JEMMME (Journal of Energy, Mechanical, Material, and Manufacturing Engineering)
Vol. 8, No. 1, 2023

ISSN 2541-6332 | e-ISSN 2548-4281
Journal homepage: http://ejournal.umm.ac.id/index.php/JEMMME

Systematic literature review supported VOSviewer: Geothermal energy as an alternative energy in Indonesia

Anisa Ayu Solikah[a], Sulistyo Saputro[a], Sentot Budi Rahardjo[b]
[a] Science education, Sebelas Maret University
Jl. Ir Sutami No.36, Surakarta, 57126, Indonesia

[b] Department of Chemistry, Sebelas Maret University
Jl. Ir Sutami No.36, Surakarta, 57126, Indonesia
e-mail: anisaayusolikah2023@gmail.com

Abstract

The need for electricity in Indonesia is still high due to its population and large area. However, power plant fuels such as coal are less able to meet the electricity needs in the community. This is because the amount of coal is running low and cannot be renewed. To overcome this, the government focuses on developing power plants from alternative energy that is new renewable so that it will not run out. To achieve this goal, studies are needed that can inform the public and researchers in the future. The study of geothermal energy as an alternative energy for power plants in Indonesia from 2013-2023 aims to provide information and analysis related to obtain: 1) the principle of changing geothermal energy into electrical energy. 2)The use of geothermal energy in the world today. 3)The research on the use of geothermal energy so far in Indonesia? 4) The potential of geothermal energy as an alternative power plant for Indonesia? The research on the use of geothermal energy so far in Indonesia through literature review and supported by VOSviewer, 5) The challenges and solutions in developing geothermal energy as an alternative to power generation in Indonesia.

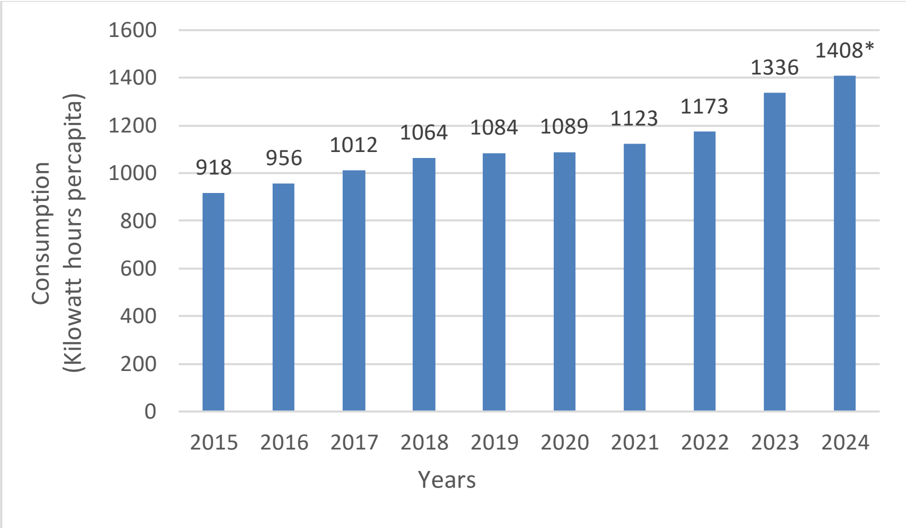
***Keywords**: Geothermal energy; renewable energy; systematic literature review*

1. INTRODUCTION

Electricity is one form of energy that has an important role for human life, where this energy consists of positive charges and negative charges. Electric current is an electric charge that moves from a place of high potential to a place of low potential, passing through an electric sculptor (1). In carrying out electric current, electric sculpting media is needed, one of which is media made of metal.

The need for electricity for the Indonesian people is very high, shown by data in 2022 reaching 1,173 kWh / capita and is predicted to increase in 2023 in line with Indonesia's economic growth which is targeted to reach 5.3% (2). This is reinforced from statistical data on electricity demand in Indonesia in 2015-2022 which continues to increase to 1,408 kWh / capita in 2024. Data on electricity demand in Indonesia is presented in Figure 1.

So far, electricity generated by power plants amounted to 308,002 GWh (3). However, the power plant has not met the electricity needs in Indonesia. Several articles and news media explain that Indonesia is still experiencing a shortage of electricity which is shown from several regions in Indonesia still experiencing a shortage of electricity sources, such as Papua and Maluku (4). Referring to data from the Ministry of Energy and Mineral Resources, Directorate General of Electricity (2021), it shows that the regions of Indonesia that are still experiencing a shortage of electricity availability through Steam Power Plants (PLTU) are Papua and Maluku (5). Data related to the availability of electric power in several provinces in Indonesia in 2020 are presented in Table 1.



Note: (*) Prediction

Graph 1. The electricity demand in Indonesia
Source: (Statista, 2023)

Table 1. Regions of Indonesia with Steam Power Plant Capacity

No.	Wilayah	PLTU (MW)	PLTU-MT (MW)	PLTGU (MW)
1.	Aceh	130	-	20,00
2.	North Sumatra	950	-	501,00
3.	West Sumatra	187,74	180	
4.	Riau	296	-	26,00
5.	Kepulauan Riau	133,30	-	145,60
6.	Bengkulu	230	-	
7.	Jambi	16,20	-	
8.	South Sumatra	-	1.243,72	453,38
9.	Bangka Belitung Islands	101,60	-	
10.	Lampung	379,86	-	
11.	Banten	8.145,05	-	769,20
12.	West Java	2.809,00		
13.	DKI Jakarta	-	-	4.154,45
14.	Central Java	5.995,00	-	810
15.	D.I. Yogyakarta	-	-	-
16.	East Java	6.011,87	-	6.011,87
17.	Bali	380	-	-
18.	West Kalimantan	305	-	-
19.	Central Kalimantan	340,07	-	-
20.	South Kalimantan	95,80	521,60	-
21.	East Kalimantan	790,18	150,00	83,55
22.	North Kalimantan	15,88	-	8,91
23.	North Sulawesi	85	-	-
24.	Gorontalo	76	-	-
25.	Central Sulawesi	1.069,44	-	-
26.	West Sulawesi	50	-	-
27.	South Sulawesi	849,20	-	275
28.	Southeast Sulawesi	233,50	-	-
29.	West Nusa Tenggara	256,20	-	126,88
30.	East Nusa Tenggara	63	-	-
31.	Maluku	-	-	-
32.	North Maluku	14	-	-
33.	Papua	197,45	-	-
34.	West Papua	4	-	-

Source: (4)

The uneven distribution of electrical energy is caused by difficult geographical conditions and limited electrical energy (6). where Steam Power Plants still dominate as much as 66% and are the highest among other power plants. Meanwhile, coal-fired steam power plants also dominate compared to renewable electricity, where steam power is still used as much as 47%, higher than other renewable electricity. So far, electrical energy in Indonesia is mostly supplied by Steam Power Plants (PLTU). PLTU uses coal as its main fuel. This data refers to: Databook, (2023) where Steam Power Plants still dominate as much as 66% and are the highest among other power plants. Meanwhile, coal-fired steam power plants also dominate compared to renewable electricity, where steam power is still used as much as 47%, higher than other renewable electricity (8).

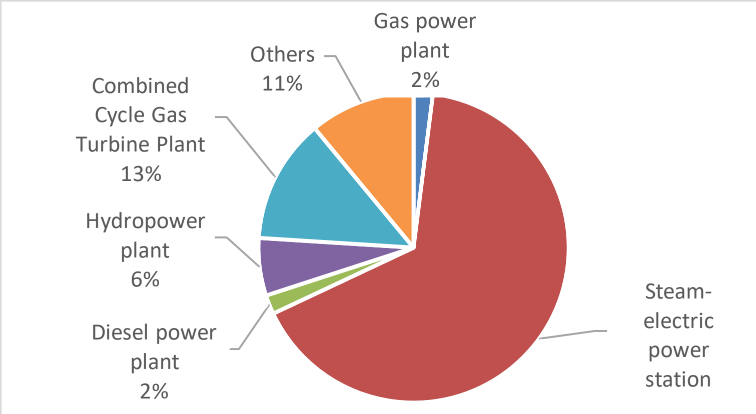


Figure 1. Percentage of Installed Capacity of Power Plants in Indonesia by Type (2021)
Source: (7)

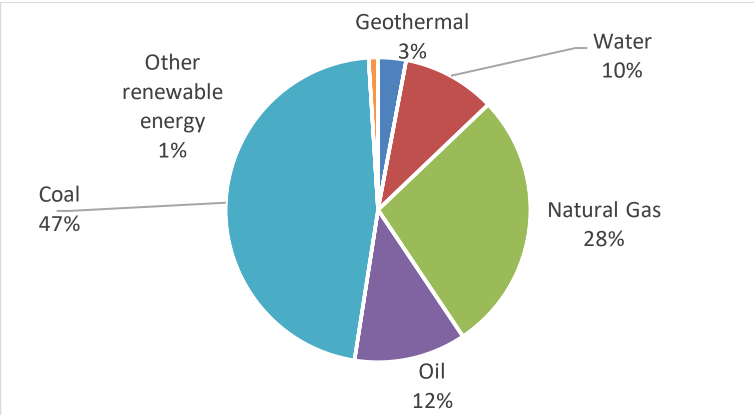


Figure 2. Percentage of Power Plant Sources
Source : (8)

Based on data in figures 1 and 2, it shows that coal-fired steam power plants dominate electrical energy in Indonesia. However, there are negative impacts resulting from the PLTU, namely engine vibration and radiation due to noise from large-capacity cooling fans, air pollution, and coal waste remaining fuel from the PLTU engine (9). Seeing the dangers of coal-fired power plants and the increasing demand for electricity, but still difficult to meet evenly, alternative energy is needed to replace coal that is renewable, otherwise known as new renewable energy. New renewable alternative energy substitutes energy whose nature can be utilized continuously available in nature. The use of this new renewable alternative energy has been regulated by the government through Perpres No. 5 Tahun 2006 about National Energy Policy 2006-2025 which explains that energy supply must be met 17% renewable energy. New and renewable energy (EBT) forms available in Indonesia include geothermal, water, biomass, and solar energy. Among these forms of renewable energy, geothermal energy (geothermal) is energy that requires less land and less water than other energy.

Geothermal energy is the heat energy originating from the earth. The amount of heat released from within the earth through units of area per time, geothermal flow from one place to another and over time varies depending on the geology and physical conditions of the underground (10). The heat generated from continental plate flow is 57mW.m^2 and in Oceanic plates is 99 mW/m2 Barbier, 2002). To get energy from underground, the water can be used as a heat carrier because the earth's crust is easily cracked so that it can be penetrated by liquids that can penetrate into and exchange heat with rocks. The principle of using geothermal energy as an alternative to this power plant is by changing and separating energy from geothermal with a separator so that dry steam is obtained to drive the electric turbine, while hot water or brine from the separation of the separator is discharged back into the bowels of the earth (11).

There are several countries that already use geothermal energy, including Italy, Canada, Japan, France, Germany, Turkey, Sweden, the United States, and China. China is the country with the highest geothermal power in the world, where more than 15000 MWt was generated in 2015 (10). Compared to other countries, Indonesia is still lagging behind in using geothermal energy because currently geothermal only contributes 1% to national energy with the development of alternative energy caused by several things, including limited human resources, governance issues, community involvement in the development process problematic in licensing and price negotiations (12). However, Indonesia has the potential to use geothermal energy because Indonesia has the largest geothermal energy potential in the world with geothermal potential of approximately 29 Giga Watt, while currently only 1.2 Giga Watt is used (13). Therefore, through government policies contained in Perpres No. 5 Tahun 2006, geothermal is targeted to support 5% of national energy by 2025.

Geothermal energy has advantages over other energy, which includes renewable energy sources because it comes from the earth's core and fluid circulation can return to the earth, low electricity generation costs, more competitive and better competitiveness compared to fossil fuel power plants because its capacity is 95% so higher than coal which is only 60-70%, emissions are one-eighth of coal-fired power plant emissions, no fuel is purchased and facility costs are largely fixed so that the cost of geothermal power generation is relatively constant, energy sources are constant all the time (not intermittent such as wind or solar), require less land and water than other alternative energy, geothermal binary-cycle does not produce pollution and greenhouse gas emissions, geothermal energy can be generated by itself so that it can reduce dependence on petroleum imports (14). Geothermal power includes renewable energy because its heat extraction is much smaller compared to geothermal charge. However, there are still several disadvantages of geothermal energy, including exploration, drilling and construction of geothermal power plants requires a lot of costs and the construction of geothermal power plants can affect soil stability in the surrounding area. Therefore, research is needed to overcome problems or threats that will exist when geothermal energy power plants are made.

Based on the background that has been described, this study aims to provide a review related to the principle of changing geothermal energy into electrical energy, the use of geothermal energy in the world today, review and analysis of research on the use of geothermal energy so far in Indonesia with the support of VOSviewer, the potential of geothermal energy as an alternative plant for Indonesia, as well as geothermal energy challenges and solutions when applied in Indonesia. The study updates previous geothermal energy studies conducted by Meilani & Wuryandani, (2010) in terms of policy and politics, as well as reviewing several references to geothermal energy research in Indonesia (15)(16) supported by VOSviewer analysis to see how literature studies related to geothermal energy in Indonesia are conducted. VOSviewer is the application which can be used for analyzing bibliometric networks, creating, visualizing, and exploring maps based on any type of network data (17). It is hoped that through the study of geothermal energy as an alternative energy for power plants in Indonesia from 2013-2023 through a s VOSviewer. This study can provide basic information related to geothermal energy in Indonesia to the public, researchers, students, and parties who focus on the use of new renewable geothermal energy so that future research to meet the needs of electrical energy in Indonesia will grow.

2. METHODS

In this study, researchers used bibliometric analysis methods and systematic literature review by examining geothermal energy in Indonesia. Research questions are asked, namely: 1) What is the principle of changing geothermal energy into electrical energy? 2) How is geothermal energy used in the world today? 3) How is the research on the use of geothermal energy so far in Indonesia? 4) What is the potential of geothermal energy as an alternative to power generation in Indonesia? 5) What are the challenges and solutions in developing geothermal energy as an alternative to power generation in Indonesia?, This study uses 5 steps starting with systematic review and obtaining valid data (18). The steps in this study are shown in Figure 3.

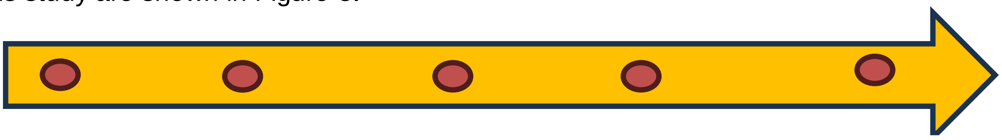


Figure 3. The procedure of systematic review

2.1 Determining Keywords

In this study, the keywords used were "Geothermal" and "Indonesia". This keyword is then used to obtain literature data from the Google Scholar database through PoP (Publish or Perish) software.

2.2 Initial Literature Data Mining

PoP search results show there are 995 articles for 2013-2023. PoP searches are obtained from the Google Scholar database using the keywords "Geothermal" and "Indonesia". From 995 search articles, researchers selected with the criteria that the articles were in the form of proceedings or journals with research results (not review results) and related to geothermal in Indonesia. In addition, another criterion is that the article is not a dissertation or thesis article. The results of data mining literature are presented in Table 2.

Table 2. Results of Initial Data Analysis

No	Initial Literature Data Mining	Results
1	Publication years	2013-2023
2	Papers	995
3	Citations	20087
4	Authors/paper	3.12
5	H-Index	63

2.3 Literature Data Selection

The selection of literature data is done manually through reading titles and abstracts related to geothermal and Indonesia because in the initial data mining results many references are not in accordance with the topic studied so they need to be omitted from publication or perish. After going through the selection process, 383 relevant articles were obtained, the results of the selection are presented in Table 3.

Table 3. Literature Data Selection Results

No	Literature Data Selection	Results
1	Publication years	2013-2023
2	Papers	383
3	Citations	3225
4	Authors/paper	3.02
5	H-Index	26

2.4 Final Data Mining

383 articles from Google Scholar were downloaded through PoP software to further analyze the content of the article. Each article is reviewed to obtain data related to geothermal research in Indonesia as a new renewable energy substitute.

2.5 Literature Data Extraction and Analysis Data

The data obtained is then analyzed using VOSviewer software which is software for constructing and visualizing bibliometric networks. The analysis in this article is related to geothermal energy research in Indonesia in various power plants in Indonesia.

3. RESULT AND DISCUSSION

3.1 What is the principle of changing geothermal energy into electrical energy?

Geothermal energy is sourced from geothermal. Geothermal energy can be used as an electric power plant by changing and separating energy from geothermal with a separator so that dry steam is obtained to drive electricity-producing turbines, while hot water or brine from the separation of separators is discharged back into the bowels of the earth (11). Geothermal energy does not produce carbon dioxide gas and does not require combustion with coal.

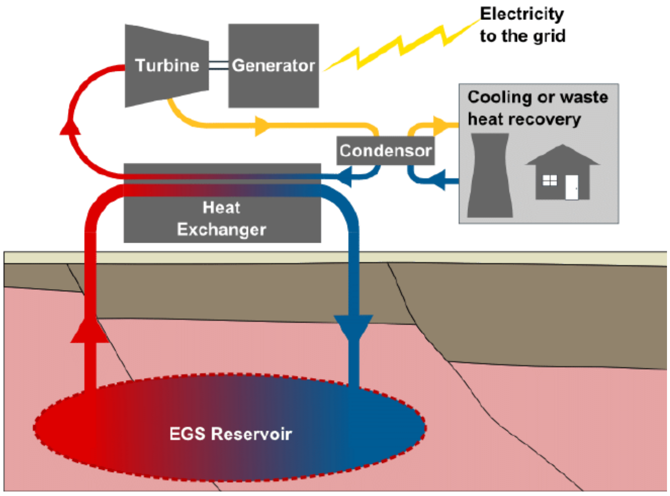


Figure 4. Geothermal Power Plant System
Source : (19)

The principle of changing geothermal energy into electrical energy is like the process of boiling water in a kettle, but the heat in power plants is sourced from geothermal. Geothermal heat originating from magma or hot rocks that melt then forms geothermal resources. The heat becomes a source of energy. Over the course of several years, rainwater enters and seeps through soil and rock and then enters and collects in reservoirs above magma. By magma, the collected water is then heated to 500ºF. To get the hot water and steam, a borehole with a depth of 10,000 feet below the earth's surface is needed. Due to the high pressure in the reservoir area, the vapor will scientifically flow up and through the management facility then through the wellhead and pipes. These pipes will drain steam into a separator that aims to separate steam and hot water. The separated hot water called (brine) will be returned to the reservoir and then heated by the reservoir again. From the separator, hot steam is flowed into the scrubber to separate the hot steam from the impurities and then flowed to the power plant. These vapors will drive the turbines contained in the power plant which then produce electrical charges from the generator magnet. Electric charge is flowed through copper wires and then flowed to transformers outside the plant. Before being supplied to industrial houses, the electric voltage is increased in the transformer.

Basically, geothermal processes occur due to the theory of plate tectonics, namely the existence of phenomena such as earthquakes, the occurrence of mountains, folds, troughs, volcanism processes related to geothermal directly. The structure of the earth from the outside to the inside is the crust on the outermost, mantle, and core on the inside. The deeper it goes, the geothermal heat increases to more or less 4200°C (20).

Geothermal heat will flow to rocks in the earth's crust. Rocks have a melting point lower than the core of the earth so that the rock will melt which is called magma. Because magma has a lower density than rock, the magma will flow to the surface of the earth which will later be called lava, where lava comes out during a volcanic eruption.

There are components needed in the geothermal system, namely:

a. Heat Source

Generally, volcanoes, both active and dormant, are the heat source of geothermal systems. This is found in Indonesia where generally geothermal systems are hydrothermal systems associated with volcanism centers or volcanoes. In this case, the volcano becomes the heat supply of nearby geothermal systems. Therefore, volcanoes are a potential heat source of a geothermal system, so areas that are in the path of volcanoes have great potential to have high temperature geothermal systems (above 225 ^{0}C). This is the reason Indonesia, which is known to be on the ring of fire, is claimed to have the largest geothermal potential in the world. Other potential areas are areas that have high heat capacity due to radioactive decay contained within rocks, areas that have shallow magmatism beneath basemen. However, geothermal in this area is lower than the energy from volcanoes.

b. Reservoir

Geothermal reservoirs are subsurface rock formations capable of storing and draining thermal fluids (steam and/or hot water). Reservoirs are usually rocks that have good porosity and permeability. Porosity plays a role in storing thermal fluid while permeability plays a role in flowing thermal fluid.

c. Recharge

Infiltration areas are areas where groundwater can seep to move below the earth's surface.

d. Discharge

Discharge is an area where soil flows in water can move towards the land surface, or from the inside to the surface of the earth. To be able to know the location of geothermal, research related to geothermal energy reservoirs is needed through various means. The ways to determine the location of geothermal geography are presented in Table 4.

Table 4. Methods of Estimating Geothermal Location

Method	Short description	Advantages	Lack
Surface thermal flux	Estimate the reservoir enthalpy and reservoir temperature by reducing the external heat of thermal manifestations, through combination conductive and convective heat transfer calculations.	The simplest method that requires only thermal surface waste and conductive heat from ground to atmospheric/surface water data	The result of the method. It can only be assumed to be the minimum natural heat flux of the system, so it does not represent the whole reservoir system.
Magmatic heat budget	Estimating the volume of a silicate magma chamber by assessing the age of their location and calculating the amount Geothermal Energy remaining in the intrusion and	This method can be used at the very top in the initial phase	This method only gives a broad picture of accessible resources with little quantitative information that may exist.

	adjacent rustic rock using conventional conductive calculation heat loss.		
Stored heat (volumetric)	One of the oldest methods which uses isotherms for estimates the total amount of heat contained in the reservoir.	The simplest method. One of the most numerous methods. Commonly applied in industry.	a. No or very little experimental evidence to validate the recovery factor used. b. The volume that can be calculated easily is the region with low permeability. c. Frequent causes d. Excessive field capacity.
Numerical modelling	Geothermal resource sharing into that block represents a reservoir Parameters. Active data including temperature, pressure, enthalpy and mass flow are calibrated with stone property, which is suitable with these conditions, resources, starting from the pre-exploitation stage to the stage of presenting production data.	Viewed as the most accurate method	a. Requires deep well or production history data. b. Calibration time and c. The need for high-performance computers

3.2 How is geothermal energy used in the world today?

The use of geothermal energy is generally recorded by the World Geothermal Congress as used by 83 countries, but only 26 countries use geothermal energy as power generation in 2015 (10). Geothermal energy is used in general, such as for heating pumps, toiletries, space heaters, greenhouses for plants, and industrial processes. Of the countries that use geothermal energy as a power plant, there are 9 countries that have the largest geothermal energy electricity capacity in the world as depicted in Table 5.

Table 5. Countries with Geothermal Energy Capacity as the Largest Source of Electricity in the World

Countries	Capacity (MW)						
	2007	2010	2013	2015	2018	2019	2021
United States	2687	3086	3389	3450	3591	3676	3722
Indonesia	992	1197	1333	1340	1948	2133	2276
Philippines	1969.7	1904	1894	1870	1868	1918	1918
Turkiye	38	82	163	397	1200	1526	1710
New Zealand	471.6	628	895	1005	1005	1005	1037
Mexico	953	958	980	1017	951	962.7	962.7
Italy	810.5	843	901	916	944	944	944
Kenya	128.8	167	215	594	676	861	861
Iceland	421.2	575	664	665	755	755	755
Japan	535.2	536	537	519	542	601	603

Source: (21)

Meanwhile, if based on power plants that use geothermal energy, there are 10 largest geothermal power plants in the world in 2021 located in countries in the United States, Italy, Mexico, the Philippines, Iceland, and Indonesia. The geothermal power plants are presented in Table 6.

Table 6. List of the World's Largest Geothermal Power Plants

No.	Power plants	Countries	Capacity (MW)
1.	The Geysers	United states	900
2.	Larderello	Italy	769
3.	Cerro Preito	Mexico	720
4.	Makban	Philippines	458
5.	Hellisheioi	Iceland	400
6.	Malitbong	Philippines	377
7.	Salton Sea	United states	340
8.	Tiwi	Philippines	289
9	Derajat	Indonesia	259
10.	Wayang Windu	Indonesia	227

Source: (22)

3.3 How is the research on the use of geothermal energy so far in Indonesia?

The results of the analysis using VOSviewer obtained network visualization, overlay visualization, and density visualization where this analysis is related to 383 articles. Based on the results of VOSviewer analysis shows that geothermal and Indonesia have a larger size compared to other items. This shows that geothermal words are many and Indonesia is widely used as the current topic researched until 2023. The size of circles and letters in the network visualization indicates the frequency of occurrence, where the larger the size of circles and letters visible, the more those keywords appear in the literature (23). Based on data from 383 articles, 6 clusters with 45 items were obtained which formed 469 links with a power of 2335.

Table 7. Clusters and Items on VOSviewer Analysis

Cluster	Items	Description
1	Application Geothermal energy Geothermal energy utilization Government Indonesia Lahendong North Sulawesi Power generation research Sulawesi Sumatera	Red
2	Area East Java Geothermal energy potential Geothermal energy resources Geothermal industry Geothermal resource Geothermal system Lampung Volcano	Green
3	Development electricity geothermal geothermal development	Blue

	Geothermal energy development Impact Strategy Utilization	
4	Analysis Case study Energy Geothermal power plant Kamojang Renewable energy resources West java	Yellow
5	Aceh exploration Geothermal exploration Geothermal potential Study	Purple
6	Central Java Evaluation Policy Renewable energy	Cyan

Network visualization consists of items represented by labels and networks, where the size of the labels and circles of the items is determined by the number of items. The more an item has, the larger the label and circle size of the item. While the color of an item is represented by clusters on the item. Overlay visualization represents the year in which research related to the item was carried out aimed at color changes, where the more recent the research, the lighter (yellow), the lighter (yellow), the color of the group of items. While the density visualization represents the density of items shown in blue, green, to red. The greater the number of items, the closer the red color is. Conversely, the smaller the number of items, the closer the color is blue.

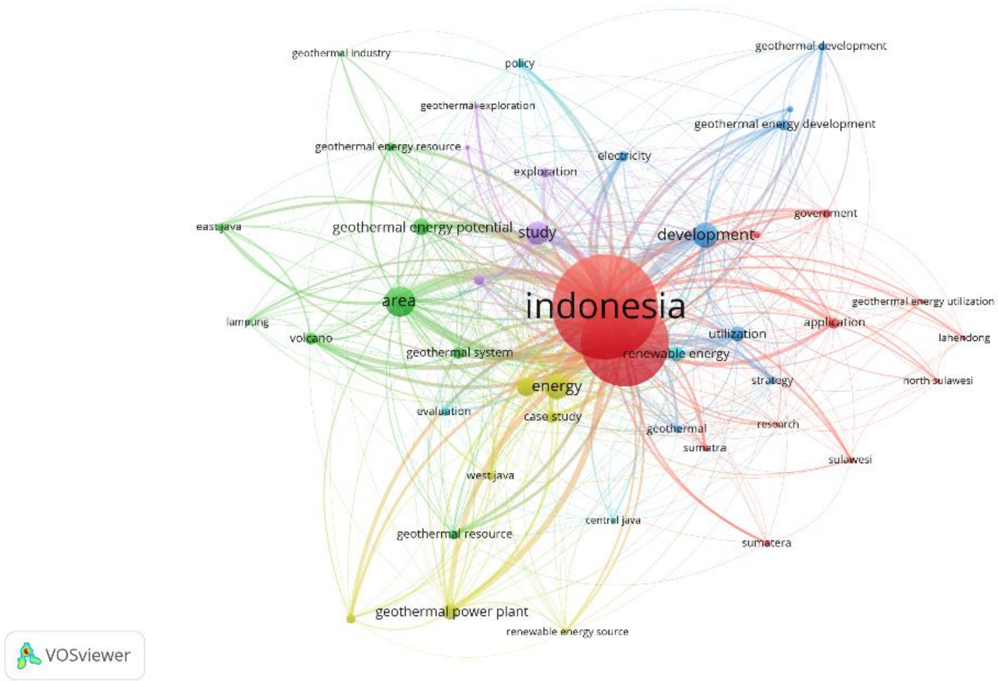


Figure 5. Network Visualization Results

Based on the image of the network visualization results in Figure 5, it shows that geothermal energy and Indonesia are very related and dominate compared to other items. This shows that geothermal energy is the center of attention and began to conduct many research and studies in Indonesia. Based on the results of network visualization also shows that geothermal energy is widely associated with its use as a source of electricity which is a source of new renewable energy. The names of power plants, islands, and provinces that dominate in geothermal energy studies and research in Indonesia are also mentioned, including West Java, East Java, Sumatra, Sulawesi, North Sulawesi, Lampung, and Kamojang. However, some further studies related to geothermal energy in Indonesia are related to policies and strategies that are still little studied. This could be due to previous regulations that prohibited research, study, and exploration of geothermal energy areas around conservation forests (16). Therefore, the author suggests that a deeper study related to geothermal energy regulations in Indonesia can be developed so that the community can play a role in the development of geothermal energy as an alternative energy for power plants in Indonesia.

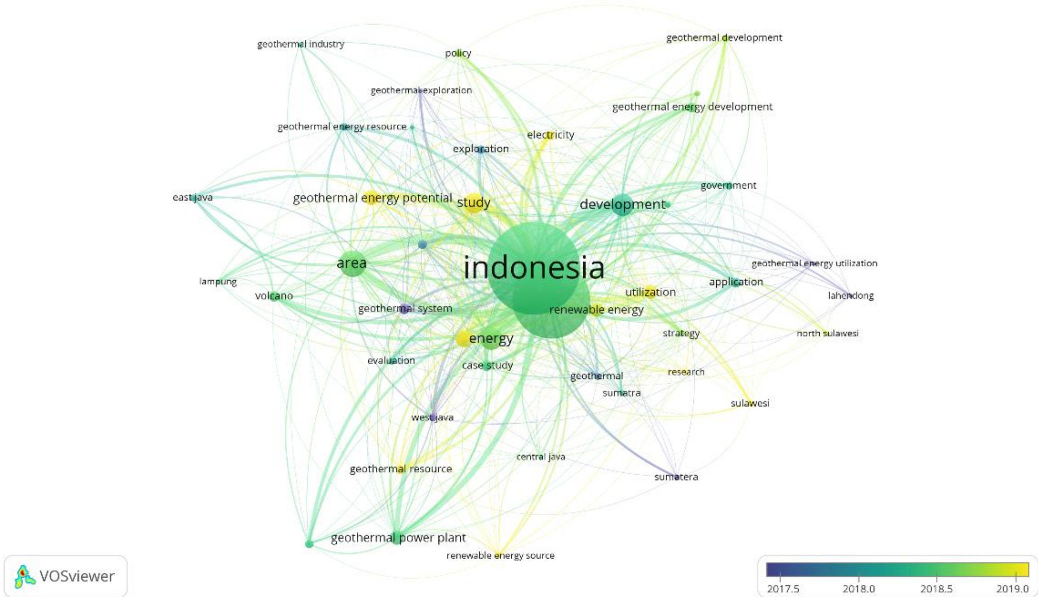


Figure 6. Overlay Visualization Results

Based on Figure 6 which is the result of Overlay Visualization shows that geothermal energy research in Indonesia has become research and studies that have begun to be carried out since the 2018s Research in 2018 shows that Indonesia focuses on areas that have the potential to have geothermal energy. Sumatra Island and West Java Province have been the focus of research since the 2017s, while areas on Sulawesi Island began to be explored and researched since the 2019s. Research in Indonesia until 2023, emphasizes renewable energy sources, electricity, geothermal sources, and the potentials and uses of geothermal energy in Indonesia.

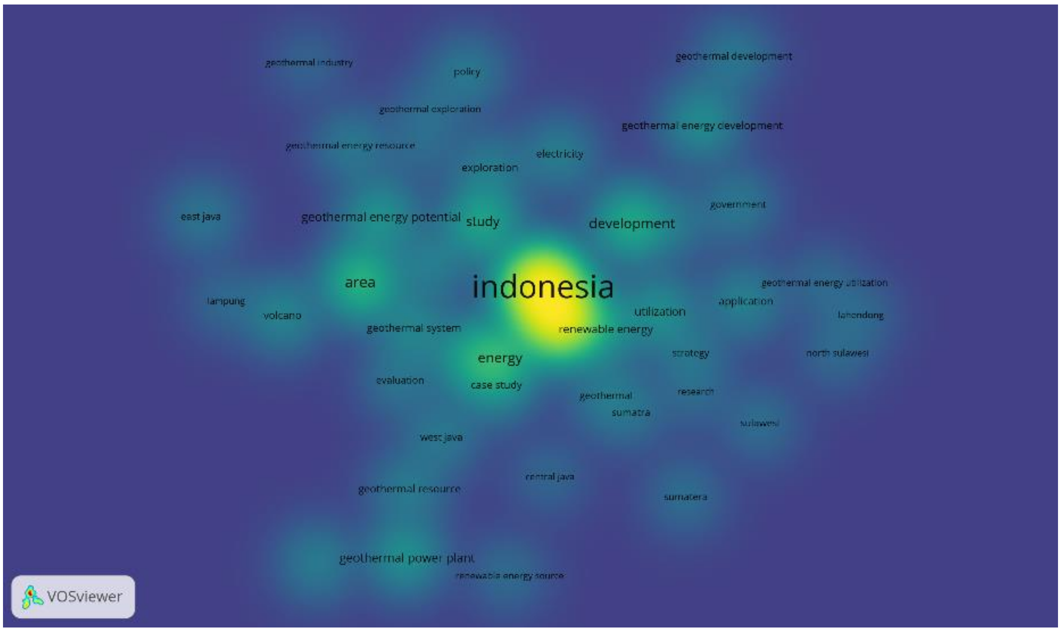


Figure 7. Density Visualization Results

Strengthening VOSviewer analysis in Figures 5 and 6, shows that the results of Density Visualization of geothermal energy items and Indonesia have a greenish-yellow color which means that geothermal energy research and studies in Indonesia are quite a lot in general but to be associated with certain problems and studies are still lacking, such as policies, their use as renewable energy sources, and geothermal energy in certain areas such as in East Java and Central Java, the consequences, and development are still small. We can mention that because the greater the number of items, the closer the red color is. Conversely, the smaller the number of items, the closer the color is blue. Therefore, it is hoped that more research and publications will study geothermal energy in Indonesia.

3.4 What is the potential of geothermal energy as an alternative to power generation in Indonesia?

Referring to several references, geothermal energy has high potential as a power plant in Indonesia to replace coal fuel. This is because geothermal is available in Indonesia in high quantities in Indonesia after water. The reason why Indonesia has high geothermal energy, which is more than 28.61 Gigawatts from low to high enthalpy is because Indonesia is located on the "ring of fire" which is on the boundary of the Pacific Ocean, home of many active volcanoes and earthquakes (24).

Table 8. Development of Renewable Energy with its Target in 2025

No.	Renewable energy	Capacity (MW)					
		2017	2018	2019	2020	2021	2025 (Target)
1.	Water	5.706,8	5.792,7	5.976,0	6.140,6	6.601,9	13.000
2.	Geothermal	1.808,3	1.948,3	2.130,7	2.130,7	2.276,9	6.331
3.	Bioenergy	1.856,8	1.882,8	1.889,8	1.903,9	1.920,4	2.100
4.	Solar	49,7	59,3	134,9	169,3	200,1	6.500
5.	Wind	1,5	143,5	154,3	154,3	154,3	1.900

Sources : (25) (26)

Based on data from the Ministry of Energy and Mineral Resources (2019), Geothermal sources and reserves that are currently studied on eight islands of Indonesia, Indonesia have a geothermal potential of 23765.5 MW or 23.7 GB which has currently been studied for its potential. Resources are mining resources contained within the earth whereas Reserves are the part of Resources that allow them to be mined. Proven reserves are estimates of petroleum volumes that can be taken with a high degree of confidence.

Probabilistically, this high level of confidence translates as there is a 90% chance that the volume taken will be greater than that listed as proven reserves. A reserve may be an incremental volume that has the opportunity to be produced when viewed from a reference to the volume of proven reserves.

Table 9. Geothermal Potential Areas in Indonesia

Region	Province	Number of dots	Resources		Reserves			Total (MW)
			Speculative	Hypothesis	Possible	Probable	Proven	
Sumatera	Aceh	19	324	22	515	25	0	1086
	Sumatera Utara	18	250	388	705	180	503	2026
	West Sumatra	19	471	579	495	50	85	1680
	Riau	4	45	0	0	0	0	45
	Jambi	9	352	87	319	54	0	812
	Bengkulu	5	134	0	299	221	110	764
	Bangka Belitung Islands	7	100	5	0	0	0	105
	South Sumatra	7	225	230	363	221	202	1241
	Lampung	13	375	40	898	225	220	1758
Java	Banten	7	125	161	365	0	0	651
	West Java	42	985	469	1555	174	1580	4763
	Central Java	14	79	271	622	130	240	1342
	D.I. Yogyakarta	1	0	0	10	0	0	10
	East Java	11	70	290	851	73	0	1284
Bali- Nusa Tenggara	Bali	6	70	21	104	110	30	335
	West Nusa Tenggara	3	0	6	169	0	0	175
	East Nusa Tenggara	31	225	142	723	121	12.5	1223.5
Kalimantan	West Kalimantan	5	65	0	0	0	0	65
	East Kalimantan	2	17	0	0	0	0	1
	North Kalimantan	4	20	17	6	0	0	43
	South Kalimantan	3	49	1	0	0	0	50
Sulawesi	Sulawesi Utara	9	55	73	410	180	120	838
	Gorontalo	5	129	11	20	0	0	160
	Central Sulawesi	30	401	64	368	0	0	833
	South Sulawesi	21	259	117	140	0	0	516
	Southeast Sulawesi	13	200	25	93	0	0	318
	West Sulawesi	13	321	53	32	0	0	406
Maluku-Papua	North Maluku	15	190	7	379	0	0	576
	Maluku	18	370	84	106	6	2	568
	West Papua	3	75	0	0	0	0	75
Total			**5981**	**3363**	**9547**	**1770**	**3104.5**	**23765.5**

Source: (27)

Data from (27) shows that Indonesia has a geothermal energy potential of 23.7 GW for those studied, while data from World Wide Fund for Nature [WWF], (2012), Indonesia has a geothermal potential of more than 29 GW. This number places Indonesia as one of the countries with geothermal energy covering 40% of the world's geothermal energy supplies (28). Therefore, geothermal energy potential data has the opportunity to increase if more research is carried out to find potential areas of geothermal energy. Besides that, based on the data in Table 9 it also shows that West Java Province has the highest geothermal potential compared to other regions. Therefore, further research and utilization of geothermal energy in West Java province is very necessary

Although until now, research proves that Indonesia has geothermal energy of 23.7 GW, only about 2.1 GW is currently used in Indonesia. This is confirmed by Permana, (2022) which explains that Indonesia has 23.36 GW of geothermal energy, but only 2.29 GW has been utilized (29). The utilization of geothermal energy includes 16 Thermal Power

Plants spread across several islands in Indonesia, such as Sumatra, Java, Nusa Teggara, and Sulawesi. The data related to Thermal Power Plants (PLTP) in Indonesia are presented in Table 10.

Table 10. Data on Thermal Power Plants (PLTP) in Indonesia

No.	PLTP	Operator	Total Energy Capacity (MW)	Geothermal Area
1.	PLTP Sibayak	PT Pertamina Geothermal Energy	12	Sibayak-Sinabung, North Sumatra
2.	PLTP Sarulla	Sarulla Operation Ltd	330	Sibual-buali, North Sumatra
3.	PLTP Ulubelu	PT Pertamina Geothermal Energy	220	Waypanas, Lampung
4.	PLTP Salak	PT Star Energy Geothermal Salak	377	Cibeureum Parabakti, West Java
5.	PLTP Wayang Windu	PT Star Energy Geothermal Wayang Windu	227	Pangalengan, West Java
6.	PLTP Patuha	PT Geo DIpa Energy	55	Pangalengan, West Java
7.	PLTP Kamojang	PT Pertamina Geothermal Energy	235	Kamojang-Darajat, West Java
8.	PLTP Darajat	PT Star Energy Geothermal Darajat	270	Kamojang-Darajat, West Java
9.	PLTP Dieng	PT Geo DIpa Energy	60	Dataran tinggi Dieng, Central Java
10.	PLTP Karaha	PT Pertamina Geothermal Energy	30	Karaha Bodas, West Java
11.	PLTP Matalako	PT PLN Indonesia	2,5	Matalako, East Nusa Tenggara
12.	PLTP Ulumbu	PT PLN Indonesia	10	Ulumbu, East Nusa Tenggara
13.	PLTP lahendong	PT Pertamina Geothermal Energy	120	Lahendong Tompaso, North Sulawesi
14.	PLTP Lumut Balai	PT Pertamina Geothermal Energy	55	West Java
15.	PLTP Sorik Merapi	PT Sorik Marapi Geothermal Power (SMGP)	42,4	North Sumatra
16.	PLTP Muara Laboh	PT Supreme Energi Muara Laboh (SEML)	85	West Sumatra
Total			**2.128,4**	

Source: (30)

3.5 What are the challenges and solutions in developing geothermal energy as an alternative to power generation in Indonesia?

Based on the analysis of the review that has been carried out, Indonesia has a high potential for geothermal energy. However, to develop geothermal energy, Indonesia has several challenges that are currently still being worked on. The challenges and solutions are presented in Table 11. These solutions are already underway, and efforts are being made for further implementation.

Table 11. Challenges and Solutions to Develop Geothermal Energy as an Alternative to Power Generation in Indonesia

No.	Challenges	Solution
1.	Many geothermal areas are located in conservation forest areas. Indonesia's Forest Law prohibits mining operations in conservation forests. Geothermal is included in mining activities.	The new Geothermal Regulation No. 21/2014 explains that geothermal as an energy process rather than a mining activity. This Ministerial Regulation on Forests prevents the development of Geothermal projects in forest conservation or other areas.
2.	The lack of funds provided by the Government of Indonesia in carrying out geothermal exploration has resulted in national geothermal developers facing the problem of increasing funds when carrying out dangerous exploration.	The government has set a cost of as much as 3 trillion to anticipate the possibility of exploration. Research has been carried out to design hazard guarantees from geothermal exploration.
3.	Lack of competence among local government employees to manage the tender process.	New Regulation on Geothermal No. 21 of 2014 states that the geothermal tender process by the Central Government
4.	The hatred of local people for geothermal development in their area relates to roads and locations and their benefits in the project for them.	New Geothermal Regulation No. 21 of 2014 stipulates that regions will receive geothermal production bonuses
5.	As a result of the economic and financing crisis, the exchange rate increased drastically from 2400 to 16,000 rupiah to US Dollars. PLN pays for electricity from US dollar IPPs and pays them to consumers in rupiah.	Renegotiate ESC/PPA contracts to lower electricity costs. Postpone projects and negotiate contracts and resettle them through international arbitration law
6.	a. In proper geothermal pricing policies, economic value is not met to attract investment b. The high cost of electricity from geothermal electricity does not meet the criteria and is only of sufficient value c. Thinking about the high cost of geothermal electricity compared to electricity from coal	a. The regulation of MERM No. 17 of 2014 introduces a new cost of geothermal electricity, it relies on the capacity and location of geothermal power plants to attract investment b. Ministerial Regulation No. 49 and 50 of 2017 retracts the fee rule and replaces it with 85% of the National BPP and establishes other costs and fee schemes to reduce electricity costs.

7.	Increased cost of land compensation for roads and locations.	Local governments need to create new breakthroughs
8.	Long process for licensing and licensing.	The Indonesian government has established a one-stop policy for licensing and licensing. The number of licenses and litigations has been reduced from 96 to 34 and will be reduced further.

Sources: (16), (28)

4. Conclusion

The result of the literature review presents the principle of changing geothermal energy into electrical energy. Geothermal evaporates water in the reservoir and the water vapor is taken up by the well and the steam is separated from the water. The steam is, furthermore, flowed to the power plant so that it can drive turbines and generate electricity. The use of geothermal energy in the world as a power plant is currently still relatively small, because only 26 countries out of 83 countries use geothermal energy as a source of electricity. The top 10 geothermal producing countries include the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Italy, Kenya, Iceland, and Japan.

Research on the use of geothermal energy so far in Indonesia is still little that examines the specifics of certain topics, such as policy, its use, development, and exploration. To teach about new renewable energy, education is needed both for the community through service and for students as the next generation of the nation through education in Indonesia.

Indonesia has the potential of geothermal energy as an alternative power plant for good because Indonesia is in the "ring of Fire" area and has many volcanic mountains. This puts Indonesia as one of the countries with geothermal energy potential. As it has a potential energy of more than 29 Giga Watt. There are several challenges and solutions when developing geothermal energy as power generation energy in Indonesia, one of which is that many geothermal areas are in conservation forest areas, where there are laws prohibiting mining operations in conservation forests. The solution provided is the existence of a new law, namely Law on Geothermal No. 21/2014 explaining that geothermal as an energy process rather than a mining activity. This Ministerial Regulation on Forests encourages the development of Geothermal projects in forest conservation or other areas.

References

1. P. Lumbantoruan, “Uji Linieritas Antara Beda Potenial Dengan Kuat Arus Listrik Pada Beberapa Medium,” *J. Penelit. Fis. dan Ter.*, vol. 1, no. 1, p. 20, 2019, doi: https://doi.org/10.31851/jupiter.v1i1.3109.
2. Direktorat Jenderal Energi Baru Terbarukan dan Konservasi Energi, “Dirjen EBTKE Paparkan Pemenuhan Kebutuhan Listrik Indonesia Melalui Pemanfaatan EBT,” 2023. https://ebtke.esdm.go.id/post/2023/01/20/3405/dirjen.ebtke.paparkan.pemenuhan.kebutuhan.listrik.indonesia.melalui.pemanfaatan.ebt.
3. CEIC, “Indonesia Electricity Production,” 2022. https://www.ceicdata.com/en/indicator/indonesia/electricity-production.
4. Kementrian Energi dan Sumber Daya Mineral Direktrat Jenderal Keteragalistrikan, “Statistik Kelistrikan 2020,” *Kementrian Energi dan Sumber Daya Miner. Direktrat Jenderal Keteragalistrikan*, vol. 13, no. April, p. 122, 2021.
5. Statista, “Electricity consumption per capita in Indonesia from 2015 to 2022, with targets until 2024,” 2023. https://www.statista.com/statistics/1092084/household-electricity-consumption-per-capita/.
6. Latif Adam, “Dinamika Sektor Kelistrikan Di Indonesia: Kebutuhan Dan Performa Penyediaan,” *J. Ekon. dan Pembang.*, vol. 24 no. 1, pp. 29–41, 2016.
7. Databook, “PLTU Mendominasi Kapasitas Terpasang Pembangkit Listrik di Indonesia pada 2021,” 2023. https://databoks.katadata.co.id/datapublish/2023/02/21/pltu-mendominasi-kapasitas-terpasang-pembangkit-listrik-di-indonesia-pada-2021.

8. M. A. Sihotang and K. Okajima, "Photovoltaic Power Potential Analysis in Equator Territorial: Case Study of Makassar City, Indonesia," *J. Power Energy Eng.*, vol. 05, no. 01, pp. 15–29, 2017, doi: 10.4236/jpee.2017.51002.
9. B. A. Prakoso *et al.*, "EVALUASI DAMPAK PEMBANGUNAN PEMBANGKIT LISTRIK TENAGA UAP (PLTU) TANJUNG JATI B di DESA TUBANAN KECAMATAN KEMBANG KABUPATEN JEPARA," *Juournal Public Policy Manag. Rev.*, vol. 5, no. 2, pp. 1–14, 2016, [Online]. Available: https://ejournal3.undip.ac.id/index.php/jppmr/article/view/10898.
10. A. Manzella, "Geothermal energy," *EPJ Web Conf.*, vol. 148, pp. 1–26, 2017, doi: https://doi.org/10.1051/epjconf/201714800012.
11. G. A. Kusuma, G. Mangindaan, and M. Pakiding, "Analisa Efisiensi Thermal Pembangkit Listrik Tenaga Panas Bumi Lahendong Unit 5 Dan 6 Di Tompaso," *J. Tek. Elektro dan Komput.*, vol. 7, no. 2, pp. 123–134, 2018.
12. A. El Fandari, A. Daryanto, and G. Suprayitno, "Pengembangan Energi Panas Bumi," *J. Ilm. Semesta Tek.*, vol. 17, no. 1, pp. 68–82, 2014.
13. World Wide Fund for Nature [WWF], *Igniting the Ring of Fire : A Vision for Developing Indonesia's Geothermal Power*. Jakarta: WWF, 2012.
14. H. Meilani and D. Wuryandani, "Potensi Panas Bumi Sebagai Energi Alternatif Pengganti Bahan Bakar Fosil Untuk Pembangkit Tenaga Listrik Di Indonesia," *J. Ekon. dan Kebijak. Publik*, vol. 1, no. 1, pp. 47–74, 2010.
15. D. Purba *et al.*, "Expediting Geothermal Exploration in Indonesia : Should We Consider Slimhole Drilling ?," *PROCEEDINGS, 46th Work. Geotherm. Reserv. Eng.*, no. December, pp. 0–11, 2021.
16. A. Wahjosoedibjo and Madjedi Hasan, "Indonesia's Geothermal Development: Where is it Going?," in *Proceedings 43rd Workshop on Geothermal Reservoir Engineering*, 2018, pp. 1–12.
17. N. J. Van Eck and L. Waltman, "Manual VOSviewer," *Univeristeit Leiden*, no. January, p. 54, 2021.
18. J. A. Garza-Reyes, "Lean and green-a systematic review of the state of the art literature," *J. Clean. Prod.*, vol. 102, pp. 18–29, 2015, doi: https://doi.org/10.1016/j.jclepro.2015.04.064.
19. J. Hayward and P. Graham, *Developments in technology cost drivers–dynamics of technological change and market forces*, vol. 2011, no. April 5. 2011.
20. W. J. Wadsworth Dr., "Processes in Magma Chambers," *J. Geol. Soc. London.*, vol. 138, no. 3, pp. 221–222, 1981, doi: https://doi.org/10.1144/gsjgs.138.3.0221.
21. T. Geoenergy, "ThinkGeoEnergy's Top 10 Geothermal Countries 2021 – installed power generation capacity (MWe)," 2022. https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2021-installed-power-generation-capacity-mwe/.
22. Statista, "Ranking of Largest Geothermal Plants Worldwide as of January 2021," 2023. https://www.statista.com/statistics/525206/geothermal-complexes-worldwide-by-size/#:~:text=The largest geothermal plant in,located north of San Francisco.
23. Kartimi Kartimi, Y. Yunita, I. Addiin, and A. S. Shidiq, "A Bibliometric Analysis on Chemistry Virtual Laboratory," *הארץ*, vol. 33, no. 8.5.2017, pp. 2003–2005, 2021.
24. S. W. Yudha, B. Tjahjono, and P. Longhurst, "Unearthing the Dynamics of Indonesia's Geothermal Energy Developmen," *Energies*, vol. 15, no. 5009, pp. 1–18, 2022.
25. Indonesia-Investment, "Wind Power Generation in Indonesia; What Are the Challenges & Opportunities?," 2023. https://www.indonesia-investments.com/news/news-columns/wind-power-generation-in-indonesia-what-are-the-challenges-opportunities/item9505.
26. D. J. E. B. T. dan K. E. (EBTKE), "KESDM – Danish Energy Agency Luncurkan Laporan Renewable Energy Pipeline," 2023. https://ebtke.esdm.go.id/post/2021/09/13/2960/kesdm.danish.energy.agency.luncurkan.laporan.renewable.energy.pipeline?lang=en.
27. T. dan K. E. Layanan Informasi dan Investigasi Energi Baru, "Potensi Pengembangan Energi Panas Bumi di Indonesia," 2023. https://ebtke.esdm.go.id/lintas/id/investasi-ebtke/sektor-panas-bumi/potensi.
28. A. Aziz, "SWOT Analysis on Geothermal Energy Development in Indonesia and Fiscal

Incentives Needed," *Int. J. Smart Grid Clean Energy*, vol. 10, no. 3, pp. 234–243, 2021, doi: 10.12720/sgce.10.3.234-243.

29. A. Permana, "Determining Indonesia Geothermal Potential and Its Current Development," 2022. https://www.itb.ac.id/news/determining-indonesia-geothermal-potential-and-its-current-development/58683#:~:text=Moreover%2C geothermal is considered a,investment value of 0.731 USD.
30. A. C. Adi, "2019 Handbook of Energy and Economic Statistics of Indonesia (HEESI)," *Minist. Energy Miner. Resour.*, p. 129, 2019, [Online]. Available: https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia.pdf.