systems have improved heat recovery while reducing environmental impacts and operational risks (Horne *et al.*, 2025; Zhu, 2025). Continuous geomechanical monitoring and risk-informed operational practices are increasingly adopted to mitigate induced seismicity and maintain safe reservoir operation, particularly in deep and engineered geothermal systems (De Santis *et al.*, 2026). Collectively, these integrated management strategies enhance reservoir resilience, maximize resource utilization, and support the sustainable development of geothermal energy in sedimentary basins.

Integration with Existing Energy Infrastructure

Integrating geothermal energy with existing energy infrastructure enhances resource utilization, improves system flexibility, and supports the transition to low-carbon energy systems. Unlike intermittent renewable sources, geothermal energy provides continuous baseload power and heat, making it well suited for integration with electricity grids, district heating networks, industrial facilities, and agricultural operations (Dickson and Fanelli, 2013; IEA, 2024). Such integration maximizes the value of geothermal resources while improving overall energy system reliability. In sedimentary basins, geothermal development increasingly exploits existing subsurface infrastructure to reduce capital costs and accelerate project deployment. Abandoned hydrocarbon wells, depleted oil and gas reservoirs, and mining infrastructure can be repurposed for geothermal production, minimizing drilling requirements and extending the productive use of existing assets (Ma *et al.*, 2025). This approach also facilitates the co-development of geothermal energy with conventional energy systems, creating economically attractive pathways for sustainable energy transition (Vatanpour *et al.*, 2026). Recent advances in digital energy management, integrated reservoir modelling, and efficient heat extraction technologies have further strengthened geothermal integration within modern energy networks. Coupling geothermal systems with heat pumps, thermal energy storage, and hybrid renewable energy systems improves operational flexibility, seasonal energy balancing, and overall system efficiency (Zhu, 2025). In parallel, enhanced geothermal systems and advanced reservoir engineering expand the range of exploitable resources, enabling geothermal energy to complement existing infrastructure across diverse geological settings (Horne *et al.*,

2025; Yuan *et al.*, 2025). Consequently, integrated development strategies improve economic competitiveness,

enhance energy security, and support the long-term decarbonization of electricity and heat supply.

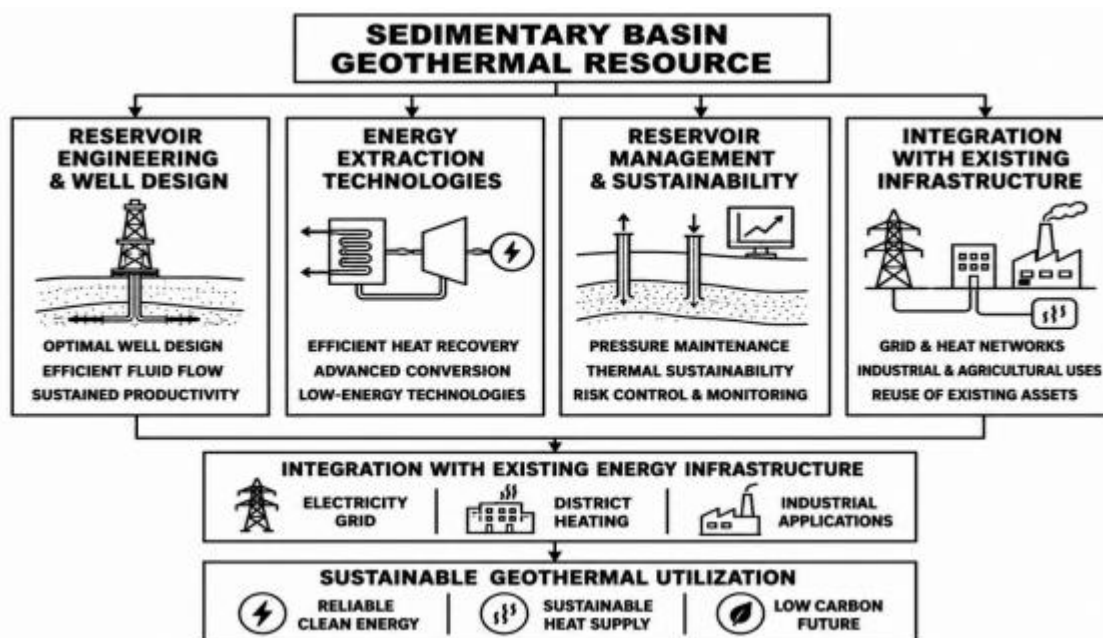


Figure 2. Integrated development strategies for sustainable geothermal utilization in sedimentary basins. The figure summarizes the integration of reservoir engineering, energy extraction technologies, reservoir management, and existing energy infrastructure to maximize geothermal recovery, improve operational efficiency, and ensure long-term sustainable utilization of sedimentary basin resources Source: [Horne *et al.* \(2025\)](#)

Challenges, Opportunities, and Future Perspectives

Despite significant advances in geothermal exploration and development, several technical and economic challenges continue to constrain the large-scale utilization of sedimentary basin geothermal resources. Reservoir heterogeneity, uncertainty in permeability distribution, temperature prediction, and long-term reservoir performance remain major technical limitations that increase exploration and development risks ([Birdsell *et al.*, 2024](#); [Khan *et al.*, 2025](#)). Deep drilling, well completion, and reservoir stimulation also

represent substantial capital investments, often accounting for the largest proportion of project costs and contributing to financial uncertainty, particularly during the early stages of development ([Horne *et al.*, 2025](#); [IEA, 2024](#)). Furthermore, limited subsurface data, inadequate infrastructure, and restricted access to investment capital continue to hinder geothermal deployment in many emerging economies despite the widespread occurrence of sedimentary basin resources ([Ashagrie and Admasie, 2024](#); [Elshehabi and Alfehaid, 2025](#)). Nevertheless, advances in artificial intelligence, integrated reservoir modelling, and multidisciplinary exploration workflows are progressively reducing geological uncertainty, improving drilling success, and enhancing project feasibility ([AlGaier *et al.*, 2024](#); [Llanos and Blessent, 2025](#)).

The sustainable expansion of geothermal energy also depends on effective environmental management and supportive regulatory frameworks. Although geothermal energy has a substantially lower environmental footprint than conventional fossil fuels, responsible development requires careful management of groundwater resources, induced seismicity, land use, scaling, corrosion, and fluid reinjection to maintain long-term reservoir integrity and public acceptance ([Menberg *et al.*, 2025](#); [De Santis *et al.*, 2026](#)). Regulatory uncertainty, lengthy permitting procedures, and inconsistent policy incentives further delay project implementation in several regions, emphasizing the need for harmonized regulatory frameworks that balance environmental protection with investment attractiveness ([Meirbekova *et al.*, 2024](#); [IEA, 2024](#)). Strengthening environmental monitoring, adopting risk-based reservoir management, and promoting transparent stakeholder engagement will therefore be essential for ensuring sustainable geothermal development while maintaining social and environmental responsibility.

Future geothermal development will increasingly be driven by technological innovation and integrated energy system planning. Emerging technologies, including enhanced geothermal systems, advanced drilling techniques, digital reservoir management, coupled thermo-hydraulic-mechanical modelling, and low-energy heat extraction processes, are expanding the technical and economic viability of both conventional and previously inaccessible geothermal resources ([Horne *et al.*, 2025](#); [Zhu, 2025](#); [Vatanpour *et al.*, 2026](#)). The

integration of geothermal energy with thermal energy storage, district heating, industrial processes, and existing oil, gas, and mining infrastructure further enhances resource utilization and supports energy system decarbonization (Ma *et al.*, 2025; IEA, 2024). Future research should prioritize high-resolution reservoir characterization, intelligent exploration and production optimization, sustainable reservoir management, innovative well technologies, and supportive policy frameworks that accelerate commercial deployment while ensuring long-term resource sustainability. Collectively, these priorities provide a clear pathway for transforming sedimentary basin geothermal resources into a resilient, economically competitive, and environmentally sustainable component of the global clean energy transition.

Conclusion

Sedimentary basins represent a significant and widely distributed geothermal resource capable of supporting sustainable heat and power generation. Their successful development depends on the integration of robust geological characterization, advanced exploration techniques, effective reservoir engineering, efficient energy extraction technologies, and adaptive reservoir management to maximize resource recovery while ensuring long-term operational sustainability. Recent advances in digital modelling, artificial intelligence, enhanced geothermal systems, and integrated energy infrastructure have expanded the technical and economic potential of these resources, enabling broader utilization across diverse geological settings. Although challenges related to subsurface uncertainty, drilling costs, environmental management, and regulatory frameworks remain, continued technological innovation and multidisciplinary collaboration are steadily improving project feasibility and reducing development risks. Advancing these integrated strategies will strengthen the role of sedimentary basin geothermal resources in enhancing energy security, supporting decarbonization, and accelerating the global transition toward resilient, low-carbon energy systems.

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Conflict of Interest

The authors declared that there are no conflicts of interest.

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References

- AlGaier, M., Hossain, M., Petrovski, A., Lashin, A. and Faisal, N. (2024). Applications of artificial intelligence in geothermal resource exploration: A review. *Deep Underground Science and Engineering*. 3(3): 269–285. <https://doi.org/10.1002/dug2.12122>
- Ashagrie, T. A. and Admasie, A. T. (2024). Opportunities, challenges and future perspectives of geothermal energy in Ethiopia: A review. *EAI Endorsed Transactions on Energy Web*. 11(1). <https://doi.org/10.4108/ew.4863>
- Banks, D. (2012). *An Introduction to Thermogeology*. Ground Source Heating and Cooling. Wiley-Blackwell Publishing, Oxford. <http://dx.doi.org/10.1002/9781118447512>
- Beardsmore, G. R. (2025). A review of hot sedimentary aquifer geothermal resources in Australia. *New Zealand Journal of Geology and Geophysics*. 68(3): 378–398. <https://doi.org/10.1080/00288306.2024.2374065>
- Birdsell, D. T., Adams, B. M., Deb, P., Ogland-Hand, J. D., Bielicki, J. M., Fleming, M. R. and Saar, M. O. (2024). Analytical solutions to evaluate the geothermal energy generation potential from sedimentary-basin reservoirs. *Geothermics*. 116:102843. <https://doi.org/10.1016/j.geothermics.2023.102843>
- Cao, X., Poh, J., Singh, R. M. and colleagues. (2026). Geophysical and geomechanical characterization of deep geothermal reservoirs: A critical review. *Renewable and Sustainable Energy Reviews*. <https://doi.org/10.1016/j.rser.2026.117293>
- Castillo-Reyes, O., Prol-Ledesma, R. M., Corbo-Camargo, F. and Rojas, O. (2024). Geothermal resources in Latin America and their exploration using electromagnetic methods. *Geothermal Energy*. 12: 34. <https://doi.org/10.1186/s40517-024-00314-5>
- De Santis, F., Klein, E., Thoraval, A. and Maury, J. (2026). Patterns and controls of induced seismicity in geothermal reservoirs: Insights from case studies and implications for hazard assessment and mitigation. *Geothermics*. 139: 103665. <https://doi.org/10.1016/j.geothermics.2026.103665>
- Dickson, M.H. and Fanelli, M. (2013). *Geothermal Energy: Utilization and Technology*. Routledge, London. <https://doi.org/10.4324/9781315065786>
- Elshehabi, T. and Alfehaid, M. (2025). Sustainable Geothermal Energy: A Review of Challenges and Opportunities in Deep Wells and Shallow Heat Pumps for Transitioning Professionals. *Energies*. 18(4): 811. <https://doi.org/10.3390/en18040811>
- Gardner, R. and Birdwell, J. E. (2023). Hidden system identification: Basin modeling as a tool for examining sedimentary geothermal resource potential. In *Proceedings of the Geothermal Rising Conference*. 47:1407–1414. *Geothermal Rising*
- Grant, M. A. and Bixley, P. F. (2011). *Geothermal Reservoir Engineering* (2nd ed.). Academic Press. DOI:10.1016/C2010-0-64792-4
- Horne, R., Genter, A., McClure, M., Ellsworth, W., Norbeck, J. and Schill, E. (2025). Enhanced geothermal systems for clean firm energy generation. *Nature Reviews Clean Technology*. 1: 148–160. <https://doi.org/10.1038/s44359-024-00019-9>
- IEA (2024). *The Future of Geothermal Energy*, IEA, Paris. <https://www.iea.org/reports/the-future-of-geothermal-energy>
- Khan, F., Raza, A., Mahmoud, M., Patil, S. and Al Shafloot, T. (2025). A Comprehensive Review of Geothermal Reservoirs: Current Understanding and Future Outlook. *Arabian Journal for Science and Engineering*. 50(18): 14415-14439. <https://doi.org/10.1007/s13369-025-10246-2>
- Kolawole, F. and Evenick, J. C. (2023). Global distribution of geothermal gradients in sedimentary basins. *Geoscience Frontiers*. 14(6): 101685. <https://doi.org/10.1016/j.gsf.2023.101685>
- Kolo, I., Brown, C. S., Nibbs, W., Cai, W., Falcone, G. and Nagel, T. (2024). A comprehensive review of deep borehole heat exchangers (DBHEs): Subsurface modelling studies and applications. *Geothermal Energy*. 12: 19. <https://doi.org/10.1186/s40517-024-00297-3>

- Kumar, L., Hossain, M. S., Assad, M. E. H. and Manoo, M. U. (2022). Technological Advancements and Challenges of Geothermal Energy Systems: A Comprehensive Review. *Energies*. 15(23): 9058. <https://doi.org/10.3390/en15239058>
- Limberger, J., Boxem, T., Pluymaekers, M. P. D., Bruhn, D. F., Manzella, A., Calcagno, P. *et al.* (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renewable and Sustainable Energy Reviews*. 82: 961–975. <https://doi.org/10.1016/j.rser.2017.09.084>
- Llanos, E. M. and Blessent, D. (2025). A scoping review of numerical modelling studies of geothermal reservoirs: Trends and opportunities post-COP25. *International Journal of Renewable Energy Development*. 14(4):668–693. <https://doi.org/10.61435/ijred.2025.61071>
- Lu, J., Li, C., Wang, M. and Zhang, C. (2023) Review of deep fluids in sedimentary basins and their influence on resources, with a focus on oil and geothermal exploitation. *Front. Earth Sci.* 10:896629. doi: 10.3389/feart.2022.896629
- Ma, D., Gao, X. and Zhang, J. (2025). Co-exploitation of mine-derived geothermal energy: Recent advances and emerging perspectives. *GeoEnergy Communications*. 1:12. <https://doi.org/10.1007/s44421-025-00013-2>
- Meirbekova, R., Bonciani, D., Olafsson, D. I., Korucan, A., Derin-Güre, P., Harcouët-Menou, V. and Bero, W. (2024). Opportunities and challenges of geothermal energy: A comparative analysis of three European cases—Belgium, Iceland, and Italy. *Energies*. 17(16): 4134. <https://doi.org/10.3390/en17164134>
- Menberg, K., Hemmerle, H., Bayer, P., Bott, C., Bidarmaghaz, A., Ferguson, G. *et al.* (2025). Opportunities, benefits and impacts of shallow geothermal energy. *Nature Reviews Earth & Environment*. 6: 808–823. <https://doi.org/10.1038/s43017-025-00736-0>
- Meryem, R., Hind, K., Faouziya, H., Othman, S., Berkati N. E. and Mohammed, R. (2024). A state-of-the-art review on geothermal energy exploration in Morocco: Current status and prospects. *Deep Underground Science and Engineering*. 3(3): 302–316. <https://doi.org/10.1002/dug2.12116>
- Moeck, I. S. (2014). Catalog of geothermal play types based on geologic controls. *Renewable and Sustainable Energy Reviews*. 37: 867–882. <https://doi.org/10.1016/j.rser.2014.05.032>
- Nwaiwu, U., Leach, M. and Liu, L. (2023). Development of an improved decision support tool for geothermal site selection in Nigeria based on comprehensive criteria. *Energies*. 16(22): 7602. <https://doi.org/10.3390/en16227602>
- Procesi, M., Ciotoli, G., Mazzini, A. and Etiope, G. (2019). Sediment-hosted geothermal systems: Review and first global mapping. *Earth-Science Reviews*. 192: 529–544. <https://doi.org/10.1016/j.earscirev.2019.03.020>
- Rasheed, A., Wahid, A., Janjuhah, H. T., Hameed, F., Ali, S. H., Riaz, M. T. *et al.* (2026). GIS-, geochemistry-, and geophysics-based identification of geothermal energy resources in sedimentary basins: A case study of the Zindapir Anticlinorium Zone, Eastern Sulaiman Fold and Thrust Belt, Pakistan. *Frontiers in Earth Science*. 13: 1644690. DOI:10.3389/feart.2025.1644690
- Redouane, M. (2025). Overview of geothermal resource exploration and development in North Africa. *Deep Underground Science and Engineering*. 4(4): 673–685. <https://doi.org/10.1002/dug2.70042>
- Vatanpour, A., Nikooee, E. and Hataf, N. (2026). Geothermal energy as a sustainable energy resource: A review of mechanisms and systems of its extraction and storage. *Geoenergy Science and Engineering*. <https://doi.org/10.1016/j.geoen.2026.214563>
- Yuan, Y., Zhang, X., Yu, H., Zhong, C., Wang, Y., Wen, D. *et al.* (2025). Research Progress and Technical Challenges of Geothermal Energy Development from Hot Dry Rock: A Review. *Energies*. 18(7): 1742. <https://doi.org/10.3390/en18071742>
- Zayed, M. E., Shboul, B., Yin, H., Zhao, J. and Zayed, A. A. A. (2023). Recent advances in geothermal energy reservoirs modeling: Challenges and potential of thermo-fluid integrated models for reservoir heat extraction and geothermal energy piles design. *Journal of Energy Storage*. 62:106835. <https://doi.org/10.1016/j.est.2023.106835>
- Zhu, D. (2023). New Advances in Oil, Gas, and Geothermal Reservoirs. *Energies*. 16(1):477. DOI:10.3390/en16010477
- Zhu, D. (2025). New Advances in Low-Energy Processes for Geo-Energy Development. *Energies*. 18(9):2357. <https://doi.org/10.3390/en18092357>

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