

A Review Of Sustainable Development Of Geothermal Energy

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ABSTRACT

Renewable energy is undoubtedly more environmentally friendly because it can reduce air pollution and environmental damage due to exploration. The costs incurred in producing energy are lower because the energy source is free. Electricity is essential now, but the obstacle faced is reducing and replacing fossil energy because continuously using it will hurt the world. The best solution is to replace it with new renewable energy, such as geothermal energy, which has great potential in Indonesia. This research was conducted using a qualitative descriptive research method. The data used in this study were taken through in-depth interviews with an expert and a literature study from various relevant sources. The data was collected through in-depth interviews based on the IAEA's Sustainable Development Energy Indicator framework, which Prof. Thierry Lefèvre simplified. The results of the in-depth interviews are then combined with relevant data and literature.

Keywords: *electricity; fossil energy; geothermal energy*

INTRODUCTION

Electricity is needed in industries and households because the supply of electricity is the key to those activities. This condition causes dependence on the availability of electrical energy, which is increasing daily. Considering that Indonesia is still dependent on fossil energy, it will harm climate change if it continues to be used. Indonesia is blessed with abundant renewable energy potential, such as geothermal energy. The most considerable geothermal potential in the world is 29,038 Mw. This is due to its geographical position in the Ring of Fire area, which generally holds a significant potential for exploiting geothermal energy for electricity generation.

To overcome the energy supply crisis and the impact of environmental damage due to global warming, can switch to alternative energy sources, namely renewable energy, which is more environmentally friendly. Indonesia is blessed with abundant renewable energy potential, such as geothermal energy. Therefore, this literature review aimed to discover that geothermal energy has the potential to be an alternative to fossil energy sources that produce environmental impacts in the form of CO₂ greenhouse gas emissions.

Indonesia ranks first in the country with the largest geothermal potential in the world, where this energy potential is spread across 285 locations along volcanic areas. The potential for geothermal energy in Indonesia is significant, making it possible to develop and utilize it as a power plant. After the enactment of Government Regulation Number 24 of 2018 concerning Electronically Integrated Business Licensing, the Indonesian bureaucratic system wants

an integrated permit to increase investment so that the debureaucration process also exists in geothermal permits. Centralization of geothermal permits issued by the government for all phases of geothermal exploitation involves more than one scope of authority of the ministry by attribution. It is delegated to the coordinating board for investment. This centralization then created problems with government coordination with local governments and communities. Another paradigm that emerged was related to the enactment of the manpower act, which changed the provisions of the geothermal law with the classification of permits based on risk. The aim is to describe licensing problems in Indonesia's geothermal sector for indirect use.

This study uses a juridical-normative approach with descriptive-exploratory research specifications. In research prioritizing Indonesia, a specific authority body that provides risk assessment assessments based on the classification of its business activities is recommended. This assessment then becomes a consideration for granting permits or approvals related to the environment.

METHODS

This research was conducted using a qualitative descriptive research method. The data used in this study were gathered through a literature review from various relevant sources.

RESULTS AND DISCUSSION

Based on the description of the method above, 30 (Thirty) scientific articles were selected as the main articles to answer the research objectives in this paper. From this article, the authors found several things to conclude (a)

Sustainable development of geothermal energy, (b) Renewable energy in sustainable development, (c) What is the impact of geothermal potential on the climate in the future,

(d) Moreover, geothermal development, is shown in Table 1.

Table 1. Research on the potential, utilization, and impact of geothermal energy.

Article Title	Authors, Year	Paper description
<i>Pengembangan energi panas bumi yang berkelanjutan</i> (Sustainable development of geothermal energy)	El Fandari A, et al 2014	Sustainable development of geothermal energy in Indonesia. This article highlights the country's growing demand for electricity and the need for renewable energy sources. Indonesia has great potential for geothermal energy, but its utilization is still limited. This article also mentions the challenges and obstacles in developing geothermal energy, such as policy and regulatory issues, coordination between sectors, and technical issues. This article concludes by emphasizing the importance of sustainable geothermal energy development in Indonesia.
<i>Energi terbarukan dalam pembangunan berkelanjutan</i> (Renewable energy in sustainable development)	Lubis Abubakar, 2017	The importance of renewable energy in achieving sustainability and reducing dependence on fossil fuels. Policy steps that can be taken to promote renewable energy include energy conversion, energy certification, and energy intensification.
<i>Potensi dan pemanfaatan energi panas bumi di Indonesia.</i> (Potential and utilization of geothermal energy in Indonesia)	Hakim, 2022	Indonesia first ranks as the country with the most extensive geothermal potential in the world, where this energy potential is spread across 285 locations along volcanic areas. The potential for geothermal energy in Indonesia is significant, making it possible to develop and utilize it as a power plant.
<i>Pembangkit listrik tenaga panas bumi(PLTP) dan kendala pembangunannya</i> (Geothermal power plants and obstacles to their development)	Joko D.L., 2015	Challenges and obstacles in developing geothermal power plants in Indonesia: One of the main challenges is obtaining environmental permits because geothermal locations are usually located in protected forest areas. Local communities also resist because they are worried about the negative impact on the ecosystem and the reduction of their water supply.
<i>Tinjauan terhadap pengembangan potensi panas bumi blawan-ijen,jawa timur</i>	Riski L.S. and Haeruddin, 2021	Based on the analysis of samples in the Ijen area, the southwestern part of Kawah Ijen is an outflow area characterized by low Cl content, high SO ₄ content, and high HCO ₃ content.

(Review of the development of geothermal potential in Blawan-Ijen, East Java)

Indonesia has a significant geothermal potential, including the Blawan-Ijen area, which is indicated by the presence of hot springs and solfataras. Exploration using remote sensing, geophysics, geochemistry, and drilling has further confirmed the geothermal potential in this area.

The Blawan-Ijen geothermal power plant operation was initially planned for 2018 but has been delayed multiple times. According to the latest plan, the power plant is targeted to start operating in 2021, with a capacity of 55 MW. Comprehensive studies are needed to ensure the utilization of geothermal potential according to the planned timeline.

Geothermal energy development in the Blawan-Ijen area will have social, economic, and environmental impacts. It requires high investment costs, high risks, and modern technology. Strong collaboration between the government, stakeholders, and the community is necessary to realize the development of geothermal potential as a 2x55 MW power plant and to ensure positive impacts on the development of the Bondowoso district and its surrounding areas.

Potensi dan Tantangan Badan Layanan Umum di Bidang Penelitian dan Pengembangan Panas Bumi
(Potential and Challenges of Public Service Agencies in Geothermal Research and Development)

Lia Putriyana, et al
2018

Based on the analysis and discussion in this study, geothermal research and development (R & D) in Indonesia faces various challenges, including regulatory issues, mindset changes, and limited competencies. However, the potential for geothermal utilization is still significant, as the current utilization is minimal compared to the available reserves. The transition to a Public Service Agency (PSA) status provides bureaucratic advantages for geothermal R&D activities. The recommended strategies for geothermal R&D PSA include anticipating negative impacts through reservoir simulation studies, conducting environmental impact assessments (EIA), providing sound analysis services, and promoting direct utilization of geothermal energy.

Penyuluhan kegiatan pengembangan panas bumi cluster a di desa touure 1 kecamatan tompaso kabupaten minahasa propinsi Sulawesi Utara

Hendra R. G.,
2019

Based on the conducted seminar and scientific study, it can be concluded that there is a best solution between the community and PT. PGE in the development of unit 8 geothermal power plant. The project can proceed without negatively impacting the natural water sources

<p>(Counselling on cluster A geothermal development activities in Toure 1 village, Tompaso sub-district, Minahasa district, North Sulawesi Province)</p>		<p>used by the residents of Toure 1. The minimization of land use for the project and the provision of alternative land for horticulture farming are not only compensated with monetary compensation but also aim to ensure the sustainable livelihoods of the community. This outcome aligns with the strategic goals of Unsrat, which include maintaining the main livelihoods or increasing the income of the village community through horticulture farming.</p>
<p><i>Merekonstruksi Arah Politik Hukum Pengembangan Perizinan Panas Bumi untuk Pemanfaatan Tidak Langsung</i></p> <p>(Reconstructing the Political and Legal Direction of Geothermal Licensing Development for Indirect Use)</p>	<p>Dara S, et al., 2021</p>	<p>After the enactment of Government Regulation Number 24 of 2018 concerning Electronically Integrated Business Licensing, the Indonesian bureaucratic system wants an integrated permit to increase investment so that the debureaucratization process also exists in geothermal permits. Centralization of geothermal licenses issued by the government for all phases of geothermal exploitation involves more than one scope of authority of the ministry by attribution. It is delegated to the coordinating board for investment. This centralization then created problems with government coordination with local governments and communities. Another paradigm that emerged was related to the enactment of the Human Resources Act, which changed the provisions of the geothermal law with the classification of permits based on risk, and the authors conducted a comparative study of similar arrangements in other countries, such as the Netherlands and Australia. The aim is to describe licensing problems in Indonesia's geothermal sector for indirect use. This study uses a juridical-normative approach with descriptive-exploratory research specifications. In research prioritizing, Indonesia should have a specific authority body that provides risk assessments based on the classification of its business activities. This assessment then becomes a consideration for granting permits or approvals related to the environment.</p>
<p><i>Kerjasama indonesia – islandia dalam pengembangan energi panas bumi (geothermal) periode 2012-2016</i></p>	<p>Larasati N, 2018</p>	<p>Indonesia's energy conditions continue to use fossil fuels, which will evaporate later, making the government think of alternative energy sources, such as geothermal energy, which is still available in Indonesia. To maximize</p>

(Indonesia – Iceland cooperation in developing geothermal energy for the 2012-2016 period)

geothermal development efforts, Indonesia cooperates with Iceland, which has successfully used geothermal energy as its domestic demand. Indonesia-Iceland Cooperation form in Geothermal Development period 2012-2016, in the form of technical assistance through the UNU-GTP program and investment that make the two countries more closely linked and reach their respective.

Pengembangan strategi pada aktivitas rantai nilai panas bumi (Studi Pada PT Geo Dipa Energi (Persero))

Maharani A.H et al.,
2019

(Strategy development in geothermal value chain activities (Study at PT Geo Dipa Energi (Persero))

Indonesia's geothermal potential is the second largest in the world. However, the magnitude of its geothermal potential has yet to be utilized optimally. With investments and risks that are pretty high and a relatively long period, investors only invest a little in this energy sector. Especially with the presence of a single buyer, in this case PT PLN (Persero). The power purchase agreement between developers and PT PLN (Persero) remains the biggest obstacle to geothermal power plant development. This study aims to formulate an appropriate strategy priority used by PT Geo Dipa Energi (Persero) in producing the optimal cost of generating electricity based on Minister of Energy and Mineral Resources Regulation Number 50 of 2017 concerning the Utilization of Renewable Energy Sources for Electricity Supply. Data collection uses judgment sampling techniques. External environmental analysis is carried out through PESTLE analysis, while internal ecological analysis is carried out through value chain analysis. TOWS analysis is conducted to provide alternative strategies, and alternative strategies will be prioritized using AHP analysis. The study results produced the chosen strategy priority: to conduct intensive coordination with PT PLN (Persero) in negotiations to develop a new prospect area.

Tantangan Pengembangan Energi Panas Bumi Dalam Perannya terhadap Ketahanan Energi di Indonesia
(Challenges of Geothermal Energy Development in Its Role in Energy Security in Indonesia)

Mukhamad F.U.,
2018

Through the Presidential Regulation of the Republic of Indonesia Number 5 of 2006, the Government of Indonesia has set a target to achieve an optimal energy mix by 2025, where the role of renewable energy in national energy consumption will be around 17%. In the composition of renewable energy, geothermal energy sources account for more than 5% of the total. The target of this energy mix is to secure domestic energy supply, although it does not mention whether this target is also related to

		<p>environmental issues. Unfortunately, geothermal energy, one of the primary energy sources in the renewable energy category, has yet to be optimally utilized in this country. Since the first geothermal power plant, Kamojang-1 was inaugurated in 1983 to 2017, Indonesia has only succeeded in using geothermal energy around 6% of the total national potential. Through a literature review, this study aims to summarize the challenges the Indonesian state faces in encouraging the use of geothermal energy to achieve the government's target in 2025.</p>
<p><i>Geothermal Energy</i> (Energi Panas Bumi)</p>	<p>Manzella A, 2017</p>	<p>Geothermal energy is the thermal energy stored underground, including any fluid available for extraction and conversion into energy products. Electricity generation, which nowadays produces 73.7TWh (12.7GW of capacity) worldwide, usually requires geothermal resources temperatures of over 100 ° C. For heating, geothermal resources spanning a more comprehensive range of temperatures can be used in applications such as space and district heating (and cooling, with proper technology), spa and swimming pool heating, greenhouse and soil heating, aquaculture pond heating, industrial process heating, and snow melting. Geothermal heat worldwide accounts for 164.6TWh, with a capacity of 70.9 GW. Geothermal technology, which has focused for decades on ex-tracking naturally heated steam or hot water from natural hydrothermal reservoirs, is developing more advanced techniques to exploit the heat where underground fluids are scarce and to use the Earth as a potential energy battery by storing heat. The success of the research will enable energy recovery and utilization from a much more significant fraction of the accessible thermal energy in the Earth's cru.</p>
<p><i>(Advantages, Challenges, and Recommendations Policies for Geothermal Energy Development in Indonesia)</i> <i>Keunggulan, Tantangan, dan Rekomendasi</i></p>	<p>Wisriansyah, S.Z et al., 2021</p>	<p>this study discusses the biggest obstacle causing the sluggish development of geothermal power plants and is also expected to give the government strategic recommendations to solve this. The result of this study shows that the biggest obstacle in developing geothermal power plants lies in the exploration phase. The government of Indonesia has taken some actions to support the exploration phase. However, this</p>

<p><i>Kebijakan akan Pengembangan Energi Panas Bumi di Indonesia</i></p>		<p>study believes there are still some solutions the government needs to take to support geothermal exploration in Indonesia, such as establishing a geothermal exploration entity and funding the exploration phase. These recommendations are expected to help the government achieve 7200 MW by 2025.</p>
<p><i>Mapping the spatial distribution of fossil geothermal manifestations and assessment of the geothermal potential of the Tangyin rift, Southeast of Taihang Mountain in China</i></p>	<p>Mahwa J, et al. 2022</p>	<p>Lastly, all the thematic layers of geothermal factors were reclassified, ranked, and integrated by the weight overlay logic model based on the influence of geothermal suitability to map potential areas for geothermal resources, whereby five zones were obtained ranging from very poor to very good. The promising potential sites are mostly found along the intense structures of the significant Tangxi fault, crosscutting the permeable lithology of carbonate rocks and around the Hebi volcanoes. The distribution of hot springs and geothermal wells of the Hebi field were correlated and verified against the potential geothermal anomalies map. The overall integrated method proposes an advanced technique for designing the Tangyin Rift's exploration plan and development actions for geothermal resource utilization, which can be used to explore any unveiling geothermal potential sites.</p>
<p><i>(The Potential of Geothermal Energy, Wind, and Biomass Becomes Electrical Energy in Indonesia) Potensi Energi Panas Bumi, Angin, Dan Biomassa Menjadi Energi Listrik Di Indonesia</i></p>	<p>Nurul A. A., 2020</p>	<p>Installed capacity towards the 2019-2028 energy plan of geothermal, wind, and biomass, wind energy or PLTB has the most significant percentage at 82.76%. Followed by geothermal with a value of 25.31% and biomass with a value of 4.92%. So, in 2020, NRE could not reach the target set by the government. Many factors hinder the achievement, such as funding factors, planning coordination, and implementation difficulty. Coupled with the COVID-19 pandemic, which is still occurring, the implementation is slowing down. This makes the budget diverted to focus on handling the pandemic. Indirectly, the budget for energy projects becomes increasingly hampered in their development. The energy policy still in use today has not efficiently impacted Indonesia's development of renewable energy. It needs research and further and thorough discussion, too.</p>
<p><i>Analysis of Indirect Utilization of Thermal Energy Potential</i></p>	<p>Pradipta A, et al. 2021</p>	<p>Indonesia is committed to developing new and renewable energy, which is listed in laws,</p>

<p><i>Earth in Indonesia (Analisis Pemanfaatan Tidak Langsung Potensi Energi Panas Bumi di Indonesia)</i></p>		<p>government, presidential, ministers, and other supporting regulations. The purpose of this analysis is to find out how to utilize the potential of geothermal energy in Indonesia indirectly. With geographical conditions, Indonesia is located in the Ring of Fire zone, so most of the system is of the volcanic type (hydrothermal system), which causes each field to have great potential. Potential This makes it the government's priority to achieve the most new and renewable energy mix, which will be a little 23% in 2025 and 31% in 2050. The government determines the policy direction and strategic plan listed in the Energy General Plan National (RUEN) to achieve this target. Geothermal energy can be utilized according to the potential power that can be produced, namely PLTP.</p>
<p><i>Potential and Utilization of Geothermal Energy in Indonesia. (Potensi dan Pemanfaatan Energi Panas Bumi di Indonesia)</i></p>	<p>Auzan F. H., 2022</p>	<p>Indonesia is an area that has enormous geothermal potential, supported by Indonesia's location, which is in a volcanic ring. Almost all regions in Indonesia have geothermal resources that can be utilized as a substitute for fossil fuels. Utilizing geothermal resources that are converted into energy will reduce pollution in the environment. This study examines geothermal potential in Indonesia and how geothermal energy is utilized in areas with geothermal potential. The preparation of this article uses a qualitative research method with the approach used in the form of a literature study. Data was collected by studying more than 25 previous articles used as references. The literature study showed that Indonesia has geothermal potential spread over Java, Sumatra, Kalimantan, Sulawesi, Maluku, and Papua. Most of the geothermal energy is utilized on these islands for power plants. However, geothermal potential is still not used in some areas.</p>
<p><i>Robust geothermal investment decisions under uncertainty: An exploratory financial modeling and analysis approach (Keputusan investasi panas bumi yang kuat di bawah ketidakpastian: Pendekatan pemodelan dan analisis keuangan eksplorasi)</i></p>	<p>Samuel A, et al., 2025</p>	<p>The inherent uncertainty in geothermal projects, high upfront development costs, and insufficient incentives pose significant barriers for investors in achieving returns commensurate with the extensive risks. Therefore, addressing key uncertainties in highly risky phases of geothermal development, such as exploration and exploitation, is needed to pursue the right strategy to minimize the risk of failed investments and increase appropriateness for</p>

budget allocation. Using Indonesia's geothermal projects as a case study, this research proposes an exploratory financial modeling and analysis approach to investigating key uncertainties in geothermal projects by combining real options and exploratory modeling. Feature scoring identifies four key uncertainties in the exploration phase (electricity price, fluid dryness, exploration drilling cost, capacity factor) and three in the exploitation phase (production sound ratio and costs of development and injection wells). Meanwhile, dimensional stacking explores potential robust scenarios. For instance, this study reveals that when the electricity price is limited to 8.36 cents/kWh, achieving fluid dryness above 22 % and exploration drilling costs below \$8.14 million are crucial for ensuring robustness. Under more unfavorable conditions, real options can loosen the robustness thresholds by incorporating managerial options into asset valuation, thereby avoiding early abandonment of the project.

Current status and advancement from high yield and oilfield geothermal energy production: A systematic review (Status dan kemajuan saat ini dari produksi energi panas bumi dan hasil tinggi dan ladang minyak: Tinjauan sistematis)

Abubakar M. et al.,
2025

This review comprehensively assesses the current state and advancements in geothermal energy production from enhanced geothermal systems and oilfields. As the emphasis on developing a sustainable environment intensifies, it is crucial to use energy sources judiciously. Adopting renewable energy technologies is essential to establishing energy systems that are significantly more sustainable than the current reliance on fossil fuels. Over the past few decades, research has demonstrated that harnessing geothermal energy and improving existing geothermal systems' efficiency are effective strategies for addressing energy challenges. Although geothermal energy, particularly from enhanced geothermal systems and oilfields, has certain limitations relative to other renewable sources, it offers significant advantages by reducing environmental impacts and lowering emissions of harmful gases. The current study reveals that at least 18 enhanced geothermal systems sites have been in operation, with approximately 40 years of development experience in several case studies and pilot projects related to oilfield geothermal energy. As of 2023, the total

		<p>installed capacity of geothermal energy worldwide stands at 14,846 megawatts. The past decade has seen significant improvements in geothermal energy extraction techniques. Geothermal energy is poised to play a pivotal role in the global energy transition, offering a reliable and low-emission energy source essential for achieving long-term sustainability goals.</p>
<p><i>Exploring geothermal energy-based systems: Review from basics to innovative systems. (Menjelajahi sistem berbasis energi panas bumi: Tinjauan dari dasar hingga sistem pintar).</i></p>	<p>Belka A, et al., 2024</p>	<p>Most of the energy demand is currently supplied from fossil fuels, leading to greenhouse gas accumulation and air pollution. A sustainable future can be created globally through the efficient use of renewable energy sources. These sources include wind, solar, geothermal, biomass, and more. Geothermal energy can meet the energy needs of the future as a clean and reliable source and stands out due to certain distinctive features among renewable energy sources. Unlike other renewable energy sources, geothermal energy is not dependent on time or weather, making it a reliable and continuous energy supply. Additionally, it has a lower environmental impact. This review examines the development of geothermal energy systems and their integration into innovative technologies, highlighting the potential of geothermal energy for innovative energy systems. The focus is on integrating innovative systems into geothermal-based setups to enhance efficiency and analyze the state-of-the-art technologies of such systems. Geothermal-based systems are single-generation, co-generation, multigeneration, innovative energy systems, and energy hubs. Consequent to examining systems, it has been concluded that geothermal systems have considerable potential, but unfortunately, not all of them are used due to some difficulties. Its development will occur faster, and its share in the renewable energy sector will grow with smart system integration.</p>
<p><i>Geothermal development in South, Southeast and East Asia: A review. (Pengembangan panas bumi di Asia Selatan, Tenggara dan Timur: Sebuah tinjauan)</i></p>	<p>Jonathan P. et al., 2025</p>	<p>Global geothermal energy utilization for power generation and direct-use applications has increased over the past 25 years. Asia has the fastest growth in direct-use applications, suggesting a high demand for geothermal resources. This review seeks to fill a critical gap in the existing literature on geothermal development in South, Southeast, and East Asia.</p>

It covers geological background, government policy, technological advancement, and socio-economic factors. This review also provides each country's current geothermal energy usage and insights into government plans and initiatives to maintain and increase geothermal energy utilization. The countries have been categorized into low- and high-temperature resource countries, and their primary geothermal heat utilization has been identified. Countries trying to increase geothermal energy in their energy portfolios should continue to explore geothermal resources and develop a pool of local expertise to be rightly positioned to adopt these emerging technologies.

Advances in geothermal drilling: A comparative study of oil and gas techniques. (Kemajuan dalam pengeboran panas bumi: Studi komparatif dengan teknik minyak dan gas)

Fatemah Isania, et al., 2024

Geothermal energy is an essential clean and renewable resource that is reliable and has significant reserves not impacted by the weather or the seasons. However, many barriers exist to draw heat out of high-temperature geothermal reservoirs, especially regarding drilling, completion, and fracturing. Geothermal projects frequently include complex rock formations and high temperatures, challenging traditional petroleum drilling techniques. The cutting-edge technology for drilling in complex rock formations is the main topic of this review, with a special emphasis on developments in drill bits and drilling methods. Because of their strength and abrasiveness make complex rock formations like granite challenging to work with, resulting in increased operational costs and equipment wear quickly. Technological developments in drill bits are essential. Because of the high temperatures and hardness of the rock, conventional petroleum drill bits frequently break in geothermal wells. Technological advancements like thermally stable PDC bits and polycrystalline diamond compact (PDC) bits can enhance robustness and efficiency in harsh environments. Among the promising techniques are laser-assisted drilling and high-pressure water jet-assisted drilling. Drilling rates and bit longevity can be increased using high-pressure water jets to cool the drill bit and remove debris. To increase the effectiveness and economy of geothermal energy extraction, this review recommends that future research concentrate on new developments in drill bit

<p><i>Unlocking geothermal energy by repurposing abandoned wells as enhanced geothermal systems for sustainable heat production: A numerical investigation. (Membuka energi panas bumi dengan menggunakan kembali sumur yang ditinggalkan sebagai sistem panas bumi yang ditingkatkan untuk produksi panas yang berkelanjutan: Investigasi numerik)</i></p>	<p>Xincheng H. et al., 2025</p>	<p>technology, creative drilling methods, and the integration of real-time monitoring and adaptive control systems.</p> <p>Deep borehole heat exchangers (DBHEs) have garnered significant interest due to their potential to reduce costs and repurpose existing infrastructure in extracting geothermal energy from abandoned wells. However, their effectiveness is significantly constrained by the plummeting production temperature and limited power, leading to unsustainable heat production and restricting the practical applications of the extracted heat. Enhanced geothermal systems (EGSs) present a promising alternative to overcome these limitations associated with DBHEs. Despite this potential, previous studies on EGS developed from abandoned wells have mainly been conceptual, lacking quantification of geothermal potential and reliable field-data-based models. This research developed an EGS simulation model using an equivalent continuum method to address these gaps. It was verified with another EGS model that had explicit fractures using field data from abandoned wells in the Western Canadian Sedimentary Basin (WCSB). The study quantified the sustainable heat production potential from abandoned wells using EGS on a large scale, proving its broad application potential, from district heating to power generation. The production temperatures of EGSs in WCSB can still be over 80 °C even after 30 years, producing as much as 15.9×10^6 GJ heat. Optimizing reservoir and operational parameters within EGS presents a viable strategy for enhancing heat production from abandoned wells. Additionally, the research showed that a doublet EGS configuration was superior to a triplet system as it promotes more fluid flow distribution and mitigates preferential flow paths within the reservoir. These findings provide critical guidance for unlocking geothermal from abandoned wells by scaling up geothermal energy production using EGS.</p>
<p><i>Exploration of potential geothermal fields using GIS-based entropy method: A case study of the Sandikli.</i></p>	<p>Mustafa Y. et al., 2024</p>	<p>Geothermal energy has great potential among Turkey's sustainable energy sources. Especially the western regions of our country are the regions where these sources are intensified. The study area, Sandıklı district, is one of the regions</p>

(Eksplorasi medan panas bumi potensial menggunakan metode entropi berbasis GIS: Studi kasus Sandıklı)

west of Turkey with high geothermal energy. In the study, potential geothermal fields are tried to be explored in Sandıklı. Drainage density, slope, proximity to faults, geological indicators, and land surface temperature (LST) anomaly are used to determine the study area's geothermal potential based on literature research and experts' opinions. Within the scope of multi-criteria decision analysis (MCDA), a geothermal favorability map is created by synthesizing the layers formed with the weights that are calculated with the Entropy Method. The results of the entropy method were compared with the AHP results to evaluate their consistency and precision. It has been seen that the same potential geothermal areas were detected using both methods. Besides, the Entropy results were sharper and had higher sensibility. As a result of the study, Kusura, Çakır, Koçhisar, Başkuyucak, and Ekinhisar, extremely high geothermal potential regions, were proposed as new geothermal fields in the Sandıklı province.

Geothermal energy for sustainable development: A review of sustainability impacts and assessment frameworks. (Energi panas bumi untuk pembangunan berkelanjutan: Tinjauan dampak keberlanjutan dan kerangka penilaian).

Ruth S. et al, 2024

Sustainable development calls for the use of sustainable energy systems. However, how a geothermal resource is utilized will ultimately determine whether or not the utilization is sustainable. Energy usage will increase worldwide, and geothermal energy usage for electricity generation and heating will also increase significantly. The world's geothermal resources will need to be used sustainably. The sustainable utilization of geothermal energy means that it is produced and used in a way compatible with the well-being of future generations and the environment. This paper provides a literature review of the linkages between geothermal energy developments for electricity generation and sustainable growth and a review of currently available sustainability assessment frameworks. Significant impacts occur due to geothermal energy projects for electricity generation, and these impacts may be positive or negative. The need for correct management of such effects through a customized sustainability assessment framework is identified, and the foundation for sustainability assessment framework for geothermal energy development is built in this paper.

<p><i>Exploring the role of geothermal energy consumption in achieving carbon neutrality and environmental sustainability. (Menggali peran konsumsi energi panas bumi dalam mencapai netralitas karbon dan kelestarian lingkungan).</i></p>	<p>Ghalieb M. et al., 2024</p>	<p>While there is extensive research on the environmental impacts of renewable energy sources, a notable gap remains in understanding the specific environmental effects of geothermal energy. This knowledge shortfall is particularly critical for Indonesia, which holds the world's second-largest geothermal potential but has yet to harness these valuable resources effectively. This study aims to address this gap by providing a preliminary evaluation of the dynamic impact of geothermal energy consumption and various macroeconomic variables on carbon dioxide (CO₂) emissions in Indonesia from 1995 to 2020. The study employs the Fully Modified Ordinary Least Squares (FMOLS) method and conducts robustness checks using the Dynamic Ordinary Least Squares (DOLS) method. Our findings reveal that geothermal energy consumption, military expenditure, and technology innovation contribute to a reduction in CO₂ emissions, while non-renewable energy consumption increases CO₂ emissions. Additionally, the pairwise Granger causality test results indicate a unidirectional causality running from geothermal energy consumption to CO₂ emissions, suggesting that trends in geothermal energy use can reliably predict changes in CO₂ levels. This study provides valuable insights for policymakers and stakeholders in formulating sustainable policies for carbon reduction in Indonesia.</p>
<p><i>Unlocking geothermal energy by repurposing abandoned wells as enhanced geothermal systems for sustainable heat production: A numerical investigation. (Membuka energi panas bumi dengan menggunakan kembali sumur yang ditinggalkan sebagai sistem panas bumi yang ditingkatkan untuk produksi panas yang berkelanjutan: Investigasi numerik)</i></p>	<p>Xincheng H. et al., 2025</p>	<p>Deep borehole heat exchangers (DBHEs) have garnered significant interest due to its potential to reduce costs and repurpose existing infrastructure in extracting geothermal energy from abandoned wells. However, their effectiveness is significantly constrained by the plummeted production temperature and limited power, leading to unsustainable heat production and restricting the practical applications of the extracted heat. Enhanced geothermal systems (EGSs) present a promising alternative to overcome these limitations associated with DBHEs. Despite this potential, previous studies on EGS developed from abandoned wells have mainly been conceptual, lacking quantification of geothermal potential and reliable field-data-based models. This research developed an EGS simulation model using an equivalent</p>

continuum method to address these gaps. Another EGS model verified it with explicit fractures using field data from abandoned wells in the Western Canadian Sedimentary Basin (WCSB). The study quantified the sustainable heat production potential from abandoned wells using EGS on a large scale, proving its broad application potential, from district heating to power generation. The production temperatures of EGSs in WCSB can still be over 80 °C even after 30 years, producing as much as 15.9×10^6 GJ heat. Optimizing reservoir and operational parameters within EGS presents a viable strategy for enhancing heat production from abandoned wells. Additionally, the research showed that a doublet EGS configuration was superior to a triplet system as it promotes more fluid flow distribution and mitigates preferential flow paths within the reservoir. These findings provide critical guidance for unlocking geothermal from abandoned wells by scaling up geothermal energy production using EGS.

Optimizing sustainable energy systems: A comparative study of geothermal-powered desalination for green hydrogen production. (Mengoptimalkan sistem energi berkelanjutan: Studi komparatif desalinasi bertenaga panas bumi untuk produksi hidrogen hijau)

Nazanin C. et al.,
2025

The synergy between hydrogen and water is crucial for a sustainable energy future. This study explores integrating geothermal energy with desalination and hydrogen production systems to address water and clean energy demands. Two configurations were designed and compared, one using multi-effect distillation (MED) and the other using reverse osmosis (RO). Both configurations utilize geothermal energy, with MED directly using geothermal heat and RO converting geothermal energy into electricity to power desalination. The systems are evaluated based on performance indicators, including net power output, desalinated water production, hydrogen production, exergy efficiency, and levelized costs. Multi-objective optimization using an artificial neural network (ANN) and genetic algorithm (GA) was conducted to identify optimal operational conditions. Results highlighted that the RO-based system demonstrated higher water production efficiency, achieving a broader range of optimal solutions and lower levelized water (LCOW) and hydrogen production costs, while the MED-based system offered economic advantages under specific conditions. A case

		<p>study focused on Canada illustrated the potential benefits of these systems in supporting hydrogen-powered vehicles and residential water needs, emphasizing the significant impact of using high-quality desalinated water to enhance the longevity and efficiency of proton exchange membrane electrolyzers (PEME). This research provides valuable insights into the optimal use of geothermal energy for sustainable water and hydrogen production.</p>
<p><i>An assessment of prospects of geothermal energy in India for energy sustainability (Penilaian prospek energi panas bumi di India untuk keberlanjutan energi)</i></p>	<p>Susmita G. et al., 2024</p>	<p>The search for indigenous, renewable, environment-friendly, and sustainable energy resources has increased globally during the past few decades. Geothermal energy is a ubiquitous energy source, potentially becoming an alternate energy resource with a reduced carbon footprint. In this study, eight crucial characteristic parameters, i.e., heat flow, thermal gradient, Curie point depth, lithology, basement depth, crustal thickness, and seismicity, were integrated into a multi-criteria decision model framework to identify areas that may have the potential for geothermal energy in India. The weights of various parameters estimated using AHP are in the order of heat flow (~ 0.252), followed by the Curie point depth (~ 0.195), thermal gradient (~ 0.173), and crustal thickness. Our analysis indicates that the geothermal province in the Himalayas (including the NW and NE regions), SONATA lineaments, central parts, and some parts of the west coasts and Mahanadi graben may have better prospects of geothermal energy compared to other tectonic provinces. We find that ~14.86% and ~ 21.98% of the study region have extremely high geothermal potential. About ~ 27.18 % of the area has medium geothermal prospects, whereas ~ 11.78 % and 24.20 % have very low potential for geothermal energy.</p>
<p><i>Investigation of geochemically induced permeability alteration in geothermal reservoirs and its implications for sustainable geothermal energy production (Investigasi perubahan permeabilitas yang diinduksi secara geokimia di reservoir panas bumi dan implikasinya)</i></p>	<p>Taylor S. et al., 2024</p>	<p>Geothermal resources constitute a significant portion of the world's low-carbon, renewable energy potential, with about 75% classified as low-temperature. One such potential resource exists in Precambrian basement rocks underlying the Williston Basin in southern Saskatchewan, Canada, with a reservoir temperature of 120 °C. However, geochemically induced permeability alteration in these highly</p>

*terhadap produksi energi
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reactive low-temperature granitoid resources poses a significant risk to long-term heat production. We conducted a geochemical and mineralogical study of altered and unaltered samples to assess and potentially mitigate this risk. Our findings facilitated the parameterization of geochemical simulations of water-rock interactions to predict mineral volume changes and, by extension, draw inferences on porosity and permeability changes resulting from these interactions. The simulations indicate an increased mineral volume in both samples, yet geothermal alteration of the unaltered. Thus, more reactive rocks induced relative mineral volume changes by about 30% greater than those in the altered rocks. The resulting absolute change in porosity is 0.5 vol% for the unaltered rocks and 0.35 vol% for the altered rocks. Utilizing an empirical porosity-permeability relationship, the computed change in permeability indicates that the unaltered basement rock experienced a more significant change in total permeability than the altered basement rocks. Additional calculations demonstrate the sensitivity of the porosity-permeability equation to critical porosity and power exponent, forecasting various scenarios with permeability changes ranging from 1.0×10^{-13} to 1×10^{-20} m². Consequently, we infer that altered, permeable zones of the examined Precambrian basement rocks are likely to offer favorable conditions for sustained, multi-decade heat production and, thus should be targeted over less altered zones to justify initial capital expenditures. Globally, geothermal heat extraction from these rocks remains an underexplored yet promising resource for generating reliable, low-carbon renewable energy, crucial in our efforts to decarbonize the global economy.

From the above table, geothermal energy is a renewable and environmentally friendly energy source that prevents climate change due to the continuous use of fossil energy. Here are some things that we can see from

the development of geothermal energy in Indonesia:

(a) Geothermal Potential Geothermal potential is a source of heat energy in hot water, water vapor, rocks, and accompanying minerals and other

gases, which are genetically inseparable in a geothermal system. Geothermal (geothermal) is formed naturally under the earth's surface. From year to year, electricity demand continues to increase, with an average growth of around 7% yearly. Climate change today is believed to have the impact of global warming. This condition is one of the critical environmental damage issues caused by the development of the energy sector. The world community's concern about the issue of climate change is driven by the increasing effects of GHG (greenhouse gases), especially CO₂ emissions. CO₂ gas plays a vital role in increasing the earth's temperature, but it can have a detrimental effect if excessive. That is because they still depend on fossil energy.

(b) Geothermal development There is ample potential for geothermal energy in Indonesia to be developed and utilized, for example, for power generation and the agricultural industry, because most have a relatively high enthalpy of a total potential of around 29 GWe. In addition, the total potential reserves and resources of geothermal energy reach approximately 28,579 Mwe. This energy is most widely used as a power plant, but its utilization has yet to be optimal. Based on data from the Geological Agency of the Ministry of Energy and Mineral Resources in 2010, Indonesia has enormous geothermal potential, namely ± 29 GW or 40% of the world's geothermal potential. However, its utilization is still tiny, namely 1,189 MW, equivalent to 4.2% of the existing potential. Geothermal energy is one of the renewable energies that can be used as a power plant to minimize the negative environmental impact.

Table 2. Comparison of Renewable Energy

Aspect	Geothermal	Solar	Wind	Hydro
Emissions	Low	None	None	None
Realibility	High (24/7)	Medium (Daytime)	Medium (Variable)	High (Continuous)
Cost	Medium-High	Low-Medium	Low-Medium	Medium-High
Renewability	Renewable	Renewable	Renewable	Renewable
Land Use	Low	High	High	Medium
Safety	High	High	High	High

Current Weaknesses of Geothermal Energy

1. Limited Locations: Geothermal energy can only be exploited in areas with significant geothermal potential, limiting its widespread use.
2. High Initial Costs: Building infrastructure, such as drilling geothermal wells and installing processing facilities, requires a substantial investment.
3. Seismic Activity Risks: Geothermal extraction can trigger small earthquakes around the drilling area, although this risk is relatively low.
4. Thermal Pollution: Hot water pumped from underground can contain harmful chemicals and minerals that, if not appropriately managed, can cause environmental pollution.
5. Lifespan of Geothermal Wells: Some geothermal wells may experience a decline in heat production over time, reducing

their efficiency and operational lifespan.

New Potential Methods

1. **Enhanced Hydrothermal Systems (EHS):** This involves developing wells in hydrothermal reservoirs and using pumped water to heat underground water, producing steam for electricity generation.
2. **Enhanced Geothermal Systems (EGS):** This technology creates geothermal systems in areas without natural hot water sources by injecting water to create artificial heat pathways in hot rocks.
3. **Phased Development:** PT Pertamina Geothermal Energy (PGE) proposes a phased development approach in geothermal working areas to improve success rates and cost optimization.
4. **Technological Advancements:** Using new technologies and increasing operational volumes can reduce development costs per unit (USD per MW). Collaboration among geothermal developers can

also help build markets and consolidate demand.

5. **Business Diversification:** PGE suggests diversifying through related business development and local manufacturing to enhance the profitability of geothermal energy developers.

CONCLUSIONS

From the literature study, it can be seen that the potential for geothermal energy is excellent as a substitute for fossil energy if it is continuous when compared to the geothermal potential, namely energy that comes from natural processes contained in hot water, water vapor, and rocks along with minerals and associated and other gases. Geothermal energy also has several advantages over other renewable energy sources, including:

1. saving space and minimal visual impact,
2. being able to produce continuously for 24 hours, so it does not require energy storage and
3. a very high level of availability, which is above 95%.

So, this can be relied upon in the future and will always be there.

REFERENCES

- Abubakar Magaj, B. Dou, G. Gola, G. Alkhulaidi, A.-W. Ibrahim, and M. Ramadhani Ngata, "Current status and advancement from high yield and oilfield geothermal energy production: A systematic review," *Appl Therm Eng*, vol. 258, p. 124575, Jan. 2025, doi: 10.1016/j.applthermaleng.2024.124575.
- Auzan Fildzah Hakim, F. Sholihah, R. Ismawati, dan Nuryunita Dewantari. Pemanfaatan Energi Panas Bumi di Indonesia, P. Pendidikan IPA Universitas Tidar, and K. Kunci Panas bumi, "Indonesian Journal of Conservation," *Indonesian Journal of Conservation*, vol. 11, no. 2, pp. 71–77, 2022, doi: 10.15294/ijc.v11i2.40599.
- Belka Anya, M. Mohammadpourfard, G. G. Akkurt, and B. Mohammadi-Ivatloo, "Exploring geothermal energy based systems: Review from basics to smart systems," *Renewable and Sustainable Energy Reviews*, vol. 210, p. 115185, Mar. 2025, doi: 10.1016/j.rser.2024.115185.
- Dara Salsabila, Abi Radjab Ma'ruf, Yulinda Adharani," Merkonstruksi Arah Politik Hukum Pengembangan Perizinan Panas Bumi untuk Pemanfaatan Tidak Langsung"2021.
- El Fandari Andiesta, Daryanto Arief, Suprayitno Gendut. "Pengembangan energi panas bumi yang berkelanjutan"jurnal ilmiah semester teknika (2014).
- Fatemah Isania and B. Elahifar, "Advances in geothermal drilling: A comparative study with oil and gas techniques," *Geoenergy Science and Engineering*, p. 213638, Dec. 2024, doi: 10.1016/j.geoen.2024.213638.
- Ghalieb . M. Idroes et al., "Exploring the role of geothermal energy consumption in achieving carbon neutrality and environmental sustainability," *Heliyon*, vol. 10, no. 23, p. e40709, Dec. 2024, doi: 10.1016/j.heliyon.2024.e40709.
- Hakim, A. F., Krismadiana, K., Sholihah, F., Ismawati, R., & Dewantari, N. (2023). Potensi dan Pemanfaatan Energi Panas Bumi di Indonesia. *Indonesian Journal of Conservation*, 11(2), 71-77.
- Hendra Rio Gilang," Penyuluhan kegiatan pengembangan panas bumi cluster a di desa toure 1 kecamatan tompaso kabupaten minahasa propinsi sulut"2019.
- Joko Dwi Atmanto. "Pembangkit Listrik Tenaga Panas Bumi (PLTP) dan Kendala Pembangunannya." *Orbith: Majalah Ilmiah Pengembangan Rekayasa Dan Sosial* 11, no. 1 (2015).
- Jonathan Poh et al., "Geothermal development in South, Southeast and East Asia: A review," *Renewable and Sustainable Energy Reviews*, vol. 209, p. 115043, Mar. 2025, doi: 10.1016/j.rser.2024.115043.
- Larasati anandita," Kerjasama indonesia – islandia dalam pengembangan energi panas bumi (geothermal) periode 2012-2016"2018.
- Lia Putriyana, Ayuta Fauzia Ladiba, Subhan Nafis & Hari Soekarno," Potensi dan Tantangan Badan Layanan Umum di Bidang Penelitian dan Pengembangan Panas Bumi"2018.

- Lubis abubakar.” Energi terbarukan dalam pembangunan berkelanjutan”*J,Tek.Ling*(2007).
- Maharani Ayuningtya, Harianto, Arief Safari,” pengembangan strategi pada aktivitas rantai nilai panas bumi (Studi Pada PT Geo Dipa Energi (Persero)’2019.
- Mahwa, J. Jiang Li, D. J. Hua Ping, W. Leng, J. Bo Tang, and D. Yun Shao, “Mapping the spatial distribution of fossil geothermal manifestations and assessment of geothermal potential of the Tangyin rift, Southeast of Taihang Mountain in China,” *J Mt Sci*, vol. 19, no. 8, pp. 2241–2259, Aug. 2022, doi: 10.1007/s11629-022-7329-2.
- Manzella, Adele. "Geothermal energy." *EPJ Web of conferences*. Vol. 148. EDP Sciences, 2017.
- Mukhamad Faeshol Umam, Farhan Muhammad, Daniel W Adityatama, Dorman P Purba.” Tantangan Pengembangan Energi Panas Bumi Dalam Perannya terhadap Ketahanan Energi di Indonesia”2018.
- Mustafa Yalcin, S. Kalaycioglu, C. Basaran, F. Sari, and F. K. Gul, “Exploration of potential geothermal fields using GIS-based entropy method: A case study of the Sandikli,” *Renew Energy*, vol. 237, p. 121719, Dec. 2024, doi: 10.1016/j.renene.2024.121719.
- Nazanin Chitgar and M. Sadrzadeh, “Optimizing sustainable energy systems: A comparative study of geothermal-powered desalination for green hydrogen production,” *Desalination*, vol. 593, p. 118219, Jan. 2025, doi: 10.1016/j.desal.2024.118219.
- Nurul Amandha Adistia, R. Aditya Nurdiansyah, J. Fariko, and J. Welman Simatupang, “Potensi Energi Panas Bumi, Angin, dan Biomassa Menjadi Energi Listrik di Indonesia.”
- Pradipta Ahluriza and Udi Harmoko, “Analisis Pemanfaatan Tidak Langsung Potensi Energi Panas Bumi di Indonesia,” *Jurnal Energi Baru dan Terbarukan*, vol. 2, no. 1, pp. 53–59, Mar. 2021, doi: 10.14710/jebt.2021.11075.
- Riski laksmita sari dan haeruddin,” Tinjauan terhadap pengembangan potensi panas bumi blawan-ijen,jawa timur”2021.
- Ruth Shortall, B. Davidsdottir, and G. Axelsson, “Geothermal energy for sustainable development: A review of sustainability impact and assessment frameworks,” *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 391–406, Apr. 2015, doi: 10.1016/j.rser.2014.12.020.
- Samuel Adam, A. D. Setiawan, and M. P. Dewi, “Robust geothermal investment decisions under uncertainty: An exploratory financial modeling and analysis approach,” *Energy*, vol. 314, p. 134302, Jan. 2025, doi: 10.1016/j.energy.2024.134302.
- Susmita Goswami and A. K. Rai, “An assessment of prospects of geothermal energy in India for energy sustainability,” *Renew Energy*, vol. 233, p. 121118, Oct. 2024, doi: 10.1016/j.renene.2024.121118.
- Taylor Smith, A. N. Awolayo, S. E. Grasby, and B. M. Tutolo, “Investigation of geochemically induced permeability alteration in geothermal reservoirs and its implications for sustainable geothermal energy production,” *Applied Geochemistry*, vol. 175, p. 106193, Nov. 2024, doi: 10.1016/j.apgeochem.2024.106193.

Wisriansyah, S. Z. Purba, D. and Napitu, A. “Keunggulan, Tantangan, dan Rekomendasi Kebijakan akan Pengembangan Energi Panas Bumi di Indonesia,” *Jurnal Nasional Pengelolaan Energi*, pp. 31–47, 2021.

Xincheng Hu, Jonathan Banks, Y. Guo, and W. V. Liu, “Unlocking

geothermal energy by repurposing abandoned wells as enhanced geothermal systems for sustainable heat production: A numerical investigation,” *J Hydrol (Amst)*, vol. 651, p. 132577, Apr. 2025, doi: 10.1016/j.jhydrol.2024.