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Strategy of geothermal energy development as a renewable energy source in West Java Indonesia

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ABSTRACT
Background: Indonesia has vast renewable energy potential, including biofuels, biomass, and bioenergy from tropical biodiversity spread across the country. Hydropower and geothermal energy are the only forms of renewable energy used to generate electricity and are connected to the grid. Geothermal energy may be incorporated into the grid to create hybrid energy systems that will help to reduce the high energy demand while maintaining low energy costs and net present costs. There are now 14 biosphere reserves in Indonesia, divided into 24 units of core zones, six units of buffer zones, and 13 units of transition zones. The West Java Province has a geothermal potential of 6,101 MWe or 21% of Indonesia's total geothermal resources. Currently, the installed capacity of electricity from geothermal energy in West Java is 1075 MWe or 89% of the total national installed capacity of 1196 MWe**.** **Method:** This paper reviews West Java Province data collection from official government bureaus, state-owned businesses, and non-governmental organizations (NGO) reports on geothermal energy capacity, electricity installation, and used area of geothermal power plant and will be limited to the years 2010 through 2020. The collected data will then be refined, extrapolated, and analyzed by the connected trend to aid in studying West Java geothermal growth and use SWOT method analysis. **Finding:** The result of this research is a strategy for optimizing the development of geothermal energy utilization. The strategies that can be developed are infrastructure improvement as an investment facilitation strategy, a strategy to leverage a costly investment and capital investment, underground mining in conservation forest areas to avoid degradation improvement and supervision of related institutions and stakeholders, implementation of environmentally sustainable development, and socializing programs and providing job opportunities for the local community. **Conclusion:** Indonesia has an enormous potential for renewable energy, especially geothermal, with West Java Province having the largest installed capacity. This study suggests strategies to optimize geothermal energy development, including improving infrastructure, investment facilities, underground mining, improving supervision, and sustainable development. **Novelty/Originality of this study:** Research on geothermal energy in West Java provides a comprehensive analysis and specific strategies to optimize the development of this energy in the area, including innovative underground mining approaches.

KEYWORDS: geothermal energy; power plant; renewable energy; strategy; sustainable; West Java

1. Introduction

Indonesia is a developing country with a population of 270 million lifes (BPS, 2020). Located in Southeast Asia region on the equator, Indonesia features numerous archipelagos

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with extensive and intricate coasts. The coastline of Indonesia is 54,556 Km long, and there are 17,508 islands there that are connected to the Pacific Ocean, Indian Ocean, and Indonesian Seas through straits (Mutsuda et al., 2019). Geographically Indonesia is located between 2 continents namely Asia and Australia, as well as 2 oceans, the Indian Ocean, and the Pacific Ocean. Besides geographically, astronomically The Indonesian archipelago is located at 6° north latitude - 11° south latitude and 95° east longitude - 141° east longitude. In accordance with this astronomical location, Indonesia is also strategically located on three major world plates, namely the Eurasian Plate, the Indoaustralian Plate, and the Pacific Plate. Indonesia's position is known as the Pacific ring of fire which stretches as far as 40,000 Km and causes very frequent potential earthquakes in the Indonesian region and volcanic eruptions in the Pacific Ocean basin (Utomo & Purba, 2019).

Due to Indonesia’s position within the volcano line's ring of fire, it has the world's greatest geothermal potential. Around 28.91 GW of geothermal energy potential is spread across 312 areas on a few islands like Java, Sulawesi and Sumatra, Bali, Nusa Tenggara, and Sulawesi. Indonesia’s aims are to plan the development of a geothermal power plant in the future. The geothermal roadmap's goal of producing 9,500 MW was announced in 2005. However, this goal was revised to 7,000 MW in 2025, which was found to be more realistic (Pambudi, 2018).

The current energy crisis is significantly worsening as a result of the growing global population, the rapid expansion of businesses, the depletion of fossil fuel supplies, and climate change (El-Hadary et al., 2023; Zayed et al., 2020). Therefore, experts are working to come up with novel ideas for technologies and concepts to address the energy crisis in distant areas (El-Agouz et al., 2022; Zayed et al., 2021). Some studies made it clear that society's overuse of fossil fuels was what caused these issues (Conti et al., 2016). In this environment, it is clear that a swift and controlled switch to renewable energy sources like solar, geothermal, wind, biomass, and hydropower is required (Asgari & Ehyaei, 2015; Dincer & Zamfirescu, 2012). Renewable energy sources may improve a system's performance by being used in multi-generational energy systems, in addition to being sustainable and having a positive environmental impact (Ahmadi et al., 2020; Jamali & Noorpoor, 2019; Li et al., 2020).

An environmentally friendly source of energy, geothermal energy draws heat from the earth's crust. Geothermal heat is essentially produced when naturally occurring radioactive isotopes like thorium, uranium, and potassium trapped in magma disintegrate during the creation of the planet (Dostál & Ladányi, 2018; Ma et al., 2019; Matos et al., 2019). Geothermal energy is categorized as a form of renewable energy, therefore its supply is unaffected by a shortage of sources or rising fossil fuel prices. Geothermal energy has several benefits, one of which is that it is environmentally benign. Geothermal energy is not generally available in all nations; it is only present in those that are part of the ring of fire. As one of the nations crossed by the ring of fire, Indonesia has the potential for geothermal energy, as seen by the 117 active volcanoes that are now located around the nation. The geothermal energy potential of Indonesia is estimated to be over 28,617 MW, or around 40% of the global geothermal energy potential. Only 4.5% of this amount, though, is used for electricity in the nation. Increases in geothermal power plant capacity are being worked on regularly by the Indonesian government. By 2025, it is intended to build up to 9500 MW worth of additional geothermal power plants in Indonesia (Nasruddin et al., 2016). Geothermal energy is not climate-dependent, but it is very reliant on the underlying regional, global, and hydrological frameworks. It is used to generate power (electricity) and/or is used directly for heating (Arbad et al., 2022).

Given Indonesia's projected huge reserve potential of power plants—the second largest in the world—geothermal energy is essential for sustainably satisfying the country's energy needs. Furthermore, the nation's electricity demand increased significantly because of the surge in energy consumption, going from 910 kW-hours (kWh) per capita in 2015 to 1,084 kWh per capita in 2019, necessitating the expansion of power generation. The government of Indonesia has set a 7,241.5 megawatt (MW) target of a 23 percent share of renewable energy in the country's energy mix by 2025 to provide for growing electricity demand through renewable and low-carbon energy sources (Fan et al., 2018; Setiawan et al., 2022). Geothermal energy is anticipated to contribute up to 17,546 MW to the 31% renewable energy contribution that is anticipated to be achieved by 2050. The government's capacity to achieve the goal seems challenging, even though the extraction of such enormous geothermal deposits looks promising for delivering a sustainable electricity supply. The fiscal mismatch is one difficulty that makes the goal challenging. Despite the large-scale energy output that geothermal power plants offer being commensurable with coal-fired power plants, generating and running a geothermal power plant requires considerable investment from both public and private sources. Current selling prices of geothermal power, which are still viewed from the off-taker's perspective as more expensive compared to fossil sources of energy (such as coal, petroleum gas, and diesel), is another problem (Setiawan et al., 2022).

The West Java Province has a geothermal potential of 6,101 MWe, or 21% of Indonesia's total geothermal resources, according to statistics from the West Java Provincial Government. West Java is the province with the greatest geothermal potential in these circumstances with 49 places in 11 regions make up this potential. Currently, the installed capacity of electricity from geothermal energy in West Java is 1075 MWe, or 89% of the total national installed capacity of 1196 MW (MEMR, 2011). As shown in Figure 1, the potential for and difficulties associated with the development of geothermal energy in West Java, Indonesia, will be discussed in this paper (MEMR, 2023).

2. Literature Review

2.1 Renewable energy

Renewable energy is an energy derived from resources that are replenished by natural processes continuously or over a relatively short period of time (Miller & Spoolman, 2018). Indonesia possesses a wide array of renewable energy sources, including hydropower, geothermal energy, wind power, solar energy, wave energy, and biomass. Moreover, being a tropical nation, Indonesia boasts significant potential for renewable energy from biofuels, biomass, and bioenergy derived from the diverse tropical biodiversity found across the country.In Indonesia, the only forms of renewable energy that are already used to generate electricity and connected to the grid are hydropower and geothermal (Nasruddin et al., 2016).

According to the mandate of Law of Republic of Indonesia No. 30 of 2007 about energy, The formulation of the national energy policy is guided by the principles of equity, sustainability, and environmental considerations, aimed at fostering energy self-reliance and ensuring national energy security. As a result of this policy, there arises a necessity for diversifying the energy sources to fulfill domestic energy requirements, with a particular emphasis on the development of novel renewable energy solutions. Under the perspective of energy as development capital, renewable energy plays an important role in driving a green, sustainable and low-carbon economic system. carbon economy.

Table 1 Target of renewable energy plant development

Power plant type	Target in 2025	Target 2050
Geothermal	7,241	17,546
Hydropower	20,960	45,379
Bioenergy	5,532	26,123
Solar power	6,379	45,000
Wind power	1,807	28,607
Others	3,128	6,383

(Indonesia National Energy Council, 2016)

Stated in Presidential regulation No. 22 of 2017 about the national energy general plan, Indonesia has set specific goals for incorporating renewable energy into its national energy mix. By 2025, the target is to achieve a 23% share of renewable energy, which translates to a capacity of 45.2 GW. The remaining energy requirements will be met through biofuels, biomass, biogas, and coal bed methane. However, in the electricity sector, Indonesia faces a significant challenge. As of March 2017, the installed capacity of new renewable energy power plants stood at a mere 8.80 GW, accounting for just 2% of the total renewable energy potential of 443 GW available in the country. With the national energy general plan target, the types of new renewable energy power plants that must be built can be looked at Table 1.

As per the findings of the Indonesia National Energy Council (2017), the country possesses a significant renewable energy capacity of 443 GW for electricity generation, encompassing geothermal, hydropower, solar, wind, and ocean wave sources. Among these, solar energy exhibits the largest potential, exceeding 207 MW, while water and wind sources also hold substantial promise, as indicated in Table 2. However, despite the vast and diverse renewable energy potential, its utilization remains limited. Indonesia's progress in renewable energy development is still trailing behind that of other G20 nations who are actively transitioning towards a low-carbon economy. Indonesia has challenging homework to encourage optimal utilization of renewable energy and reduce dependence on fossil energy.

Table 2 Renewable energy potensial in Indonesia

Energy type	Potential (MW)	Capacity installed (MW)	Usage (%)
Geothermal	29,544	1,438.5	4.9
Hydropower	75,091	4,826.7	6.4
Mini and microhydropower	19,385	197.4	1
Solar power	207,898	78.5	0.04
Wind power	60,647	3.1	0.01
Bioenergy	32,654	1,671	5.1
Ocean waves	17,989	0.3	0.002

2.2 Goethermal

The term "geothermal" originates from the Greek word "geo" meaning "earth" and "thermal" meaning "heat," thus denoting energy or heat generated by the Earth. The geothermal fluid, which can exist as liquid or vapor or a combination of both, holds the energy within water. Typically, the fluid is found more than 1 kilometer below the earth's surface. A fire ring passes through the location of geothermal energy, which is similar to those in the United States, Canada, Japan, the Philippines, New Zealand, and other nations (Nasruddin *et al*., 2016). Geothermal energy can provide the world's energy needs for 100,000 years (Sofyan, 2012).

Geothermal power plant has not advanced in recent years, and there are several difficult factors that contribute to this predicament. However, a study of the worldwide geothermal power generating business reveals several intriguing characteristics. First, due to the unbalanced global development of geothermal power generation and its strong correlation with the distribution of geothermal resources, each country's potential for geothermal power generation is assessed, and candidate countries are chosen to study this unbalanced global development (Xia & Zhang, 2019).

Geothermal energy and other renewable energy sources may be incorporated into the grid to create hybrid energy systems that will assist to reduce the high energy demand while maintaining low energy costs and net present costs (Rashid *et al*., 2021). Over time, it will lower energy costs generally, enabling even the poorest individuals to obtain power. As a result, both developed and emerging nations like Bangladesh will see an increase in GDP. Economically, more jobless individuals may find employment if geothermal power plants could be built. By addressing their issues with energy demand and unemployment, this type of energy will also aid individuals in rural regions. On the other side, geothermal energy is advantageous for Bangladesh from an environmental standpoint since it produces fewer dangerous wastes, radioactive materials, environmental pollutants, and other pollutants (Islam et al., 2022).

There are two types of geothermal energy utilization in Indonesia according to Presidential Regulation No. 7 of 2017, the first one is indirect utilization that can be described as the activity of exploiting geothermal utilization through the process of converting heat energy and or fluid into electrical energy. The other one is through direct utilization is the activity of exploiting geothermal utilization directly without conducting the process of converting heat energy and or fluid into other types of energy for non-electric purposes. The implementation of geothermal for indirect utilization in all regions of Indonesia is the authority of the national government which is carried out and or coordinated by the Minister of energy and mineral resources.

The implementation of geothermal activities, according to Law of the Republic of Indonesia No. 21 of 2014, has the objective to regulate geothermal exploitation endeavors with the aim of bolstering energy security and independence, promoting sustainable development, and maximizing the welfare and prosperity of the population. This includes enhancing the use of geothermal energy as a renewable resource to meet the country's energy requirements, as well as promoting the utilization of clean and eco-friendly energy to reduce greenhouse gas emissions. Geothermal resources are regarded as a national asset under the control of the state, intended for the benefit of the people. The governance of geothermal resources involves the collaboration of the national government, provincial governments, and local governments at the regency or city level, with each entity exercising their respective authority and adhering to principles of responsible utilization

2.3 Goethermal energy in Indonesia

In Indonesia, the majority of geothermal power plant installations are found in legally protected conservation zones. Natural reserves, wildlife reserves, national parks, natural tourist parks, great forest parks, and hunting parks make up Indonesia's 27 million hectares of conservation areas. There are now 14 units of biosphere reserves in Indonesia, which are divided into 24 units of core zones, 6 units of buffer zones, and 13 units of transition zones. The UNESCO World Heritage Committee has named four world heritage sites in Indonesian conservation zones (Hidajat, 2020). To safeguard the natural legacy of the globe, these locations were chosen based on their unique and exceptional universal values in each area (Ministry of Environment and Forestry, 2020).

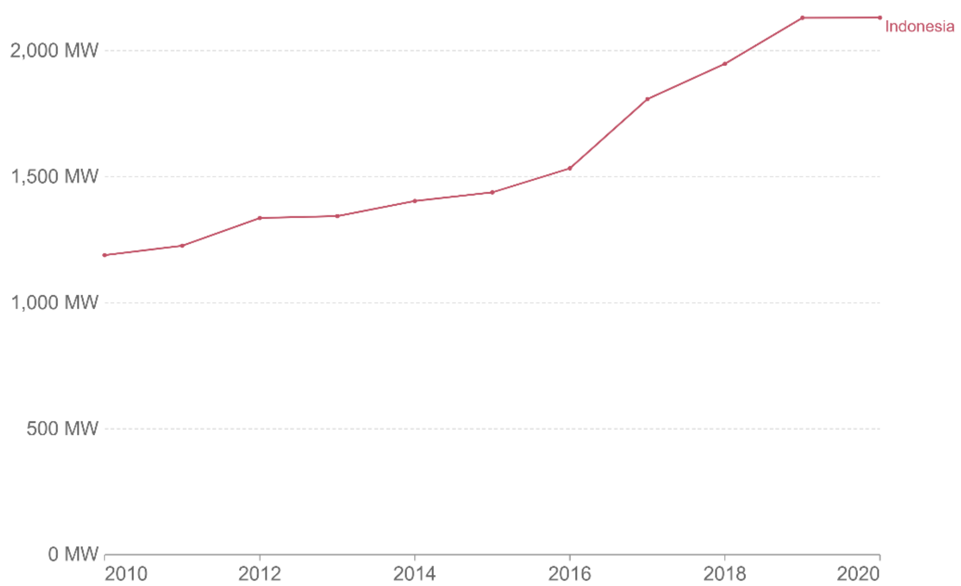

Figure 2. Installed geothermal energy capacity in Indonesia 2010-2020
(Our World in Data based on BP Statistical Review of World Energy, 2022)

The geothermal power plants at Mount Darajat and Kamojang in Garut Regency and Bandung Regency are in protected forest areas controlled by Perhutani, just like the geothermal power plant in Mount Salak, West Java Province, which is in the vicinity of the Mount Halimun Salak National Park. There are several new geothermal power plant regions that are situated on world historic sites, such as those in Lampung Province (Hidajat, 2020). From 2010 to 2020 as shown in Figure 2, geothermal energy development in Indonesia surged by 79.2%. With the installed capacity of geothermal power plants increasing from 1189 MW in 2010 to 2131 MW in 2020, this statistic is fairly substantial (Our World in Data, 2022).

2.4 Geothermal Working Area in West Java

The report of the Ministry of Energy and Mineral Resources (2017) on Indonesia's geothermal potential, especially in West Java Province, includes several significant geothermal working areas (WKP). The Cibereum Parabakti geothermal working area, managed by PT Pertamina Geothermal Energi and Star Energy Geothermal Salak, has an installed capacity of 377 MW in six generating units with a total area of 102,200 hectares. The Awibengkok (Salak) geothermal system is associated with several volcanic eruption centers around Mount Salak. This area is located in a conservation forest area, protected forest, and production forest, with an altitude of between 950 and 1,500 meters above sea level, and the Cianten Caldera, an old volcano, is located in its western part.

Furthermore, the Cibuni geothermal working area, managed by PT Kopjasa Ahli Teknosa, has geothermal reserves of 140 MW with a development plan of 10 MW in an area of 9,541 hectares. The Cisolok Cisukarame geothermal working area, which has a business license from PT Jabar Rekind Geothermal, is estimated to have reserves of 45 MW with an area of 15,580 hectares. This geothermal system is associated with the Cisolok-Cisukarame and Mount Talaga-Halimun areas, with a reservoir temperature of around 180-200°C.

The Mount Ciremai geothermal working area, with an area of 38,560 hectares, is estimated to have reserves of 150 MW and a development plan of 110 MW. This geothermal system is associated with hot springs in Sangkanhurip and Pejambon, with temperatures between 42-56.3°C, indicating the dominance of hot water. In Mount Galungung, the geothermal working area has reserves of 264 MW with a development plan of 110 MW in an area of 57,330 hectares. The reservoir temperature in this area is estimated to be 225°C, and is associated with the crater of Mount Galungung and the Sepuluh Ribu hills.

The Mount Gede Pangrango geothermal working area has reserves of 85 MW with a development plan of 55 MW and covers an area of 92,790 hectares. Potential geological hazards, including volcanic eruptions, are obstacles in this area. Mount Tampomas has reserves of around 50 MW with a development plan of 45 MW. PT Wijaya Karya Jabar Power holds a business permit with a working area of 27,010 hectares, and a reservoir temperature in the range of 187-208°C.

In the Mount Tangkuban Perahu geothermal working area, with an area of 44,710 hectares, reserves are estimated at 90 MW and a development plan of 60 MW, with a reservoir temperature between 240-320°C. This area is at risk of geological hazards such as volcanic activity and landslides. The Kamojang Darajat geothermal working area has an installed capacity of 505 MW with an area of 45,380 hectares, and eight generating units have been operating, with the latest unit having a capacity of 35 MW since 2015.

The Karaha Cakrabuana geothermal working area, managed by PT Pertamina Geothermal Energy, has reserves of 190 MW and an installed capacity of 30 MW, located in Garut Regency. The Pangalengan geothermal working area, managed by PT Geodipa (Persero) and PT Petrothermal Energy - Star Energy Wayang Windu, has an installed capacity of 110 MW for Wayang Windu 1, 117 MW for Wayang Windu 2, and 55 MW for Patuha 1, with a total area of 152,300 hectares. Unit 1 Wayang Windu has been operating since 2000, Unit 2 since 2008, and PT Geodipa has been operating Patuha Unit 1 with a capacity of 55 MW since 2014.

2.5 Greenhouse gas emissions from energy sector

The term "geothermal power plant" refers to a facility that uses geothermal energy to generate electricity. Because of the features of the energy source, the power plants are sustainable, renewable, and favorable to the environment. CO2 emissions from gas power plants are produced at a rate that is six times greater than those from geothermal power plants, while those from coal-fired power plants are 12 times greater. Geothermal power plant space requirements are also lower than those of conventional power plants. Since the energy generated is not affected by the weather or the time of year, geothermal power plants also have the benefit of being able to sustain base-load electricity (Nasruddin et al., 2016).

The climate is slowly changing due to greenhouse gas emissions from fossil fuels. Engineering superstructures' air-cooling systems use a significant quantity of the polluting, non-renewable energy sources now associated with carbon. In this light, shallow geothermal energy systems have received attention from many industrialized nations in Europe and elsewhere as a sustainable energy source deserving of investment and development. Buildings may be heated and cooled using these energy systems, which contributes to a decrease in dangerous gas emissions (Cunha & Bourne-Webb, 2022). Geothermal energy may be utilized to generate power, heat, or cool buildings, and for various industrial purposes. It is a sustainable and clean source of energy. It has lately attracted a lot of interest due to a number of benefits, such as reduced harmful impacts on the environment, continuous power generation, minimal greenhouse gas emissions, and universal accessibility (Benti et al., 2023).

3. Methods

Data collection from official government bureaus, state-owned businesses, and non-governmental organizations (NGO) reports on geothermal energy capacity, electricity installation, and used area of geothermal power plant are the key technique for this study. The data will be limited to the years 2010 through 2020. The collected data will then be refined, extrapolated, and examined in accordance with the connected trend to aid in the study of West Java geothermal growth.

The primary data source for electricity capacity and installation of renewable energy power plants will be found on the website of Ministry of Energy and Mineral Resources of the Republic of Indonesia. As a further data source, we will make use of information from Indonesian ministries, state-owned businesses, and NGO studies on the country's and the world's capacity for renewable energy. Based on a mixed (subjective-objective) assessment of strengths, weaknesses, opportunities, and threats, SWOT analysis is a cognitive process that studies the interactions between internal and external surroundings of an organization, territory, or sector of processing (Amato et al., 2021; Ghazinoory et al., 2011). Combining these analysis techniques will help to create a comprehensive, current image of the issue under study as well as a complete assessment of it (Voukkali & Zorpas, 2022).

Table 2 Energy development strategy with SWOT

External	Internal	
	Strengths (S)	Weaknesses (W)
Opportunities (O)	SO Strategy	WO Strategy
Threats (T)	ST Strategy	WT Strategy

(Sutriani & Wijayanto, 2020)

Descriptive and SWOT analysis were used as the research methodology (Table 3). SWOT assessment framework of strengths, weaknesses, opportunities, and threats supported by a participatory approach to planning and management can be useful in effectively identifying the specific challenges and opportunities that exist at each research point (Gulyas & Edmondson, 2021). SWOT analysis is helpful in deciding policy orientations and investment development plans in the geothermal energy industry. In order to create a development plan, a SWOT analysis is the first step in assessing the situation for geothermal energy development.

4. Results and Discussion

Energy resources come in many different forms in Indonesia. While a major component of the nation's energy mix still depends on oil. The PLN is advocating for the use of various main energy sources, notably coal and "nontransportable" fuels like geothermal and natural gas. The need for energy diversity, growing environmental concern, and depleting nonrenewable energy supplies have all been addressed by geothermal and hydropower.

4.1 Gunung Salak geothermal field

This geothermal field also recognised as the Awi Bengkok geothermal system. Located in the Salak Mountain National Park, at a height of 1,400 m ASL, Gunung Salak geothermal area. Administratively, the region is divided between the Sukabumi and Bogor districts, and it is located about 100 kilometers from Jakarta, the capital of Indonesia. There are a total of 100 wells that includes production, reinjection, and monitoring wells, are in use at Gunung Salak. The facility, which includes a reservoir predominately made of water, is run by Chevron Geothermal Salak (CGS). In order to turn the heated fluid into electricity, flash technology is employed. The Gunung Salak geothermal reservoirs are between 215 and 312 °C in temperature. The reservoir, with an average thickness of 1,700 m, has a surface area of about 7 km^2 (Pambudi, 2018).

Unoval Geothermal Indonesia (UGI) and Pertamina collaborated to launch the Gunung Salak geothermal development project in 1982. Drilling was then done in the Pelabuhan Ratu and Awi Bengkok regions. The project was abandoned in favor of Awi Bengkok due to limited potential in Pelabuhan Ratu. Following the exploratory stage, two power plant units producing 255 MW were constructed. This was how the facility ran up until 1994. The capacity of additional units 3, 4, 5, and 6 was increased to 55 MW each between 1995 and 1997, bringing the total capacity to 330 MW. Currently, Gunung Salak has a total capacity of 377 MW in 6 upgraded units. Gunung Salak generates electricity that is transmitted to the networks in Bali, Java, and Madura (Pambudi, 2018; Peter et al., 2015; Schotanus, 2013).

4.2 Wayang Windu geothermal field

Star Energy runs the Wayang Windu geothermal field, which is situated in Pengalengan Regency, West Java, some 40 kilometers south of Bandung. It is located at a height of around 1700 meters above sea level. In this area, geothermal activity varies in hot springs, fumaroles, and steaming earth. These manifestations develop spontaneously from cracks in the rocks above the reservoir's fluid supply. At a depth of 1300–2500 m, this reservoir has a temperature of around 260–325 °C. One of the reservoirs with a lot of water is called Wayang Windu. However, the vapor fraction rises and most likely becomes vapor-dominated to the north of the reservoir. One of Java's five active geothermal fields is Wayang Windu (Pambudi, 2018).

Crucially, there are two units of the Wayang Windu geothermal power plant, linked to the Java-Bali interconnection grid, have a combined capacity of 277 MW. The first wells were drilled in 1991, and a geological survey got underway in 1985. The unit's construction was finished in 1999, and in 2000 it was both commissioned and put into service for profit. Unit 2 was operational in 2009. 13 producing wells provide the 110 MW Unit 1 geothermal power plant. Unit 2 has six producing wells and a 117 MW capacity. Five more injection wells are present (Shoedarto et al., 2021).

4.3 Patuha geothermal field

Administratively, Patuha Rancabali geothermal field operations are situated at 7° 10'36,7′′ latitude and 107° 24'30,7" BT in the Bandung regency, West Java Province. The distance from the city of Bandung is around 50 kilometers. A vapor-dominated reservoir is included in the Patuha geothermal system. Near Patuha, there are several geothermal phenomena, including 93 °C hydrothermal alteration, acidic hot springs, and fumaroles. The hot springs, which are in the northern Patuha area, range in temperature from 35 to 83 °C and have water flows of 2 to 15 l/s. The pressure in the reservoir can reach 30 bars, and the temperature can vary from 215-230 °C (Fadillah *et al*., 2013).

Nine producing wells and four non-commercial wells meant for power generation are present in the West Javan geothermal area known as Patuha. It is possible to use the non-commercial wells for injection. Between 2400 and 2700 kJ/kg have been produced using enthalpy-producing wells. The first unit at Patuha, a 55 MW generator, was finished in 2014, and has been operating at full capacity since 2015. The manager of a geothermal field in Dieng, PT. Geodipa, also oversees the management of a geothermal field in Patuha (Swandaru, 2006).

Patuha geothermal power plant started operations in 2014. The Patuha geothermal field is a volatile steam-dominated reservoir located about 40 km southwest of Bandung, West Java. The system consists of an overburden layer, a vapor layer at the bottom, and a reservoir that is mostly fluid. These reservoirs get their heat from the primary heat source beneath Kawah Putih and Patuha volcano. The occurance of fluid flow through fault zones and within low-permeability reservoir rocks (Maghsoudi et al., 2018). The regional geology is dominated by quaternary volcanic rocks and a small proportion of tertiary sedimentary rocks. None of the structural faults in the Patuha field have been identified at the surface. Along the surrounding area, however, faults generally strike northwest - southeast and northeast - northeast - southwest (Schotanus, 2013).

4.4 Kamojang geothermal field

West Java province's Kamojang, which is 40 km south of Bandung, has a year-round temperature range of 15 to 200 °C and 2.885 millimeters of annual rainfall. It is the location where the development of geothermal energy started. JB Van Dijk proposed using Kamojang's geothermal resources in 1918. Before becoming an independent state, Indonesia was part of the Dutch East Indies during this time. Additionally, the first geothermal power plant in Tuscany, Larderello, had only been built a few years prior. In fact, the first geothermal plant at Larderello began operating virtually concurrently with the birth of the geothermal development process. With a 30 MWe capacity, this facility started running for the first time in 1982. Two more operating units in 1988 produced 55 MW. Unit IV of the Kamojang operation had a 60 MW capacity in August 2008. Thus, after more than 30 years of operation, Kamojang's geothermal power plants have a combined capacity of 235 MW. Enough resources have been found via further exploration efforts to install Unit V and expand the current plant's capacity by 35 MWe (Fadillah et al., 2013; Mansoer & Idral, 2015).

Kamojang's system is a vapor-dominated field, and energy has been generated using a dry steam power plant. The reservoir is around 235-245 °C and 31–38 kg/cm2 under pressure. The overall output of the Kamojang wells is quite unstable. It saw a strong rise from 2000 to 2008, reaching a high of 12,612 t. The most recent data show that in 2013, this amount fell to 11,256 t. Steam Receiver Headers (SRH) are installed at Kamojang Power Plant Units 2–3 to reduce steam fluctuations, which can have a direct influence on the generation of electricity (Pambudi, 2018).

4.5 Darajat geothermal field

About 22 kilometers to the west of the West Javan settlement of Garut is where you'll find the Darajat geothermal power plant. The distance between this geothermal region and the Kamojang geothermal field is roughly 10 kilometers. With a reservoir that is mostly made of vapor, Darajat shares traits with Kamojang. In this regard, these two reservoirs are in contrast to the water-dominated geothermal reservoirs in Indonesia. There are three units of the Darajat geothermal power plant that generate a total of 270 MW of power. Darajat Unit I, which went into service in 2000, generates 55 MW; Darajat Unit II, whose construction began in 2004 and which went into operation in 2007, generates 95 MW; and Darajat Unit III generates 121 MW (Pambudi, 2018).

Chevron, currently the world's largest geothermal producer with a capacity of 1273 MW and about 27% of the world's geothermal electricity generated, has its holdings in Darajat and Mount Salak. Darajat uses a dry-steam power plant to generate energy due to its vapor-dominated reservoir. A pressure regulator valve controls the pressure of the steam as it travels from the reservoir to the surface. Steam enters the scrubber through this valve, which enhances its quality by removing moisture. Dry steam is directed toward a turbine, where it turns the turbine blade. The generator generates power thanks to the turbine's spinning. To maintain pressure at the turbine outlet, steam from the exhaust turbine is directed into the condenser (Pambudi, 2018).

Based on the strategic plan of the secretariat general of the Ministry of Energy and Mineral Resources, 2020, especially in the province of West Java. As show in Table 4, geothermal power plant capacity in West Java that has been installed is 1194 MW spread over 6 fields.

Table 3 Installed Capacity of Geothermal Power Plants in West Java

No.	Field	Unit	Total Capacity	Reservoir	Technology
1	Salak	Unit-1–3 : 3 × 60 MW Unit 4–6 : 3 × 65,6 MW	377 MW	Water Dominated	Single Flash
2	Wayang Windu	Unit-1 : 110 MW Unit 2 : 117 MW	227 MW	Water Dominated	Single Flash
3	Patuha	Unit 1 : 55 MW	55 MW	Water Dominated	Single Flash
4	Kamojang	Unit-1 : 30 MW Unit 2–3 : 2 × 55 MW Unit 4 : 60 MW Unit 5 : 35 MW	235 MW	Vapor Dominated	Dry Steam Plant
5	Darajat	Unit-1 : 55 MW Unit-2 : 94 MW Unit 3 : 121 MW	270 MW	Vapor Dominated	Dry Steam Plant
6	Karaha Bodas	Unit-1 : 30 MW	30 MW	Water Dominated	Single Flash

(Ministry of Energy and Mineral Resources Republic of Indonesia, 2020)

The worry of CO_2 emissions contributing to climate change can also be solved using geothermal energy. Geothermal energy generation will still produce CO_2 as part of the energy conversion process, but at a reduced level and below CO_2 emission limits. Therefore, geothermal energy is not only recognized as sustainable energy but also an alternative energy source that plays a significant role in global CO_2 abatement.

Indonesia has long had difficulties with geothermal development. Planning a geothermal project requires consideration of the development risk, which includes risks from blowouts, microearthquakes, and contaminated water. The technologies for drilling and production maintenance are expected to have improved in the ensuing years thanks to the work of scientists and engineers. Better risk assessment and increased productivity and efficiency in the generation of energy will both be aided by the advancement of these technologies.

According to sources from the Union of Concerned Scientists, hot water pumped from subsurface reservoirs frequently includes significant levels of sulfur, salts, and other minerals. These references are related to the environmental impact of geothermal power plants on water quality and usage. Most of geothermal installations employ a closed-loop system, in which hot water that has been harvested and used to drive turbines and generate power is sent back into the geothermal reservoir, where it is subsequently heated by magma beneath the ground (Cunningham, 2008).

In Indonesia, the majority of geothermal power plants sites are found in legally protected conservation areas. There are 27 million hectares of conservation areas in Indonesia, including hunting preserves, national parks, environmental tourist parks, and animal reserves. There are now 14 units of biosphere reserves in Indonesia, with 24 units of conservation areas serving as core zones, 6 units serving as buffer zones, and 13 units serving as transition zones. The UNESCO World Heritage Committee has recognized four sites in Indonesian conservation zones as world historic sites. To safeguard the natural legacy of the globe, these locations were chosen based on their unique and exceptional universal values in each area. The geothermal power plants at Mount Darajat and Kamojang in Garut Regency and Bandung Regency are in protected forest areas maintained by Perhutani, just like the PLTP in Mount Salak, West Java Province, which is in the vicinity of the Mount Halimun Salak National Park.

Table 4 Forest Area in the Geothermal Working Area

No	Geothermal Area	Forest Area (Ha)				
		Conservation Forest	Protected Forest	Production Forest	Pangonan Forest and Reserve Forest	Other Area
1	Cibeureum Parabakti Geothermal Working Area	16,333	18,699	4,425	-	62,741
2	Cibuni Geothermal Working Area	93	48	57	-	9,341
3	Cisolok Cisukarame Geothermal Working Area	-	2,461	59	-	13,059
4	Gunung Ciremai Geothermal Working Area	13,296	-	19	207	25,035
5	Gunung Galunggung Geothermal Working Area	-	8,000	235	128	48,965
6	Gunung Gede Pangrao Working Area	26,440	-	11,243	67	56,038
7	Gunung Tampomas Geothermal Working Area	150	900	5,134	176	20,648
8	Gunung Tangkuban Perahu Geothermal Working Area	26	5,133	4,154	298	35,097
9	Kamojang Darajat Geothermal Working Area	12,678	13,361	-	1,084	126,176
10	Karaha-Cakrabuana Geothermal Working Area	275	10,132	5,237	1,421	47,443
11	Pangalengan Geothermal Working Area	10,253	41,329	1,769	2,478	61,569
12	Total Area	79,544	100063	32,332	5,859	506,112

(Potensi Panas Bumi Indonesia Jilid 1, 2017)

As shown in Table 5, the West Java province's geothermal power plant operation area is located in protected and conservation forest. There are 79.544 hectares of conservation forest and 100.063 hectares of protected forest out of a total of eleven geothermal power plant operational zones. The Law Number 21 of 2014 Concerning Geothermal Energy permits the use of geothermal energy in conservation zones. Nevertheless, as stated in Government Regulation Number 108 of 2015 concerning Nature Conservation Areas and Nature Reserve Areas, geothermal usage is only permitted in the designated utilization zone.

Some of the geothermal potential locations that have been found right now are in the core zone and cannot be developed using the environmental services provided by conservation forests. In order to best exploit geothermal potential in regions situated in conservation forests, the Ministries of Energy and Mineral Resources and Ministries of Environment and Forestry explored zoning arrangements.

A number of legislations have been passed to help this geothermal development go as smoothly as possible. Law No. 21 of 2014, one of the most current geothermal energy laws, modifies Act No. 27 of 2003's approach. Geothermal power generation is no longer considered a mining activity, which is a significant change made by the Act of 2014. This implies that property that would normally be put aside for conservation can now be used to investigate geothermal energy. Geothermal development faced challenges due to the 2003 Act's inclusion of geothermal exploration under the definition of the mining industry. The majority of the geothermal energy resources are concentrated in wooded regions where mining is not authorized. Even now, when the investigation and exploitation of geothermal energy in forests are legal, excessive growth might disturb the natural order. As a result, maintaining geothermal zones requires caution.

The administration of geothermal working zones has been strengthened by Law 2014 No. 21 as well. Since the district previously faced a coordination limitation, the federal government will now be in charge of directing this auction. Another recent piece of legislation focuses on directing the use of geothermal energy for non-electrical uses, including tourism, agriculture, and industry. These uses should be presented to local governments for evaluation of their earnings.

Table 5 Energy development strategy with SWOT

	Internal	
External	Strengths (S) 1. Energy reserve, 2. Environmentally oriented, 3. Resources available locally, 4. Supported legally and politically.	Weaknesses (W) 1. High investment costs, 2. Inadequate infrastructure and technology, 3. Lack of well-qualified human resources, 4. Lack of pro-renewable energy utilization policies.
Opportunities (O) 1. Utilize a lot of labor, 2. Creation of multiplier effects, 3. Shifting fossil energy usage, 4. Regulations related to energy utilization.	SO Strategy 1. Increase the scale and value of investment 2. Growth of Supporting business 3. Increase the role of the region and surrounding communities 4. Start using renewable energy in public areas	WO Strategy 1. Enhancement of human resource skills, 2. Define a strategy to leverage investment and capital investment 3. Execute and supervise the implementation of regulations and utilization strategies 4. Improvement and replenishment of infrastructure
Threats (T) 1. The projected area is in a conservation forest area 2. Risk of Geothermal Energy development 3. Cost efficiency to achieve economical electricity price 4. Social issues	ST Strategy 1. Underground mining in conservation forest areas to avoid degradation 2. Implementation of environmentally sustainable development 3. Socialization of the program to the local community 4. Provide job opportunities for the local community	WT Strategy 1. Enhancement of facilities and infrastructure 2. Improvement of related institutions 3. Costly reserve inevestment 4. Socialization of the scheme to the community

In order to implement this renewable energy usage program, a sizable investment is required to develop geothermal potential. A SWOT analysis of the internal and external environmental factors influencing the growth of the industry should be used to build the strategy for the development of the alternative energy sector. The SWOT analysis of geothermal energy development strategy in West Java that we examine can be shown in Table 6.

In the SWOT analysis, internal factors are used to identify the strengths or advantages of the renewable energy industry as well as the weaknesses of the industry. Strengths in the development of the geothermal energy industry are energy reserve, environmentally oriented, resources available locally, supported legally and politically. Weakness in development of the geothermal energy industry are high investment costs, inadequate infrastructure, lack of well-qualified human resources, and a lack of pro-renewable energy utilization policies that are pro towards the utilization of this renewable energy.

External factors reflect the environment outside the development of the renewable energy industry, including opportunities and threats from the existence of this industry. Opportunities in efforts to develop the geothermal energy industryare are absorbing a lot of labor, creating multiflier effects, can shift fossil energy usage which is majorly still used, and local regulations related to energy utilization. Threats in development of the geothermal energy industry are some of the geothermal working areas located in conservation forest area, dynamic development in geothermal technologies, efficiency of the cost to achieve economical electricity price, and the most common at the beginning of development is rejection from the community due to many conflicts of interest.

Referring to Table 6, we can consider a strategy for the development of the geothermal energy industry, as follows: (1) Infrastructure improvement as an investment facilitation strategy. (2) Define a strategy to leverage a costly investment and capital investment. (3) Underground mining in conservation forest areas to avoid degradation. (4) Improvement and supervision of related institutions and stakeholders. (5) Implementation of environmentally sustainable development. (6) Socializing program and provide job opportunities for the local community.

4. Conclusions

West Java's geothermal energy growth might provide an extra and different energy source to ensure energy security. Geothermal energy is dependable throughout the year and helps slow down climate change. Additionally, Indonesia has a sizable amount of energy that is kept in reserve, and there is a good chance that newer, more advanced technologies will be developed to mitigate these risks in the growth of geothermal energy. Additionally, in order to draw in investors, geothermal development will need more definite policies from both governments.

West Java has a lot of energy resources. Out of 2130.7 MW, 1194 MW of West Java's geothermal energy capacity is installed. The results of the SWOT analysis suggest that strategies like these are necessary for the development of the geothermal energy industry. To prevent environmental degradation, underground mining should be done in conservation forests, capital investments should be used wisely, related agencies and stakeholders should be led and supervised, environmentally sustainable development should be carried out, and community outreach and employment opportunities should be encouraged.

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Author Contribution

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