JIMESE
Journal of Innovation Materials, Energy, and Sustainable Engineering
JIMESE 2(2): 79–94
ISSN 3048-2380

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Geothermal power plant as a sustainable renewable energy alternative: Innovations and engineering solutions

Dany Yuda Saputra[1]*, Saputra Sibarani[2]
[1] *School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.*
*Correspondence: dany.yuda@ui.ac.id

Received Date: December 12, 2024 Revised Date: January 31, 2025 Accepted Date: January 31, 2025

ABSTRACT

Background: Indonesia is an area that has abundant geothermal energy availability, with a total of approximately 28,617 MW. This is because Indonesia is located on the ring of fire between the Atlantic and Pacific oceans. However, this availability does not automatically make Indonesia prioritize geothermal power plants (GPP) as a substitute for fossil fuels in the future. GPP only ranks third in priority below hydropower plants (PLTA) and biomass power plants (PLT Biomasa). The purpose of this study is to look at the strengths, weaknesses, opportunities, and threats of geothermal energy supply. This article uses a qualitative method with literature review and SWOT analysis to describe the phenomenon experienced by geothermal energy in Indonesia. **Methods**: This article uses a qualitative method with literature review and SWOT analysis to describe the phenomenon experienced by geothermal energy in Indonesia. **Findings:** The results of this study show that geothermal energy has strengths, namely reliable, stable, and efficient power, a clean energy with minimal emissions, does not require storage space, does not require large land and has minimal water requirements, and provides direct benefits to the community. Meanwhile, the weaknesses of geothermal energy utilization are that it has a relatively high investment cost, requires sophisticated and complex technology, so it takes a long time to develop, is highly dependent on geographic location to obtain good capacity, is sometimes far from the load center, often conflicts with indigenous communities, making it difficult to obtain social license, and has negative impacts on flora and fauna. The opportunity to utilize this technology is the existence of regulations, especially Law No. 21/2014 and other related regulations, including as the third potential renewable energy transition. The threats faced are government policies and licensing processes that still do not fully support geothermal energy, international scrutiny, and community resistance. **Conclusion**: The conclusion of this article is that geothermal energy is very suitable as a substitute for fossil fuels by mitigating and improving policy, technology, and financing aspects. **Novelty/Originality of this article:** The originality of this article lies in its application of a SWOT analysis to evaluate the geothermal energy sector in Indonesia. It provides a comprehensive review of the current challenges and opportunities in utilizing geothermal energy as a renewable resource, highlighting the need for policy improvements and technological advancements to overcome barriers and support its growth.

KEYWORDS: community; SWOT; geothermal power plants; geothermal energy; ring of fire.

1. Introduction

Indonesia has officially declared a mechanism for energy transition during the G20 Leaders' Summit in Bali on November 16, 2022. At the summit, it was explained that the G20 countries are trying to find solutions to achieve energy market stability, transparency, and availability through accelerated energy transition. The commitment to the energy transition mechanism is in line with international pressure to reduce fossil energy

Cite This Article:
Saputra, D. Y. & Sibarani, S. (2025). Geothermal power plant among renewable energy alternatives in Indonesia. *Institute for Advanced Social, Science, and Sustainable Future, 2*(1), 79-94. https://doi.org/10.61511/jimese.v2i2.2025.1489

(Kulasekara & Seynulabdeen, 2019). The intensity level of emissions from coal-fired power plants in Indonesia from 2013 to 2022 is above 600 grams of carbon dioxide equivalent per kilowatt hour (Statista, 2022). The World Bank data revealed that there was a 27% increase in emissions from power plants from 1990 to 2019 (World Bank, 2021). Meanwhile, coal consumption in Indonesia is recorded as the second largest after China, with 105 million tons, while Vietnam (85 billion tons) and the Philippines (34 billion tons) follow (World Bank, 2021).

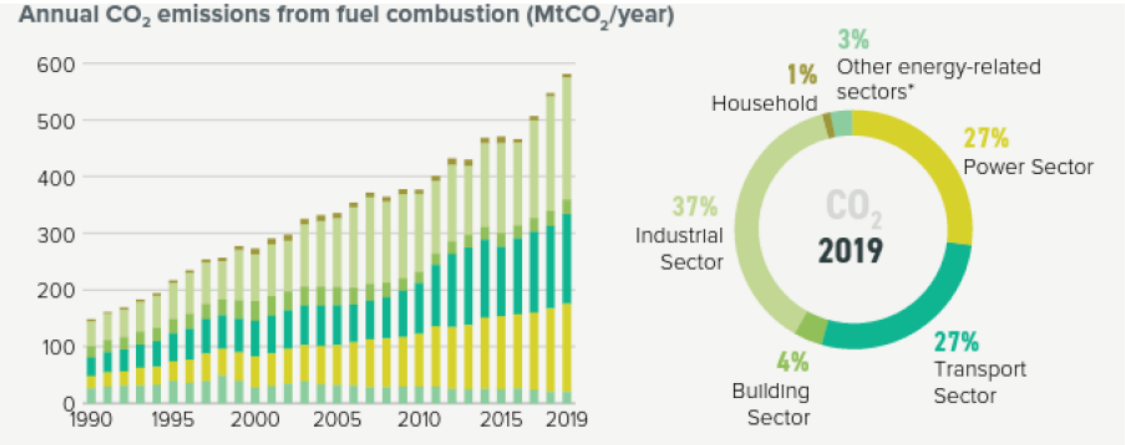

Fig 1. GHG Emission from energy sector in Indonesia from 1990 to 2019 (World Bank, 2021)

To overcome the negative impact on the environment from the use of fossil energy, it is necessary to develop clean and renewable energy. Discussions about renewable energy that can be used as a substitute for fossil fuels. Hydroelectric power plants (PLTA), both large, mini, and micro, are projected to meet 31% of Indonesia's renewable energy targets (Rahayu & Windarta, 2022). However, the use of PLTA faces challenges with water supply in the catchment area (Detrina et al., 2019). In addition, the construction of PLTA also has an impact on the relocation of communities in the context of dam construction (Wardhani et al., 2021). The construction of PLTA also has an impact on conflicts or resistance from the community at the construction site (Wadu et al., 2021). For example, the construction of Waduk Lambo in Nagekeo Regency, the construction of Waduk Jatigede in Sumedang, and the agrarian conflict of the Bener dam construction in Purworejo (Anggraeni, 2022).

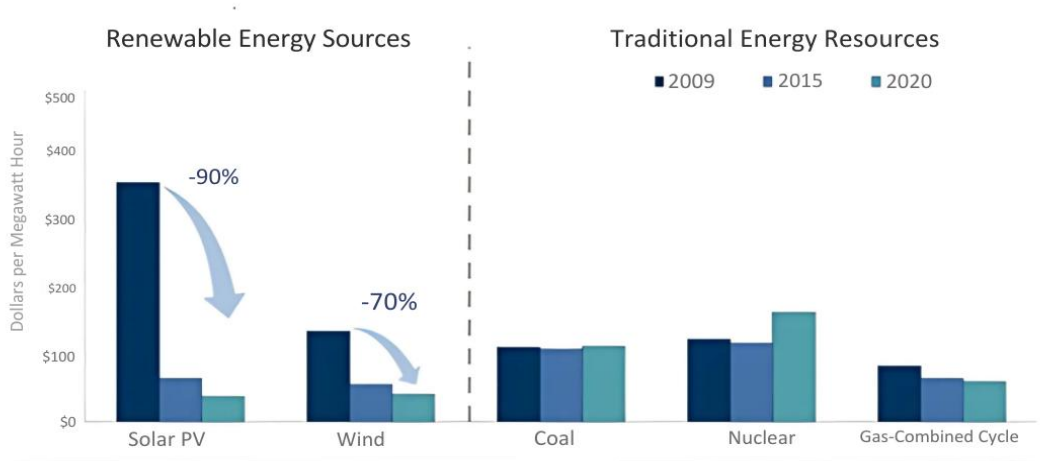

Fig 2. Commitment on investment of wind and solar power compared to traditional energy resource (Ahsan, 2021)

Wind power plants and solar power plants are also alternative power plants with challenges, as investment commitments from various parties, especially European and

South Korean countries, have decreased by 90% from 2009 to 2020 (Ahsan, 2021). The raw materials for wind and solar power plants are also still a matter of debate because they involve cases of social conflict and human rights violations (Institute for Human Rights and Business, 2022). The extraction of materials such as cobalt, copper, lithium, and rare earth materials in African and Latin American countries for turbines, generators, propellers, and towers causes many human rights violations such as child labor, forced labor, social conflict, and security and health problems (Institute for Human Rights and Business, 2022). Perhaps this is what has caused the decline in investment commitments from European countries.

In addition, biomass energy also faces its own challenges because it is still considered unproven and not yet feasible both technically and commercially (Ahsan, 2021). However, Ahsan (2021) sees that biomass has a significant proportion in the General Plan for Electricity Generation 2021-2030 (RUPTL 2021-2030). Geothermal power plants (GPP) are considered a promising alternative. Subekti (2020) stated that Indonesia has 40% of the world's geothermal energy sources or equivalent to 28,617 MW. Fig. 3 shows that Indonesia is located in the "ring of fire" area that stretches from Australia to America (Nasruddin et.al., 2016). This makes Indonesia a "warehouse" of geothermal energy (Pambudi, 2018). However, there are still many doubts about GPP, due to concerns that have existed so far such as fear of Lapindo mud experience (ebtke.esdm.go.id, January 10, 2017) and H_2S gas eruption problems that can endanger the safety of surrounding residents (ebtke.esdm.go.id, September 29, 2022).

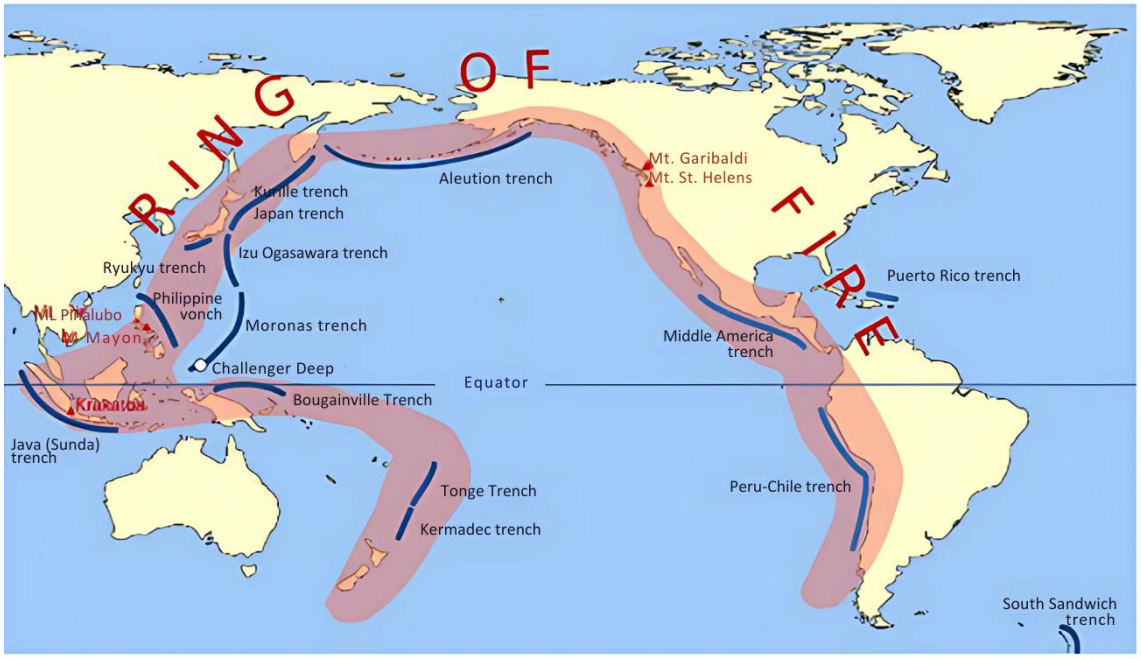

Fig 3. Map of volcano distribution in the Asia-Pacific region (ring of fire)
(BNPB, 2016)

In terms of potential resource capacity, hydropower plants (PLTA) have a potential of 75 GW, mostly distributed in Sumatra, Sulawesi, Kalimantan, and Papua (Rahayu & Windarta, 2022). However, geothermal potential is also significant (28.6 GW) (Subekti, 2020) from a total renewable energy target of 35,000 MW (Ahsan, 2021). Currently, the geothermal energy mix still ranks third in the performance report of the Directorate of New and Renewable Energy and Energy Conservation of the Ministry of Energy and Mineral Resources in 2022, with a total of 12,557 MW, where PLTA is the largest with 6,688.9 MW, PLT Bioenergy 3,086.6 MW, and PLT Geothermal 2,355.4 MW. Meanwhile, the potential for 2030, GPP is expected to reach 3,355 MW (Ahsan, 2021). Some indicators used to assess the feasibility of alternative energy are environmental sustainability, economic, and social issues. Miller & Spoolman (2015) revealed that sustainability is the ability of a system or entity, be it an environmental, economic, social, or other system, to continue over time

without sacrificing the ability of future generations to meet their own needs. Miller & Spoolman (2015) emphasized the importance of maintaining a balance between human needs, environmental protection, and economic sustainability.

2. Methods

This article uses a qualitative approach because it wants to describe the phenomenon of the existence of geothermal potential as a source of future electricity (Creswell, 2014). Meanwhile, the research method used is a literature review of previous research related to GPP to be able to explain the existence of geothermal energy as a substitute for fossil energy in the future. This article aims to analyze research related to the use of geothermal energy as an alternative energy to replace fossil fuels in Indonesia. The total number of main articles used for literature review is 12 articles with additional literature from additional articles.

Given the purpose of this research is to provide ease for practitioners and decision-makers in determining policies related to the sustainability of geothermal energy use as an alternative energy, the analysis model that will be taken is the strength, weakness, opportunity, and threat (SWOT) analysis. Rangkuti (2013) SWOT analysis is a strategic planning method used to evaluate strengths, weaknesses, opportunities, and threats that occur in a project or business, or evaluate its own product lines or competitors. Strengths and weaknesses come from internal factors while opportunities and threats come from external factors (Fahmi, 2014). The selection of SWOT analysis is used to facilitate practitioners and decision-makers in determining important factors that determine the future of geothermal energy as an alternative to fossil fuel energy. SWOT analysis also aims to predict various problems and challenges that may arise (Rangkuti, 2013) in the development of geothermal energy. Through this analysis, the current position of geothermal development and opportunities to develop it faster in the future can be known (Rangkuti, 2013).

The weighting is arranged based on the level of significance. The level of significance is determined using a Likert scale ranging from 1 to 3, where 1 is interpreted as significant and 3 is very significant (Utsalina & Primandari, 2020). The weighting is calculated from the total value of the significance level in each factor that has been filled in divided by the total number of significances. At this stage, the total weight is equal to 1. The more factors that are filled in the SWOT matrix, the smaller the weight of each factor will be. Factor ranking is done from 1 to 5 where 1-2.9 is a weakness or threat, and 3 to 5 is considered a strength or opportunity. Meanwhile, scoring is the multiplication of rating and weight.

3. Results and Discussion

As previously explained in the previous section, the purpose of this article is to describe the potential of GPP as a strategic choice to replace fossil energy in the future. This article also aims to analyze the role of the government in encouraging the development of GPP as a fossil fuel replacement strategy in the future. The SWOT matrix is filled by researchers by conducting a literature review of previous studies that have been selected and filtered. The results of filling the SWOT matrix can be seen in Appendix 1.

3.1 Strength

Geothermal Power Plant (GPP) has the strength of being one of the cleanest energy sources (Ng ett al., 2020). Far cleaner than fossil fuels that cause pollution or greenhouse gas emissions (Kulasekara & Seynulabdeen, 2019) so it can support the achievement of Net Zero Indonesia in 2060. In addition, geothermal energy provides reliable, stable, and efficient power compared to the lack of inertia, efficiency, and intermittent nature of solar and wind resources (Kulasekara & Seynulabdeen, 2019). The emissions produced by GPP

are 12 times lower than CFPP and 6 times lower than GFPP (Nasrudin et al., 2020). In addition, geothermal power plants must be integrated with energy storage devices to improve the stability and flexibility of the power system. Energy storage systems fed by gravity and rotating wheel energy storage systems are two technologies that can be integrated with geothermal power plants to improve stability and flexibility (Kulasekara & Seynulabdeen, 2019).

GPP only requires 404 m^2/GWH land and only requires 20 liters/MWH (Vorosmarty et al., 2000; Anderson & Rezaie, 2019). The minimal land requirement can minimize the potential for social conflict in the community. Resistance to projects that cause social resistance and conflict (Triatmodjo et al., 2021). The minimal water requirement can also reduce the risk of environmental damage and water scarcity in the catchment area and the ecosystem below it (Ng et al., 2021). Meanwhile GPP ratio of local Job Opportunity Ratio of 0.89 per person/year for each MWH and around 66% of employment is a long -term job for operations and maintenance (Anderson & Resaie, 2019; Hienuki et al., 2015).

The use of geothermal energy does not require storage space, thus reducing the use of hazardous raw materials and impacting human rights (Institute for Human Rights and Business, 2022). The use of lithium for storage batteries creates a bad reputation for investors related to the supply chain (Institute for Human Rights and Business, 2022). Natural and perpetual geothermal energy does not require storage like wind and solar energy.

3.2 Weakness

Kabeyi (2019) explains various weaknesses in the use of geothermal energy as described in Table 1, such as requires quite sophisticated and complex technology and requires a long time for the construction period (Kabeyi, 2019), investment costs are quite expensive for exploration and drilling without guarantees of success (Kabeyi, 2019). The location of the GPP that is far from the load center requires a transmission and distribution cable so that a lot of energy is lost (Kabeyi, 2019). Lofthouse et al. (2015) mentioned that economic feasibility of GPP is greatly influenced by geographical locations to get good capacity (Lofthouse et al., 2015; Kulasekara & Seynulabdeen, 2019). Technical risk potential such as geological risk that creates seismic disturbance (Gaucher et al, 2015; Anderson & Rezaie, 2019). In addition, Silica Scaling caused a decrease in GPP performance (Anderson & Rezaie, 2019; Karadas, et al, 2015) and the emergence of H_2S that can threaten the safety of workers and the surrounding community.

Environmental issues are also one of the weaknesses of GPP because of the location in the conservation area of flora and fauna (Ng et al., 2021; Muslihudin et al., 2022) and the existence of indigenous communities (Triatmodjo, 2021). Susila et al (2022) research explains that a conservation model of forests and biodiversity is needed at the GPP location adjacent to Mount Ceremai National Park. Conservation efforts are carried out by dividing utilization zones starting from nature preserve zones, nature tourism parks with 25-40% slope, nature tourism parks with open landscapes, and utilized areas (Susila, 2022). The zoning proportion between protected and utilized areas is 71% to 29% (Susila et al., 2022). Figure 4 (a) of the national park is dominated by core zones in the form of forests shown in red and green. Meanwhile, Fig. 4 (b) is the GPP area dominated by primary and secondary forest areas, dry agricultural land, shrubs, and residential areas shown in green, yellow, gray, pink, and black (Susila et al., 2022).

Another location of GPP that implements biodiversity management is GPP Muara Laboh. This GPP conducts biodiversity offset to replace the conservation area that is open due to project development. GPP Muara Laboh conserves areas outside the Kerinci Seblat National Park covering almost 52.54 ha. Habitat identification and reforestation efforts based on established zoning are also carried out.

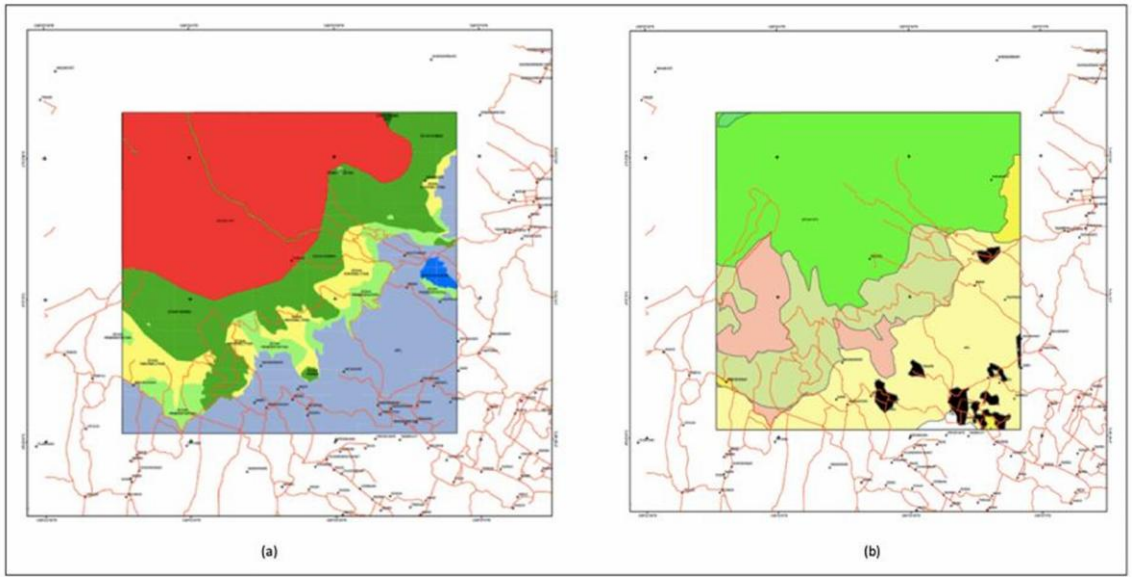

Fig 4. Map of areal function (a) and land use (b) in Gunung Ceremai national park. (Susila et al., 2022)

The biodiversity offset zoning is divided into 10 location parts that indicate the severity level of management locations ranging from the worst to the well-managed. The entire GPP Muara Laboh biodiversity offset location consisting of 10 management zones. The majority of recovery locations are at the level of enrichment and total recovery. This is because the biodiversity offset location is adjacent to the Kerinci Seblat National Park which has been open and utilized by the surrounding community for crops such as coffee, tea, fruits, and wood.

Conflicts with communities and indigenous people often occur in geothermal locations (Triatmodjo et al., 2021). Indigenous community conflicts with GPP development such as in Wae Sano, West Manggarai Regency, where the Wae Sano community rejected the existence of the Wae Sano GPP (Albab, 2023). The GPP will acquire community plantations covering an area of 22.8 hectares that produce candlenuts (Albab, 2023). In addition, there are also customary forests affected by the project that make indigenous communities through Golo Lampang protest against the GPP (Albab, 2023). In addition, the Poco Leok community in Flores also rejected the construction of the Ulumbu PTLP in 2018 (Albab, 2023; Nala, 2023). They reject the existence of this GPP because of their concerns about the danger of landslides that threaten the existence of their village. The location of this GPP is in the mountains above the Poco Leok community village in Flores (Albab, 2023).

3.3 Opportunity

The existence of Energy transition policy from the Indonesian government to meet the net zero in 2060. Indonesia has now limits the investment of large -scale CFPP. GPP has an impact on the development of new technologies. Many methods have been developed in the field of geothermal energy. Technical management of H_2S, technical management of geothermal efficiency, categorization of geothermal energy, and efforts to mitigate loss of production are also continuing to develop. Geothermal energy has now become the third priority in the renewable energy sector in RUPTL 2021 - 2030 (Ahsan, 2021).

Yilmaz (2018) raised how to improve geothermal economic calculations using binary Dora II. Conventional methods such as SPECO and MOPSA may still be used but are continuously updated to obtain a comparison between cost flow and production capacity (Yilmaz, 2018). New technology for geothermal power generation systems is also continuously developing to be more effective and efficient in maximizing existing energy (Yilmaz, 2018). The price of social costs is considered equivalent to the price of energy production that is relatively cheaper than Fossil Fuel (coal and diesel). Social cost prices

include technical total cost plus damage cost which reaches 1.18 cents/kWh (Idris & Meti, 2016).

3.4 Threat

The threat of community resistance is due to the lack of information about the geothermal mechanism which is different from gas (Lapindo mud) Kementerian Energi Sumber Daya Energi dan Mineral, 2017). People still think that geothermal drilling activities will have the same impact as the Sidoarjo mud case that drowned several residential areas. This concern always arises in every geothermal project.

The high cost of GPP development resulted in independent developers (Independent Power Producers) borrowing investment funds from investors or Lenders who are multi-national donors such as the World Bank, ADB, KfW, AIIB, and others. These Lenders apply very strict international standards to protect their business from environmental and social risks. They apply a safeguard framework that must be complied with by every customer. GPP Ulumbu 5 and 6 (Albab, 2023) are examples of GPP with international financing from KfW (Germany). The application of the safeguard framework is applied so that it feels burdensome for GPP. Monitoring and evaluation efforts for the routine and continuous implementation of safeguards are very draining. In addition to GPP Ulumbu, GPP Muara Laboh also received funding from ADB which requires GPP to carry out biodiversity offset even though it is very expensive.

Government policy obstacles both in terms of investment and implementation activities become a threat to the sustainability of geothermal utilization in Indonesia (Bina et al., 2018). Ahsan (2021) revealed that based on his research, 83% of respondents revealed that regulations and policies are the main obstacles to the development of renewable energy including geothermal. Second, the lack of coordination between ministries or government agencies was responded to by 73% of respondents (Winters & Cawvey, 2015). Third, which is the most important part, is the obstacle to obtaining a power purchase agreement which is the crucial point for IPP in developing GPP and seeking financing (Ahsan, 2021). Winter & Cawvey (2015) added that the slow licensing process is a barrier to starting GPP development. Morevover, there are still many rent seekers at the central and regional levels related to licensing (Winter & Cawvey, 2015).

3.5 Conducting weighting, ranking, and scoring on the prepared matrix.

Based on the results of filling out the SWOT matrix in Appendix 1, the next step is to perform weighting, ranking, and scoring. As explained in the methodology chapter, weighting is done by determining the level of significance of each factor using a Likert scale from 1-3, where 1 is the lowest level of significance and 3 is the highest level of significance. The weight of each factor is obtained from the level of significance of each factor divided by the total number of levels of significance. As shown in Appendix 1, there are 4 factors in the internal factor that have a level of significance of 3, namely low emission and pollution; reliability, efficiency, stability, and continuity of the GPP, technical risk may raise, and potential to environmental and social impact pembangunan GPP.

Table 1. SWOT scoring process

Internal Factors	Strategic Issue	Significancy	Weights	Rating	Scoring
Strength	Low emission and pollution	3	0.11	4	0.43
	Reliable, efficient, stable, and continuum	3	0.11	5	0.54
	Efficiency on land and water consumption	2.5	0.09	4	0.36
	Provides more job opportunity	2	0.07	3.5	0.25
	Reliable base load power	2.5	0.09	4	0.36
Weakness	Require sophisticated technology	2	0.07	2.5	0.18

	Expensive cost for investment	2.5	0.09	2.5	0.22
	located far from load center and power plant	1	0.04	2.5	0.09
	Economic feasibility depends on the location	1	0.04	2	0.07
	Potential technical risk may raise	3	0.11	2.5	0.27
	Conflict with indigenous people	2.5	0.09	2	0.18
	Potential to environmental and social impact	3	0.11	2.5	0.27
	Total Score	28	1.00		3.21
External Factorss	Strategic Issue	Significancy	Weights	Rating	Scoring
Opportunity	Existence of Indonesia energy transition mechanism	2.5	0.11	4	0.43
	Advance technology development	2	0.09	4	0.35
	Existence of Law No. 21 of 2014 and relevant regulation below it	3	0.13	5	0.65
	Third priority on RUPTL 2021- 2030	3	0.13	5	0.65
	Low of social cost	2	0.09	4	0.35
Threat	Highlight from international world/lender	2.5	0.11	2.5	0.27
	Obstacle from central and local government	3	0.13	2.5	0.33
	Rent seeker in central and local government	2.5	0.11	2	0.22
	Lack of public awareness and experience on GPP	2.5	0.11	2	0.22
	Total Score	23	1.00		3.47

Meanwhile, in the external factor, the existence of regulations regarding geothermal heat and the entry of geothermal in RUPTL has the maximum level of significance in this weighting process. Meanwhile, the location being far from the load center and power plant and dependence on location become factors with the lowest level of significance in the internal factor. The level of significance on each strategic issue will be in line with the weight. The rating is determined based on a Likert scale with a range of 1-5, where the range of 1-2.9 indicates weaknesses/threats and the range of 3-5 indicates strengths/opportunities. Table 1 is the weighting, ranking, and scoring process carried out by researchers with professional judgement.

Table 1 shows that reliability, efficiency, stability and continuity have the highest rating, namely 5, followed by low emissions, efficient land requirements and water consumption, and base load power with a rating of 4, while labor supply has a rating of 3.5. In the weakness group, only two strategic issues have a rating of 2, namely dependence on location and conflict with indigenous communities. The other factor has a rating of 2.5 which means it has a high rating. Regarding external factors, the existence of regulations and the issuance of RUPTL 2021 – 2030 has the highest rating, namely 5, meanwhile, other strategic issues have a rating of 4. In the threat column, highlights from the international world and obstacles to licensing at the central and regional levels are ranked first with a value 2.5 followed by rent seekers and low public knowledge and experience regarding GPP.

The total score on internal factors is 3.21 out of 4, indicating that both groups of strategic issues are strengths and weaknesses, while external factors have a higher score of 3.47. Based on table 2, the strength group, reliability, efficiency, stability and continuity, has the highest score, namely 0.54, followed by low emission and pollution with a score of 0.43. This strategic issue is the main and the fundamental difference with other types of renewable energy such as HEPP, wind power and solar photovoltaic. Geothermal energy is continuously produced by volcanoes which 50,000 times of availability more than gas and oil (Kulasekara & Seynulabdeen, 2019; Nagala et al., 2015). Meanwhile, wind and solar power have the potential gap in their fulfilment. Wind power really depends on the

availability of wind, while solar power only working during the day. The energy produced will be stored in the battery.

Meanwhile, in the weakness group, the highest score is the emergence of potential technical risks with a score of 0.27. Some forms such as silica scaling (Anderson & Rezaie, 2019; Karadas et al., 2015), the emergence of H_2S gas which can be dangerous for the safety of staff and the surrounding community and geological risks such as seismic disturbances (Anderson & Rezaie, 2019; Gaucher et al., 2015). Seismic disturbances result from the depletion of mud and fluid from the bowels of the earth by geothermal pressure distribution activities to be converted into electrical energy.

The strategic issue on external factors is related to the existence of regulations, especially Law No. 21/2014 and other related regulations with a score of 0.65 such as the licensing process both technical and environmental, are a huge opportunity to be able to encourage the mainstreaming of geothermal as an alternative to fossil fuel (Ahsan, 2021). The priority of geothermal in the 2021-2030 RUPTL (score 0.65) is still the third. This priority is based on capacity availability, namely HEPP has a capacity of 75,000 MWh and Biomass Power Plant 31,000 MWh (Nasruddin et al., 2015). The existence of clear and firm regulations will give hope for geothermal to become the main alternative in replacing fossil energy. The most strategic issue as a threat to geothermal development is the obstacle in licensing. One example is licensing and utilization of conservation areas and cultural heritage as GPP locations (Triatmodjo et al., 2021). Another example that is still happening is the process of obtaining a power purchase agreement, which is a crucial heart point for IPPs in developing GPPs and finding financing (Ahsan, 2021).

3.6 Proposed recommendation

Based on the results of SWOT analysis and scoring, it is clearly illustrated the ranking of strategic issues that must be followed up immediately by policy makers or practitioners. The following recommendations are proposed by researchers by looking at strategic issues, among others:

Table 2. SWOT analysis interpretation

Factors	Explanation
Strength	- Continuously study the stability, efficiency, reliability of geothermal energy to find the right technology that suits Indonesia's conditions. - Continue to campaign for the use of low emission and pollution geothermal through the creation of strategic policies at the ministerial level to encourage geothermal to be the first priority in the 2031 - 2040 RUPTL.
Weakness	- Properly mitigate potential technical and environmental risks that may arise in the development of GPP. - Carry out technological innovations to obtain cost efficiency in GPP development so that it is attractive to investors. - Develop a good stakeholder engagement plan and communication strategy starting from the early stages of GPP project planning.
Opportunity	- Develop implementing regulations from the transitional energy policy and Law No. 21/2014 that are clear, firm, and unchanging to support the mainstreaming of geothermal utilization in Indonesia. - Make geothermal power the main alternative to fossil fuel in the 2031-2040 RUPTL. - Convince investors and PLN that the social cost of GPP projects is cheaper than the development of fossil fuel and other renewable energy so that geothermal energy becomes the main alternative to fossil fuel in Indonesia.
Threat	- Structuring GPP development procedures both from the central level to the regional level. - Simplify or cut the flow of licenses both at the central level and at the regional level for GPP development. - Attract foreign investors in carrying out GPP development in Indonesia, both in the nature of financing and grants either through the state or IPP.

	This is because the social cost for the project is low compared to CFPP or diesel. - Conduct public awareness through media campaigns that are easily accessible to the public such as through electronic media and social media.

Based on the above analysis, if related to the sustainability theory of Miller & Spoolman (2018), which requires the fulfillment of environmental, social, and economic aspects of the community, the existence of geothermal energy can be a solution for sustainability. Geothermal energy is a very environmentally friendly, low-emission, and clean energy. In addition, the development of geothermal energy requires little water and land so that the negative impact on land and water use can still be well mitigated.

The existence of GPP also has positive social and economic impacts on the community, such as open access that makes it easier for the community to distribute goods and services. The entry of information technology such as cellular phone networks opens up insights and education for the local community. Economically, the community also benefits from community empowerment programs carried out by GPP.

4. Conclusions

The conclusion chapter in this study seeks to answer two main research questions, namely first related to will GPP become a strategic choice as a substitute for fossil fuel? Second, what is the role of the government in encouraging the development of GPPs as a strategic replacement for fossil fuels in the future? The SWOT analysis above has shown that geothermal energy is highly relevant to replace fossil fuels in Indonesia's electricity supply. Its abundant availability and characteristics of sustainability, cleanliness, and environmental friendliness are key to its success (Score 0.36). The existence of law-level regulations can open up opportunities for geothermal energy to become the main alternative in mainstreaming geothermal as the main replacement for fossil fuel (Score 0.65). Currently, geothermal has become the third alternative replacement under HEPP and Biomass Power Plant (Score 0.65). Although, it must also be realized that there are major weaknesses, namely potential technical and environmental risks (Score 0.27) such as seismic shifts, the emergence of H_2S which endangers workers and surrounding communities, the emergence of environmental and social impacts (Score 0.27) such as noise, damage to biodiversity in the form of flora and fauna and resistance from the community. Meanwhile, the biggest threat of geothermal energy mainstreaming is the obstacles from the government in the form of licensing both at the central and regional levels (Score 0.33) and the existence of special attention from the government.

To promote geothermal power plants (GPP) as a viable substitute for fossil fuels in the future, the government's role is crucial in several key areas. First, continuous evaluation of geothermal energy's stability, efficiency, and reliability is necessary to identify the most suitable technology for Indonesia's specific conditions. This requires ongoing research and technological advancements to enhance geothermal utilization.

Additionally, the government must develop and implement clear, firm, and consistent regulations based on the transitional energy policy and Law No. 21/2014. These regulations should provide a stable legal framework that supports the mainstream adoption of geothermal energy in Indonesia. Furthermore, geothermal power should be prioritized as the primary alternative to fossil fuels in the 2031-2040 Electricity Supply Business Plan (RUPTL), ensuring long-term commitment to its development.

To streamline GPP expansion, it is essential to simplify and expedite the licensing process at both the central and regional levels. Reducing bureaucratic hurdles will facilitate smoother project implementation and attract more investment in the sector. The government must also work to persuade investors and PLN (Indonesia's state electricity company) of the cost-effectiveness of GPP projects. By highlighting the lower social costs of geothermal energy compared to fossil fuels and other renewable sources, geothermal can be positioned as the leading alternative energy solution for Indonesia.

Moreover, effective risk mitigation strategies should be implemented to address potential technical, environmental, and social challenges from the early planning stages to the completion of GPP projects. Proper risk management will ensure the sustainability and public acceptance of geothermal development. Finally, raising public awareness is crucial to gaining support for geothermal energy. This can be achieved through accessible media campaigns on electronic and social media platforms, educating the public on the benefits of geothermal energy and its role in Indonesia's sustainable energy future.

Acknowledgement
The authors express gratitude for the support and contributions that have facilitated the completion of this research. Appreciation is extended to all parties who have provided valuable insights, resources, and assistance throughout the study.

Author Contribution
The author's contributions to this article are divided between two people, namely D.Y.S and S.S. D.Y.S contributed to the idea of writing, writing the background, problems and research results as well as discussions. D.Y.S also contributed to data acquisition and writing the article itself. Meanwhile, S.S contributed to data acquisition, writing methodology, conclusion, and translation from Indonesian to English.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

References
Ahsan, M. (2021). Tantangan dan Peluang Pembangunan Proyek Pembangkit Listrik Energi Baru Terbarukan (EBT) di Indonesia. *SUTET, 11*(2), 81–93. https://doi.org/10.33322/sutet.v11i2.1575

Albab, W. U. (2023) Kajian terhadap Pembangunan Geotermal di Pulau Florest Berdasarkan Perspektif Teori Keadilan (John Rawls). *Jurnal Publikasi Ilmu Hukum, 1*(4), 2023, 286 – 302. https://doi.org/10.59581/deposisi.v1i4.1760

Anggraeni, R. M. (2022). Konflik Agraria Pembangunan Bendungan Bener Purworejo: Perspektif Yuridis Normatif. *El-Dusturie*, *1*(1). https://doi.org/10.21154/eldusturie.v1i1.4197

Bina, S. M., Jalilinasrabady, S., Fujii, H., & Pambudi, N. A. (2018). Classification of geothermal resources in Indonesia by applying exergy concept. *Renewable and Sustainable Energy Reviews*, *93*, 499-506. https://doi.org/10.1016/j.rser.2018.05.018.

Clauser, C., & Ewert, M. (2018). The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy–Review and case study. *Renewable and Sustainable Energy Reviews*, *82*, 3683-3693. https://doi.org/10.1016/J. RSER.2017.10.095

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches (4th ed.)*. Sage.

Detrina, I., Karimi, S., & Indrawari, I. (2019). Pengelolaan Daerah Tangkapan Air untuk Keberlanjutan Pembangkit Listrik Tenaga Air di Sumatera Barat. *Ecotrophic, 13*(1), 41-48. https://dx.doi.org/10.24843/EJES.2019.v13.i01.p05

DiPippo, R. (2015). Geothermal power plants: Evolution and performance assessments. *Geothermics*, *53*, 291-307. https://doi.org/10.1016/J. GEOTHERMICS.2014.07.005 .

Fahmi, I. (2014). *Manajemen Strategis Teori dan Aplikasi*. Alfabeta.

Franco, A., & Vaccaro, M. (2014). A combined energetic and economic approach for the design of geothermal plants. *Energy Conversion and Management*, *87*, 735- sustainable 745. https://doi.org/10.1016/J.ENCONMAN.2014.07.073.

Gaucher, E., Schoenball, M., Heidbach, O., Zang, A., Fokker, P. A., van Wees, J. D., & Kohl, T. (2015). Induced seismicity in geothermal reservoirs: A review of forecasting approaches. *Renewable and Sustainable Energy Reviews*, *52*, 1473-1490. https://doi.org/10.1016/j.rser. 2015.08.026

Hienuki, S., Kudoh, Y., & Hondo, H. (2015). Life cycle employment effect of geothermal power generation using an extended input–output model: the case of Japan. *Journal of Cleaner Production*, *93*, 203-212. https://doi.org/10.1016/J.JCLEPRO.2015.01.008.

Idris, T. B., & Meti, E. (2016). Energy pricing and policies development for geothermal energy in Indonesia. *Journal of Renewable Energy and Smart Grid Technology*, *11*(2), 17-26. https://ph01.tci-thaijo.org/index.php/RAST/article/view/74868

Institute for Human Rights and Business. (2022). *What are the Rights Implications of Wind Energy?* https://www.ihrb.org/explainers/what-are-the-rights-implications-of-wind-energy

Kabeyi, M. J. B. (2019). Geothermal Electricity Generation, Challenges, Opportunities and recommendations. *International Journal of Advances in Scientific Research and EngineerinG, 5*(8), 2019. http://doi.org/10.31695/IJASRE.2019.33408

Karadas, M., Celik, H. M., Serpen, U., & Toksoy, M. (2015). Multiple regression analysis of performance parameters of a binary cycle geothermal power plant. *Geothermics*, *54*, 68-75. https://doi.org/10.1016/J. GEOTHERMICS.2014.11.003.

Kementerian Energi Sumber Daya Energi dan Mineral. (2017). *Yunus: WKP Gunung Ceremai Tidak Akan Seperti Lapindo*. https://ebtke.esdm.go.id/post/2017/01/10/1519/yunus.wkp.gunung.ciremai.tidak.akan.seperti.lapindo

Lofthouse, J., Simmons, R.T., & Yonk, R.M. (2015). *Reliability or Renewable Energy: Geothermal*. Utah: Institute of Political Economy Utah State University.

Muslihudin, M., Adawiyah, W. R., Hendarto, E., Megasari, R. D., & Ramadhan, M. F. (2022). Environmental constraints in building process a sustainable geothermal power plant on the slopes of slamet mount, central java, indonesia. *Evergreen, 9*(2), 2022, 300-309. https://doi.org/10.5109/4774210

Nasruddin, I.A., Muhammad, D., Surachman, Y., Sugiyono, A., Aditya, H. B., & Mahlia, T. M. I. (2016). Potential of geothermal energy for electricity generation in Indonesia: A review. *Renewable and Sustainable Energy Reviews, 53*(2016), 733–740. https://doi.org/10.1016/j.rser.2015.09.032

Ng, C., White, T., Katariya, V., & Pollard, E. (2020). Geothermal power generation and biodiversity: the business case for managing risk and creating opportunity. In *Proceedings World Geothermal Congress* (p. 1).

Pambudi, N. A., Pramudita, V. S., & Biddinika, M. K. (2022). So close yet so far–how people in the vicinity of potential sites respond to geothermal energy power generation: an evidence from indonesia. https://doi.org/10.5109/4774210

Rahayu, L. N., & Windarta, J. (2022). Tinjauan Potensi dan Kebijakan Pengembangan PLTA dan PLTMH di Indonesia. *Jurnal Energi Baru dan Terbarukan, 3*(2), 88-98. https://doi.org/10.14710/jebt.2022.13327

Rangkuti, F. (2013). *Teknik Membedah Kasus Bisnis Analisis SWOT Cara, Perhitungan Bobot, Rating dan OCAI*. Jakarta: Gramedia Pustaka Utama.

Subekti, R. A., & Harmoko, U. (2020). Overview dan analisis potensi pemanfaatan langsung (direct use) panas bumi pada wilayah kerja panas bumi Dieng Jawa Tengah. *Jurnal Energi Baru dan Terbarukan*, *1*(3), 133-141. https://doi.org/10.14710/jebt.2020.10047

Susila, I. M. A. D., Negara, I. G. N. S. P., Al Irsyad, M. I., Rasyid, H. A., & Ladiba, A. (2022). Model design of geothermal development plan in conservation forest: A case study in Mount Ciremai National Park. *IOP Conference Series: Earth and Environmental Science, 1108*(1), 012034. https://doi.org/10.1088/1755-1315/1108/1/012034

Triatmodjo, M., Merdekawati, A., Nurvianto, S., Hasibuan, I. A. T., & Agung, I. G. P. (2021). Geothermal exploitation in a world heritage site: a case study of Gunung Leuser National Park. *Yustisia*, *10*(1), 94-110. https://doi.org/10.20961/yustisia.v10i1.47797

Utsalina, D. S., & Primandari, L. A. (2020). Analisis SWOT dalam penentuan bobot kriteria pada pemilihan strategi pemasaran menggunakan Analytic Network Process. *Antivirus: Jurnal Ilmiah Teknik Informatika*, *14*(1), 51-60. https://doi.org/10.35457/antivirus.v14i1.889

Vorosmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth. *science*, *289*(5477), 284-288. https://doi.org/10.1126/SCIENCE.289.5477.284.

Wadu, J., Lake, P., & Pita, C. (2021). Resistensi Masyarakat Adat Dalam Pembangunan Waduk Lambo di Desa Rendubutowe Kecamatan Aesesa Selatan Kabupaten Nagekeo. *Jurnal Administrasi Publik*, *16*(2), 156-166.

Wardhani, I. S., Chrisandini, W. W. F., Tower, G. S., Unit, C., & Bonar, J. T. (2021). *Managing social and Environmental Impact in Renewable Energy Development: Case Study of Hydropower Plant*. Indonesian Parliamentary Center.

Winters, M.S & Cawvey, M. (2015). Governance Obstacles to Geothermal Energy Development in Indonesia. *Journal of Current Southeash Asian Affairs, 34*(1), https://doi.org/10.1177/186810341503400102

Wong, K. V., & Tan, N. (2015). Feasibility of using more geothermal energy to generate electricity. *Journal of energy resources technology*, *137*(4), 041201. https://doi.org/10.1115/1.4028138.

Yilmaz, C. (2018). Thermoeconomic cost analysis and comparison of methodologies for Dora II binary geothermal power plant. *Geothermics*, *75*, 48-57. https://doi.org/10.1016/j.geothermics.2018.04.002

Biography of Authors

Dany Yuda Saputra, School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.

- Email: dany.yuda@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Saputra Sibarani, School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.

- Email: saputra.sibarani@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Appendix 1. SWOT matrix

	Strength	**Weakness**
Internal Factors	• Geothermal energy is one of the cleanest energy sources with very minimal emissions and pollution. The emissions produced by GPP are 12 times lower than CFPP and 6 times lower than GFPP (Nasrudin et al., 2020) • Geothermal energy provides reliable, stable, efficient, and continuous power (not run out). Geothermal is found in the bowels of the earth which will be constantly produced by volcanoes and its existence is 50,000 times more than gas and oil (Nagala, Oumarou & Oluwole, 2015; Kulasekara & Seynulabdeen, 2019). • Efficient in land needs (Wong & Tan, 2015; Anderson & Rezaie, 2019) and water consumption (Muslihudin et al., 2022). GPP only requires 404 m2/GWH land and only requires 20 liters/MWH (Vorosmarty et al., 2000; Anderson & Rezaie, 2019). • Local Job Opportunity Ratio of 0.89 per person/ year for each MWH and around 66% of employment is a long -term job for operations and maintenance (Hienuki, Kudoh & Hondo, 2015; Anderson & Resaie, 2019). • Can produce reliable basic power or strength (reliable base load power) with lower prices than GFPP and CFPP (Clauser & Ewert, 2018; Anderson & Rezaie, 2019). Calculation using the Monte Carlo method can show the feasibility of long -term operational costs GPP (Franco & Vaccaro, 2014; Anderson & Rezaie, 2019). Calculation of thermoeconomic Specific Energy Costing (SPECO) shows that the Exergetic Electricity Cost Unit 0.0367 USD/KWH which means there is efficiency of around 13.5% to 47.3% compared to Fossil Fuel (Yilmaz, 2018).	• Requires quite sophisticated and complex technology and requires a long time for the construction period (Kabeyi, 2019). • Investment costs are quite expensive for exploration and drilling without guarantees of success so that not many investors are less interested (Kabeyi, 2019). • The location of the GPP that is far from the load center requires a transmission and distribution cable so that a lot of energy is lost (Kabeyi, 2019). In addition, the location of the well far from the generator also adds to the potential for loss of pressure and heat (Kabeyi, 2019). • Economic feasibility is greatly influenced by geographical locations to get good capacity (Lofthouse, Simmons, & Yonk, 2015; Kulasekara & Seynulabdeen, 2019). • Technical risk potential such as geological risk that creates seismic disturbance (Gaucher et al, 2015; Anderson & Rezaie, 2019). In addition, Silica Scaling caused a decrease in GPP performance (Karadas, et al, 2015; Anderson & Rezaie, 2019). The emergence of H_2S that can threaten the safety of workers and the surrounding community. • Many people intersect with indigenous peoples so it is difficult to get social licensed (Pambudi et al, 2022). • Creating adverse effects on the environment such as noise, hazardous materials, safety and security (Kabeyi, 2019) environmental sustainability and biodiversity both flora and fauna (Susila et al, 2022). Of the total 30 GPPS in Indonesia, there are 20 GPPS in the conservation area and 17 GPPS are in the Key Biodiversity Area area (Ng et al, 2021). One example is GPP on Mount Leuser National Park (Triatmodjo et al, 2021).

	Opportunity	**Threat**
External factors	• Energy transition policy from the Indonesian government to meet the net zero in 2060. Indonesia has now limits the investment of large -scale CFPP (Kemenkeu, 2022 November 24) • The development of new technology that is very fast in the geothermal field (Anderson & Rezaie, 2019). The development of this technology is more devoted to supporting cost efficiency and maximizing energy production while still paying attention to environmental and social aspects (Dipippo, 2014; Anderson & Rezaie, 2019) • The issuance of Law Number 21 of 2014 and other Implementing Regulations (Ahsan, 2021). • Become the third priority in the Renewable Energy sector in RUPTL 2021 - 2030 (Ahsan, 2021). • The price of social costs is considered equivalent to the price of energy production that is relatively cheaper than Fossil Fuel (coal and diesel). Social cost prices include technical total cost-plus damage cost which reaches 1.18 cents/kWh (Idris & Meti, 2016).	• Many highlights from the international world, especially from investors with the implementation of strict international standard. • Barriers to the Central Government and PLN policy in prioritizing geothermal as an alternative substitute for fossil fuel (Winter & Cawvey, 2015). • There are still many rent seekers at the central and regional levels related to licensing (Winter & Cawvey, 2015). • The lack of public knowledge and experience about GPP raises resistance because of their concerns (Pambudi et al, 2022). Disasters such as Lapindo mud are often associated with the construction of GPP (etbke.esdm.go.id, 2017 January 10).

(Pambudi et al., 2022; Anderson & Rezaie, 2019; Muslihudin et al., 2022; Triatmodjo et al., 2021; Kabeyi, 2019; Kulasekara & Seynulabdeen, 2019; Bina et al., 2018; Ng et al, 2021; Idris & Meti, 2016; Susila et al., 2022; Winter & Cawvey, 2015; Yilmaz, 2018; Kemenkeu, 2022 November 24)