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Geothermal Energy as An Alternative Source for Indonesia's Energy Security: The Prospect and Challenges

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ABSTRACT

Geothermal energy is a naturally occurring energy resource widely distributed in Indonesia. By 2025, the Indonesian government is expecting a rise in renewable energy installations to supply energy demand within the country. With 1,945 MW of installed capacity reported in 2017, the electricity production from geothermal power plant are expected to meet such electricity demand. Indonesia holds a large potential in geothermal energy with the possibility to meet the energy demand due to population growth. However, geothermal energy faces a challenge when competing with national LCOE. The role of government to create policy and stakeholder to provide technical aids are vital to attract investors to develop environmentally friendly and sustainable geothermal energy.

Keywords: geothermal; energy security; electricity; Indonesia; geothermal power plants.

1. Introduction

Climate change and global warming have become a concern for the past 150 years due to the rapid change in the atmospheric condition (Wuebbles *et al*, 2017). Carbon dioxide (CO_2) emissions are currently proposed as the main drive for climatic change (Le Treut *et al*, 2007). One of the sources of CO_2 emissions is the side products of power plant generation mainly from fossil fuel (Macdonald, Donner and Nikiforuk, 1996). The abatement of CO_2 can be significantly reduced as renewable energy is slowly introduced to replace fossil fuel power plants (Gielen D. *et al*, 2019). The National Energy Council of Indonesia has declared to install 7241.5 MW of renewable energy by 2025 based on Presidential Decree No.22 2017, where geothermal energy can serve as an energy source to produce electricity besides hydro, micro-hydro, solar and wind energy.

Benefiting from the location within the ring of fire, Indonesia currently 25.386 MW of geothermal energy. As illustrated in figure 1, Indonesia's Ministry of Energy and Mineral Resources (hereafter will be referred as MEMR) in 2018 reported that 2045.6 MW of the speculated geothermal energy is installed, rationing at only 7% capacity installed. In accordance with the electricity demand and regulation, it is essential to ensure the growth of clean and sustainable energy resources (Bilgen *et al*, 2004). This paper will overview the

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prospect and challenges of geothermal energy development in Indonesia. The analysis will be based on the installed capacity, electrification rate, and possible energy demand within 2035-2045 based on the population growth.

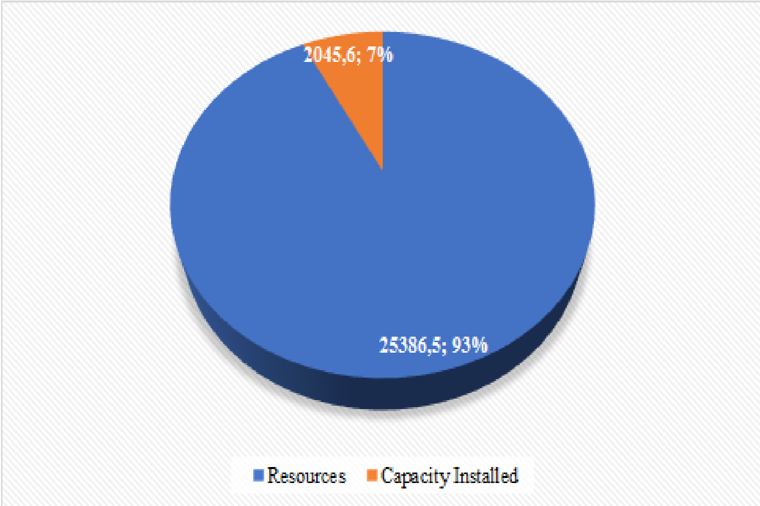

Figure 1. Geothermal Energy Potential and Production per 2018 in MW; % (MEMR, 2018)

2. Literature Review

2.1. Geothermal Energy

Geothermal energy is produced by the conversion of thermal energy produced within the Earth's crust (i.e. heat source) and transported to the surface as the heat sink through conduction or convection of heat (Hochstein *et al*, 2000). During the movement of heat to the surface, the surrounding host rocks are heated up along with the fluid trapped within the lithologies known as a geothermal reservoir. These fluids will be available for extraction if the fluid parameters such as pH, temperature, and if any fluid pathway such as fractures and faults are present as fluid pathways. The recharge-discharge of geofluid in a geothermal area must be highly monitored to maintain the geothermal reservoir condition (DiPippo, 2008). The electricity is then produced from a geothermal well after the extracted geothermal fluids are converted into a power plant. Geothermal fluid is converted to steam after being passed through a conventional power plant energy generation. Following the electricity generation is the distribution of electricity.

The main advantage of geothermal energy is that geothermal energy is independent of any weather, season, and climate as the thermal energy will continue to produce all year long (Goldstein *et al*, 2012). Some of the highest geothermal energy producers rely mostly on the presence of volcanic activities due to the stable heat generation from its source (Sigurdsson, 2015). Moreover, geothermal energy production indicated low greenhouse emission compared to conventional fossil fuel power plants. Even in some binary power plant, the emissions of CO_2 are negligible (DiPippo, 2008)

In 2018, Indonesia is ranked second in speculated resources and installed capacity for geothermal energy (MEMR, 2018). Currently, Indonesia holds 25386 MW or approximately 21.22% of the world's total geothermal energy, and only 1948.5 MW installed. With a 7.68 ratio of resources to installed capacity, Indonesia is still behind the Philippines, New Zealand respectively. The Philippines are currently loaded at 47.9 resources to installed capacity ratio, significantly higher than Italy and Turkey.

Table 1. Geothermal energy in a global scale (Think Geo Energy, 2019)

Countries	Resource		Installed Capacity		Ratio (installed: resource)
	in MW	%	in MW	%	
United States	30000	25.08	3639	26.57	12.13
Indonesia	25386	21.22	1948.5	14.23	7.68
The Philippines	4000	3.34	1916	13.99	47.9
Turkey	4500	3.76	1347	9.84	29.93
New Zealand	3650	3.05	1005	7.34	27.53
Mexico	4600	3.85	951	6.94	20.67
Italy	3270	2.73	944	6.89	28.87
Iceland	5800	4.85	755	5.51	13.02
Kenya	15000	12.54	646	4.72	4.31
Japan	23400	19.56	542	3.96	2.32

Geothermal project development is considered costly with a typical cost of geothermal power plants ranging from USD 1.870 to 5.050 per kilowatt (kW) (IRENA, 2017). In 2019, ACE reported that in Indonesia the installation cost for geothermal plant range from USD 6.251 to 12.075 per kW averaging at USD 8.593 kW. The project cost varies depending on the capital expenditure such as well drilling, site clearing, and also depending on the discount rate determined by the government. However, it is predicted that geothermal project development cost is to decline by 2050 (IRENA, 2017a) as the technologies will improve over time and the demand for renewable energy supply is high by then.

2.2. Indonesia's Electricity Generation and Consumption

In Indonesia, the main sole distributor of electricity is conducted by State-Owned Electricity Company, PT. PLN Persero. It is reported that the main source for electricity demands originated from fossil fuel power plants (in the form of diesel or steam power plants) reaching up to 17500 MW from a total of 61669 MW installed capacity (ICBS, 2020). In 2018, only 4.52% of the installed capacity originates from renewable energy such as hydropower and geothermal power.

2.3. Population Growth in Indonesia

Indonesia's Central Bureau of Statistics and National Development Planning Agency (2013) projected population growth of 67.1 million in 2035, equal to 305.6 million population. Population growth is measured based on fertility rate, mortality rate, and migration rate (international, transmigration, or urbanization) (ICBS, 2013). In the year 2020 – 2035 the population growth will not be centralized in Java island as Java is currently the densest and populated island. The population growth is projected to be in Kalimantan, Maluku, and Papua reaching up to 1.23% of growth or equal to 28.4 million of population within those regions.

The rising population growth as the main concern in energy security fulfillment in Indonesia (Prasodjo *et al*, 2016, McNeil *et al*, 2017). Increasing populations will subsequently also increase the trend of economic growth, resulting in a greater number of households that could purchase electricity and energy demand as shown in Figure 2.

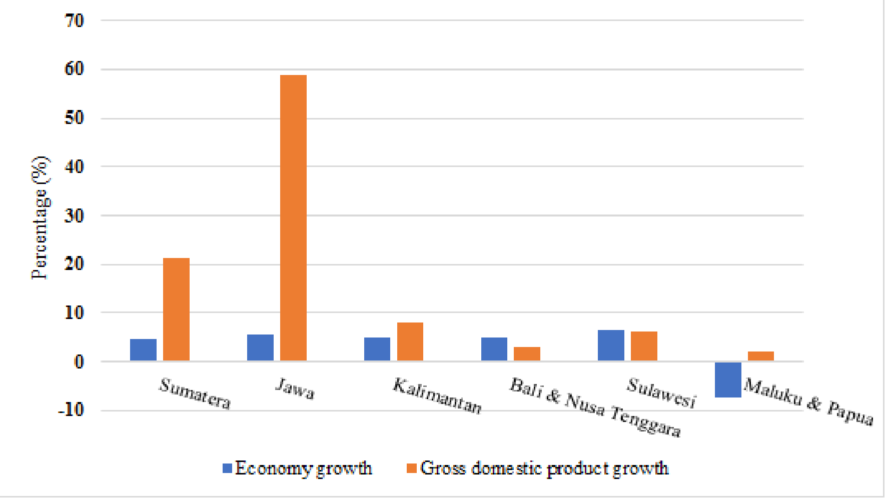

Figure 2. Economy growth and Gross Domestic Product growth (BPS, 2020)

2.4. CO_2 emission from energy sector

Greenhouse gasses such as CO_2 have risen significantly following the start of pre-industrial time and are said to have increased global temperatures by 1º C (Ritchie and Roser, 2017). Several factors that contribute to greenhouse emissions are energy producers as example burning fossil fuels, human activity since the industrial revolution, waste, and increasing population number (Reichard, S., 2011). Based on Gütschow *et al* (2016), Indonesia produces more than 590 metric tons of CO_2 by 2017 and indicates an increasing trend of CO_2 emission since 2000, where more than 85% of the CO_2 emissions are contributed by the energy sectors. This data can be supported with the number of electricity generated by the power plant are mostly fossil fuel power plant (Suharyati *et al*, 2019) and also the fulfillment for higher electrification rate (I

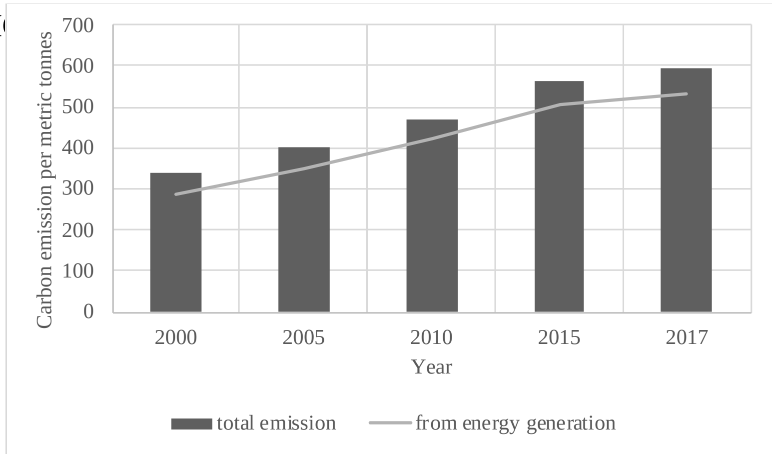

Figure 3. Total CO_2 emission in Indonesia from 2000 – 2017 (Modified from Gütschow *et al*., 2016)

3. Research Methodology

For this research, the main methodology is data acquisition from the official government bureau's, state-owned company and non-government organization (NGO) reports on geothermal energy capacity, electricity installation, usage and demands, population census from. The data will be narrowed down from the year 2010 to 2020 and the projected year is in 2035. Furthermore, the data will be filtered based on large islands (i.e. Sumatera, Java, Kalimantan, etc). The obtained data will then be narrowed down, extrapolated, and analyzed according to the correlated trend that will help the analysis of geothermal growth in Indonesia.

Indonesia's Central Bureau of Statistics website will provide the main data source in terms of population number, electricity usage, and capacity, rate of electrification, installment of renewable energy power plant. As for another source of data, we will utilize data from

Indonesia's ministries and state-owned companies as well as NGO reports on capacity in Renewable Energy both nationally and globally.

4. Results

4.1. Electricity generation from geothermal energy

ICBS (2020) and State Electricity Company (2016) reported that geothermal energy has been providing electricity since the 1990s. The data extrapolated were based on 15 years trend (Figure 4), showing that from 2010, the electricity generated from geothermal energy had increased. The ratio of geothermal energy to total energy generated had unstable fluctuation ranging just around 2-4% of the overall generated energy in Indonesia. Although there seem to be an increasing geothermal energy power capacity in the 2010s, the ratios maintained at a lower level (< 3%) because on the other side of the geothermal exploration, geoscientist researcher unveiled larger geothermal energy potential but unable to exploit all the available energy due to high risk of exploration (Antonaria *et al*, 2014).

Furthermore, State Electricity Company (2016) reported only five (out of 34) provinces in Indonesia that are located at the proximity of geothermal power plants, North Sumatera, Lampung, West Java, North Sulawesi dan East Nusa Tenggara (Figure 5). These provinces are known to have high enthalpy-volcanic geothermal energy (MEMR, 2017) and could generate sufficient energy with no intermittent period.

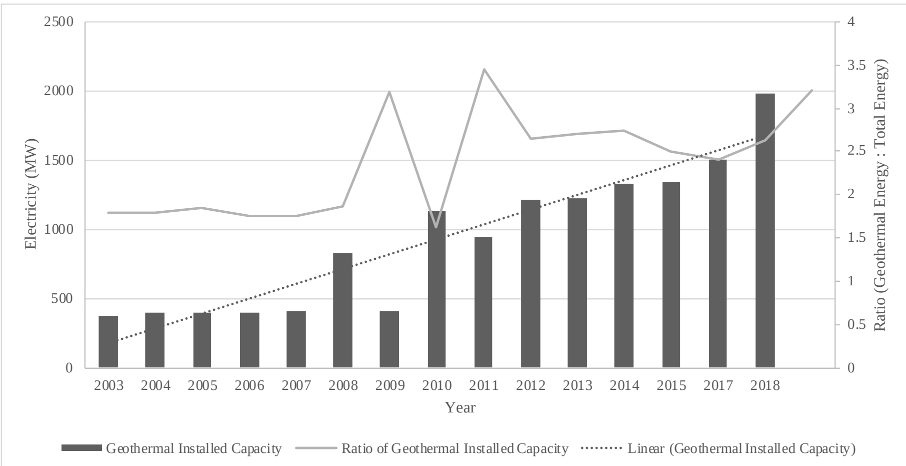

Figure 4. Geothermal installed capacity in 15 years (reproduced from ICBS, 2020)

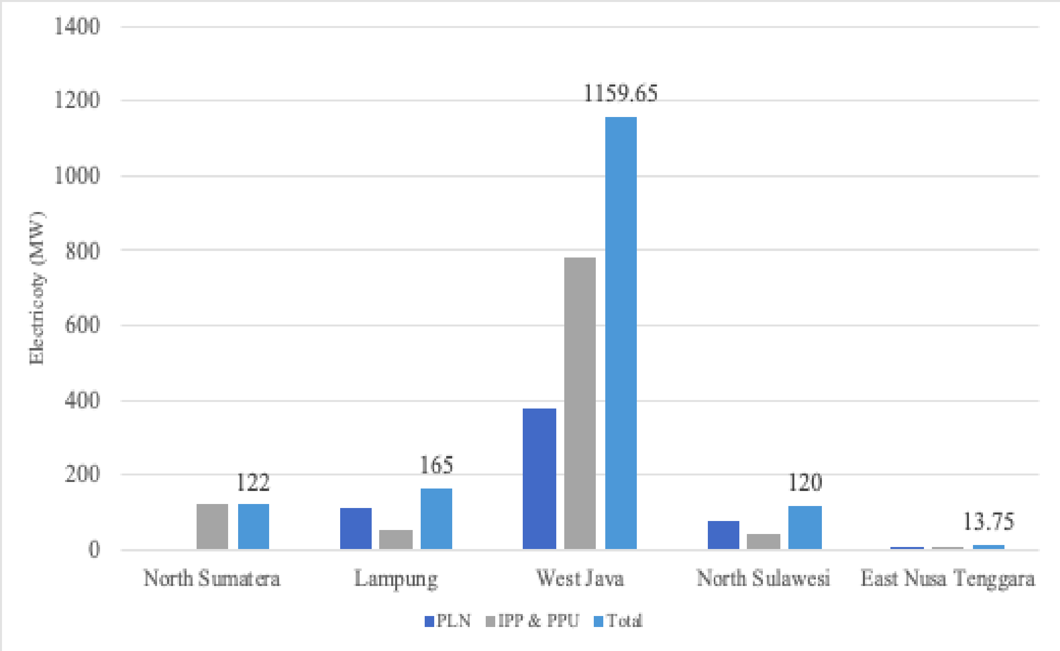

Figure 5. Geothermal power plants electricity of five provinces in Indonesia (State Electricity Company, 2016)

When determining the electricity price for geothermal energy (considered as Renewable Energy source), State Electricity Company had to comply with the Presidential Decree on Renewable Energy IPP electricity price. Currently, the national levelized cost of electricity (LCOE) supply is priced at 7.86 cents USD/kWh (MEMR, 2019). As for Renewable Energy IPP, the price is varied and is rated based on the net total capacity that could be generated from a geothermal power plant (Table 2). The larger enthalpy geothermal system has a higher chance to produce energy and thus more likely to compete with the national LCOE, where fossil fuel serves as the benchmark price for electricity cost.

Table 2. LCOE price for geothermal power plant based on total capacity (MEMR, 2019)

Total Capacity (in MW)	Price (cent USD/kWh)
10	13,380
> 10-50	12,500
> 50 - 100	11,768
> 100 - 200	11,410
> 200	9,550

OECD (2011) stated that the world is currently facing increasing energy demand due to growth in population and economic requiring 90% of energy demand growth in 2035. On the contrary, only 80% of the world's population is provided with energy security or having access to electricity. McNeil *et. al* (2019) mentioned that electricity demand in Indonesia will rise significantly due to the rapid and robust economic growth combined with unpredicted urbanization and further development of industries sectors. Based on the data acquisition of population growth from ICBS (2020), it is predicted that Indonesia will have to face increasing demand for electricity to facilitate population migration and industrialization. The aim of providing electricity to non-electricity households will be another factor for electricity demand (i.e. electrification rate).

Figure 6. Electricity demand based on the trending population growth (State Electricity Company, 2016 and ICBS, 2020)

The interpolation of data in Figure 6 predicted that Java Island will have the highest electricity demand due to the densely populated Java projected in the year 2035. Following Java, Sumatera will second for energy demand though the differential gap between Java and Sumatera is quite significant. This is most likely due to the central business and industrial areas are mostly located in Java rather than Sumatera. The need for human resources in industries and business will be the main factor for population growth within these regions.

4.3 Geothermal energy availability and costs

IESR and MEMR (2019) reported the overall potential of geothermal energy widely spread in the archipelago of Indonesia (summarized in Table 3). Sumatra holds the highest geothermal potential but with exploited geothermal energy only at 7.1%. Meanwhile, Java has the second-highest potential and has already exploit 19.3% of the proven reserve energy. The low exploitation in Sumatera is likely due to the active tectonic movement causing a higher risk of exploitation within the region and the proximity of geothermal resources to the conservation national forest. The development in the national forest are limited due to the regulations of national forestry (Indonesia Constitution No.41, 1999 on Forestry)

Table 3. Total of geothermal potential and geothermal capacity by regions.

Region	Geothermal Potential Total (MW) (IESR, 2019)	Geothermal Capacity (MW) (MEMR, 2019)
Sumatera	7387.0	525.0
Jawa	6496.0	1254.0
Kalimantan	-	-
Bali & Nusa Tenggara	1194.0	12.5
Sulawesi	1669.0	120.0
Maluku	800.0	-
Papua	-	-

In 2019, MEMR reported that there are nine provinces with electricity production price below the LCOE (< 7.86 cent USD/kWh). Other 25 provinces, mostly the provinces in Kalimantan, Sumatera and Sulawesi, has electricity production price above national's LCOE (Table 3). Comparing to IPP regulation for geothermal energy production, geothermal LCOE can compete and thus favouring faster rate of Break-Even Point from CAPEX and OPEX cost of geothermal power plant. With installation cost for geothermal aforementioned in the previous section of this article, the breakeven points for geothermal investment should last for 20 years if the electricity produced is sold at the basic feed in tariff for geothermal energy (ESMAP, 2012)

5. Discussion

The current projection for geothermal energy in Indonesia is as follows (IRENA 2017b, IESR, 2019, MEMR, 2019). Indonesia currently own 17.2 GW of reserve geothermal energy based on detailed investigations and another 12.2 GW of speculative and hypothetical energy with the probability of an overestimation. The government targeted to develop 185 MW in 2019 and further 3 and 8.9 GW in Sumatera and Java respectively by 2030. The target will definitely become resourceful especially in Java and Sumatera where most populated regions and growth are located. The target set for 2030 will take up to 30% of the reserve geothermal energy.

IRENA (2017) mentioned that Indonesia had to overcome energy demand within recent years by importing fossil fuel. More household and per capita spread across the countries had to use more energy either for transport, domestic uses, and home industries. Both State Electricity Company and the government had identified the issues and merge into implementing and developing renewable energies and geothermal energy will be one of the candidates to serve as energy security. Renewable energy (geothermal, solar, wind) are one of the reliable sources of energy to boost the rate of electrification and connecting rural and remote areas with electricity.

The concern of CO_2 emissions contributing to climatic changes can also be overcome with geothermal energy. Geothermal energy production will still emit CO_2 as part of the energy conversion process but at a lower level and below CO_2 emission standard. Therefore, geothermal energy not only considered as sustainable energy but also alternative energy that plays an important part in global CO_2 abatement.

Geothermal development in Indonesia had always faced its challenges. The risk in development (such as blow out, microearthquake, water contamination) cannot be overlooked when planning a geothermal project. However, it is projected in the coming years that scientists and engineers will have improved the technologies in drillings and production maintenance. The improvement of these technologies will aid for better risk assessment and a higher chance of productivity and efficiency during energy production.

Based on the data analysis, geothermal energy also have difficulties to reach remote island around Indonesia. Usually, the remote islands are distanced to a volcanic region, which makes it more challenging for conducting exploitation on convective geothermal energy. However, if further geoscience studies should recommend that the island contain possible conductive geothermal energy, then there are still possibilities for geothermal production in form of direct use. Otherwise, remote island should proceed with a more convenient renewable energy available such as solar energy or hydropower.

Moreover, due to the high investment cost of geothermal exploitation and long-term break-even points, we are facing a challenge in the LCOE of geothermal energy production cost. Based on MEMR (2019), the national LCOE cost is based on the energy production of fossil fuel because fossil fuel is cheaper and more conventional. LCOE in Java and Sumatera could not compete with geothermal LCOE, 5.5 cent USD / kWH in margin compared to national LCOE. However geothermal energy LCOE will definitely meet the counteracting supply and demand value if located outside Java for example in Nusa Tenggara or Maluku where geothermal energy potential can also be found (Table 3). In those regions, geothermal LCOE will be able to compete with faster return of investment.

6. Conclusion

The development of geothermal energy in Indonesia may serve as an additional and alternative source to maintain energy security. Geothermal energy contributes to climate change abatement and reliable in all seasons. Moreover, Indonesia holds a large sum of reserved energy and that there are high possibilities of better and more improved technologies to overcome such risks in geothermal development. Furthermore, geothermal development will require more decisive policy from both government in order to attract investors.

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